

PARTICULATE POLLUTANT SYSTEM STUDY VOLUME III - HANDBOOK OF EMISSION PROPERTIES



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1

PREFACE

This handbook was prepared for APCO under Contract No. CPA-22-69-104, which was monitored by Mr. Timothy Devitt and Mr. Don Felton.

The work was conducted in the Environmental Sciences Section of the Physical Sciences Division.

The handbook was written by Dr. A. E. Vandegrift, Project Director, and Dr. L. J. Shannon with the assistance of Dr. E. W. Lawless, Mr. P. G. Gorman, Mr. E. E. Sallee, and Miss M. Reichel.

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TABLE OF CONTENTS

| Chapter | | Page |
|---------|---|------------|
| 1 | Introduction | 1 |
| 2 | Emission Factors and Rates | 3 |
| - | 2.1 Introduction | 3 |
| | 2.2 Emission Rates of Industrial Sources | 4 |
| | References | 12 |
| 3 | Control Equipment | 13 |
| | 3.1 Introduction | 13 |
| | 3.2 Cyclones | 15 |
| | 3.3 Wet Scrubbers | 16 |
| | 3.4 Electrostatic Precipitators | 17 |
| | 3.5 Fabric Filters | 19 |
| | 3.6 Mist Eliminators | 19 |
| | 3.7 Afterburners | 20 |
| | References | 22 |
| 4 | Effluent Characteristics | 23 |
| | 4.1 Introduction | 23 |
| | 4.2 Particulate Characteristics | 23 |
| | 4.3 Carrier-Gas Characteristics | 39 |
| | References | 41 |
| 5 | Presentation of Effluent Data for Specific Industries | 43 |
| 6 | Stationary Combustion Processes | 4 7 |
| | 6.1 Introduction | 47 |
| | 6.2 Electric Utilities | 4 7 |
| | 6.3 Industrial Power Generation | 73 |
| | 6.4 Commercial, Institutional, and Residential Furnaces | 76 |
| | References | 78 |
| 7 | Crushed Stone, Sand, and Gravel Industries | 81 |
| | 7.1 Introduction | 81 |
| | 7.2 Crushed Stone | 81 |
| | 7.3 Sand and Gravel | 87 |
| | References | 89 |
| 8 | Operations Related to Agriculture | 91 |
| | 8.1 Introduction | 91 |
| | 8.2 Agricultural Field Burning | 91 |
| | 8.3 Grain Elevators | 94 |
| | 8.4 Alfalfa Dehydrating Mills | 102 |
| | 8.5 Cotton Gins | 104 |
| | References | 111 |

| Chapter | | Page |
|---------|--|-------------|
| 9 | Iron and Steel Industry | 113 |
| | 9.1 Introduction | 113 |
| | 9.2 Iron and Steel Manufacturing | 113 |
| | 9.3 Emission Rates from Iron and Steel Manufacture | 113 |
| | 9.4 Characteristics of Emissions from Iron and Steel | |
| | Manufacture | 119 |
| | 9.5 Control Techniques for the Iron and Steel Industry | 138 |
| | References | 167 |
| 10 | Cement Manufacture | 171 |
| | 10.1 Introduction | 171 |
| | 10.2 Cement Manufacturing Process | 17 1 |
| | 10.3 Emission Rates from Cement Manufacturing Plants . | 173 |
| | 10.4 Characteristics of Cement Plant Emissions | 178 |
| | 10.5 Control Practices and Equipment for Cement Plants | 178 |
| | References | 187 |
| 11 | Forest Products Industry | 189 |
| | ll.1 Introduction | 189 |
| | 11.2 Forestry Operations | 189 |
| | 11.3 Sawmill Operations (Lumber Production) | 193 |
| | 11.4 Plywood, Particleboard, and Hardboard Plants | 202 |
| | 11.5 Pulp Industry | 204 |
| | References | 236 |
| 12 | Lime Manufacture | 239 |
| | 12.1 Introduction | 239 |
| | 12.2 Lime Manufacturing Process | 239 |
| | 12.3 Emission Sources and Rates | 242 |
| | 12.4 Characteristics of Effluents from Lime | |
| | Manufacture | 243 |
| | 12.5 Control Practices and Equipment for Lime | |
| | Manufacture | 243 |
| | References | 255 |
| 13 | Primary Nonferrous Metallurgy | 257 |
| | 13.1 Introduction | 257 |
| | 13.2 Primary Copper Smelting and Refining | 257 |
| | 13.3 Primary Lead Smelting and Refining | 273 |
| | 13.4 Primary Zinc Smelting | 277 |
| | 13.5 Primary Aluminum Production | 281 |
| | References | 301 |

٠

| Chapter | | Page |
|---------|---|------|
| • 14 | Clay Products | 303 |
| | 14.1 Introduction | 303 |
| | 14.2 Manufacturing Processes | 303 |
| | 14.3 Emission Sources and Rates | 306 |
| | 14.4 Effluent Characteristics | 310 |
| | 14.5 Control Practices and Equipment | 310 |
| | References | 312 |
| 15 | Fertilizer Manufacture | 313 |
| | 15.1 Introduction | 313 |
| | 15.2 Phosphate Fertilizers | 313 |
| | 15.3 Ammonium Nitrate Fertilizer | 325 |
| | 15.4 Urea Fertilizer | 329 |
| | 15.5 Ammonium Sulfate | 329 |
| | 15.6 Characteristics of Effluents from Fertilizer | 330 |
| | 15.7 Control Practices and Equipment in Fertilizer | 002 |
| | Manufacture | 332 |
| | References | 338 |
| 16 | A sphalt | 330 |
| 10 | 16.1 Introduction | 339 |
| | 16.2 Airhlown Asphalt | 339 |
| | 16.3 Hot-Mix Asphalt Paving Plants | 342 |
| | 16.4 Asphalt Roofing Manufacture | 352 |
| | References | 359 |
| 17 | Ferroallov Manufacture | 361 |
| _ | 17.1 Introduction | 361 |
| | 17.2 Ferroalloy Production | 361 |
| | 17.3 Emission Sources and Rates | 364 |
| | 17.4 Effluent Characteristics | 368 |
| | 17.5 Control Practices | 368 |
| | References | 380 |
| 18 | Iron Foundries | 381 |
| | 18.1 Introduction | 381 |
| | 18.2 Foundry Processes | 381 |
| | 18.3 Emission Rates from Iron Foundries | 381 |
| | 18.4 Characteristics of Effluents from Iron Foundries | 384 |
| | 18.5 Control Practices and Equipment for Iron | |
| | Foundries | 384 |
| | References | 400 |

| Chapter | | Page |
|---------|--|-------------|
| 19 | Secondary Nonferrous Metals Industry | 401 |
| | 19.1 Introduction | 401 |
| | 19.2 Secondary Copper Smelting and Refining | 401 |
| | 19.3 Secondary Lead Smelting and Refining | 4 23 |
| | 19.4 Secondary Zinc Smelting and Refining | 4 28 |
| | 19.5 Secondary Aluminum Smelting and Refining | 434 |
| | References | 44 1 |
| 20 | Coal Preparation Plants | 443 |
| | 20.1 Introduction | 443 |
| | 20.2 Coal Cleaning Process | 443 |
| | 20.3 Emission Rates from Coal Preparation Plants | 455 |
| | 20.4 Characteristics of Coal-Preparation Plant | |
| | Emissions | 4 57 |
| | 20.5 Control Practices and Equipment for Coal- | |
| | Preparation Plants | 4 57 |
| | References | 4 62 |
| 21 | Carbon Black | 465 |
| | 21.1 Introduction | 465 |
| | 21.2 Manufacturing Processes | 465 |
| | 21.3 Emission Sources and Rates | 470 |
| | 21.4 Characteristics of Effluents from Carbon Black | |
| | Manufacture | 471 |
| | 21.5 Control Practices and Equipment | 471 |
| | References | 476 |
| 22 | Petroleum Refining | 477 |
| | 22.1 Introduction | 4 77 |
| | 22.2 Emission Sources | 477 |
| | 22.3 Catalyst Regenerator Emission Rates | 480 |
| | 22.4 Effluent Characteristics | 4 82 |
| | 22.5 Control Practices and Equipment for FCC Units . | 482 |
| | References | 493 |
| 23 | Acid Manufacture | 4 95 |
| | 23.1 Introduction | 495 |
| | 23.2 Sulfuric Acid Manufacture | 4 96 |
| | 23.3 Emission Rates | 501 |
| | 23.4 Effluent Characteristics | 504 |
| | 23.5 Control Practices and Equipment for Sulfuric | |
| | Acid Plants | 504 |
| | 23.6 Phosphoric Acid Manufacture | 508 |
| | References | 515 |

•

| Chapter | Page |
|---|---------------------------------|
| 24Incineration | 517 517 517 539 540 |
| Appendix A - Economic Considerations in Air Pollution Control Appendix B - Minor Sources | 5 4 7 603 |

List of Tables

Table .

.

<u>Title</u>

Page

| 2-1 | Major Industrial Sources of Particulate Pollutants 6 |
|-----|--|
| 4-1 | Triboelectric Series for Fabrics |
| 4-2 | Relations of Fabric Requirements to Dust Properties and |
| | Dust in the Categories Listed |
| 4-3 | Rates of Rise and Total Wetting Times Measured at |
| | Different Dust Samples |
| 5-1 | Coding Key for Tables of Effluent Characteristics 45 |
| 6-1 | Particulate Emissions, Fuel Combustion in Stationary |
| | Sources |
| 6-2 | Effluent Characteristics, Stationary Combustion Processes 53 |
| 6-3 | Polynuclear Hydrocarbon Concentrations |
| 6-4 | Elemental Analyses of Total Particulates |
| 6-5 | Dust Collectors for Coal-Fired Heating and Power Plants . 60 |
| 6-6 | Usual Expected Efficiency Ranges for Commonly Used |
| | Control Equipment |
| 6-7 | Optimum Expected Performance of Various Types of Gas |
| | Cleaning Systems for Stationary Combustion Sources 62 |
| 6-8 | Air Cleaning Equipment Installed Cost Based on |
| | 1,000 MW Unit (1968) |
| 6-9 | Precipitator Costs (1965 - 1969) |
| 7-1 | Particulate Emissions, Crushed Stone, Sand and Gravel 83 |
| 8-1 | Particulate Emissions from Rye-Grass Burns 92 |
| 8-2 | Particulate Emissions from Operations Related to |
| | Agriculture |
| 8-3 | Effluent Characteristics - Operations Related to |
| | Agriculture |
| 8-4 | Analysis of Airborne Dust Collected in Vicinity of |
| | Railway Cars During Loading |
| 8-5 | Particulate and Product Analyses (Alfalfa Dehydrating |
| | Mill) |
| 8-6 | Yields of Various Pollutants from Grasses Burned in |
| | Laboratory Tower |
| 8-7 | Results of Summer 1967 Field Burns of Various Grasses 101 |
| 9-1 | Potential Particulate Pollutant Emission Sources in Iron |
| | and Steel Manufacturing |
| 9-2 | Particulate Emissions, Iron and Steel Industry 120 |
| 9-3 | Effluent Characteristics - Iron and Steel Industry 122 |
| 9-4 | Iron and Sinter Dust Resistivity |
| 9-5 | Representative Emission-Control Applications in the |
| | Integrated Iron and Steel Industry |

List of Tables (Continued)

Title

Table

| 9-6 | Design and Operating Data for Sinter-Plant Fabric | |
|--------------|--|-----|
| | Filters on Sinter Strand Discharge | 150 |
| 9-7 | Blast-Furnace Gas-Cleaning Results | 152 |
| 9 -8 | Open-Hearth Stack Gas Data | 157 |
| 9-9 | Performance Tests of Electrostatic Precipitator on Open- | |
| | Hearth Gases | 157 |
| 9-10 | Scrubber-Pressure Drop vs. Cleaning Efficiency and Out- | |
| | let Dust Loading (Nonoxygen Periods) | 159 |
| 9-11 | Scrubber-Pressure Drop vs. Cleaning Efficiency and Out- | |
| | let Dust Loading (Oxygen Periods) | 159 |
| 9-12 | Basic Oxygen Furnace Installations and Associate | |
| | Air-Pollution Control Equipment | 161 |
| 9-13 | Comparison of Equipment Requirements, Energy and Gas | |
| | Flow for BOF | 162 |
| 9 -14 | Approximate Budge Sizing Chart | 165 |
| 10-1 | Particulate Emissions, Cement Industry | 177 |
| 10-2 | Effluent Characteristics - Cement Manufacture | 179 |
| 10-3 | Ranges of Dust Emissions from Control Systems Serving | |
| | Dry- and Wet-Type Cement Kilns | 185 |
| 11-1 | Particulate Emissions, Forest Products Industry | 192 |
| 11-2 | Characteristics of Effluents from Forest Products | |
| | Industry | 194 |
| 11-3 | Atmospheric Emission Sources in a Kraft Mill | 206 |
| 11-4 | Atmospheric Emissions from Kraft Pulp Mills | 207 |
| 11 -5 | Water Usage for Secondary Scrubbing Installations | 209 |
| 11-6 | Average Performance Data for Full-Scale TE Washer | 211 |
| 11-7 | Test Data, Lime Kiln Venturi Scrubber | 212 |
| 11-8 | Ammonia-Base Liquor Burning | 233 |
| 12-1 | Particulate Emissions, Lime Manufacture | 244 |
| 12-2 | Effluent Characteristics - Lime Manufacture | 245 |
| 12-3 | Secondary Collection of Rotary Kiln Lime Dust | 249 |
| 12-4 | Estimate of Rotary Kiln Control Costs | 250 |
| 12-5 | Hydrator | 251 |
| 12-6 | Stone Dryers | 252 |
| 13-1 | Particulate Emissions, Primary Nonferrous Metals | |
| | Industries | 262 |
| 13-2 | Effluent Characteristics, Primary Nonferrous Metals | |
| | Industries | 263 |
| 13-3 | Compounds Found in Aluminum Reduction Cell Exhaust | |
| | Streams | 269 |
| 13-4 | Atmospheric Pollutants from Secondary Sources in | |
| | Aluminum Plants | 270 |

xi

List of Tables (Continued)

Title

Table

Page

| 13 - 5 | Operation Data for Dust Collectors Applied to Primary | |
|---------------|---|---------------------|
| | Copper Smelting and Refining | 272 |
| 13-6 | Lead Smelter Control Equipment | 276 |
| 13-7 | Typical Zinc Roasting Operations | 279 |
| 13 - 8 | Cominco Fume and Dust Recovery Plants | 283 |
| 13-9 | Costs for Cleaning Metallurgical Gases (1957 Data) | 285 |
| 13-10 | Collection Efficiencies for the Floating Bed Scrubber | |
| | Used on Horizontal Stud Soderberg Cell | 294 |
| 13-11 | Current and Newest Air Pollution Controls for Primary | |
| | Aluminum Potline Air Pollution Controls | 297 |
| 14-1 | Particulate Emissions, Clay Products | 309 |
| 14-2 | Effluent Characteristics - Manufacture of Clay Products | 311 |
| 15-1 | Particulate Emissions, Phosphate Rock and Manufacture | |
| | of Fertilizer | 326 |
| 15-2 | Effluent Characteristic - Fertilizer Manufacture | 333 |
| 15-3 | Summary of Emission Data on Performance of Control | |
| | Equipment in Wet-Process Phosphoric Acid Plants | 335 |
| 15-4 | Summary of Emission Data on Performance of Control | |
| | Equipment in Wet-Process Phosphoric Acid Plants | 336 |
| 16 - 1 | Particulate Emissions - Asphalt | 341 |
| 16-2 | Effluent Characteristics - Asphalt | 346 |
| 16 - 3 | Dust and Fume Discharge from Asphalt Batch Plants | 34 7 |
| 16-4 | Findings of Florida Asphalt Plant Testing Program | 349 |
| 16-5 | Comparative Costs of Dust Collectors | 351 |
| 16 - 6 | Emissions from a Water Scrubber and Low-Voltage Two- | |
| | Stage Electrical Precipitator Venting an Asphalt | |
| | Saturator | 357 |
| 16 - 7 | Emissions from a Water Scrubber Venting an Asphalt | |
| | Saturator | 3 57 |
| 17-1 | Particulate Emissions, Production of Ferroalloys | 369 |
| 17-2 | Effluent Characteristics - Ferroalloy Manufacture | 3 70 |
| 17-3 | Ferroalloy Fume Resistivity | 372 |
| 17 -4 | Typical Ferroalloy Furnace Fume Characterizations | 3 7 3 |
| 17-5 | Approximate Furnace Gas Generation | 3 75 |
| 17 - 6 | Comparison of Furnace Gas Volumes | 3 7 5 |
| 17-7 | Estimated Cost of Furnace Controls | 3 75 |
| 17-8 | Examples of Furnace Wet Scrubbers | 3 77 |
| 18-1 | Particulate Emissions, Iron Foundries | 383 |
| 18-2 | Effluent Characteristics - Iron Foundries | 385 |
| 18-3 | Iron Foundry Dust Collector Efficiency | 390 |

List of Tables (Continued)

Title

| Table | Title | Page |
|----------------|---|---------------------|
| 18-4 18-5 | Usual Collector Selections for Foundry Operations Efficiency Tests of Dry Multiple Cyclones for Five | 391 |
| 10 0 | Different Installations | 392 |
| 70-0 | Waste Gases of a Hot-Blast Cupola | 393 |
| 18-7 | Approximate Cost of Control Equipment | 393 |
| 18-8 | Collector Characteristics for 15 Tons/Hr Cold-Slast Cupola Operated on Alternate Days | 394 |
| 18-9 | Comparison of Cupola Dust Control Systems | 395 |
| 18-10 | Cupola Plants with Electro-Precipitators | 397 |
| 18-11 | Cupola Dust Removal Installations with Fabric Filter | 398 |
| 19-1 | Particulate Emissions, Secondary Nonferrous Metals | 40 6 |
| 19 - 2 | Effluent Characteristics - Secondary Nonferrous Metals . | 408 |
| 19-3 | Electrical Resistivity of Collected Bronze Fume | 411 |
| 19-4 | Brass-Melting Furnace and Baghouse Collector Data | 416 |
| 19-5 | Baghouse Information Summary - Brass and Bronze Ingot | |
| | Institute | 417 |
| 19-6 | Annual Cost of Air Pollution Control Systems | 419 |
| 19-7 | Installed Costs of Gas-Clearing Equipment Systems, by | 4.00 |
| 10.0 | Type of Smelter | 420 |
| 19-0 | Time of Equipment | 101 |
| 19-9 | Annual Operating Costs of Cas-Cleaning Equipment Systems | -s⊂⊥ |
| 10-0 | hy Type of Smelter | 422 |
| 19 -1 0 | Dust and Fume Emissions from a Secondary Lead-Smelting | |
| | Furnace | 427 |
| 19-11 | Dust and Fume Emissions and from an Aluminum- and a | |
| | Zinc-Sweating Furnace Controlled by a Baghouse | 435 |
| 19-12 | Dust and Fume Emissions from an Aluminum-Sweating Furnace | |
| | Controlled by an Afterburner and Baghouse | 439 |
| 19-13 | Scrubber Collection Efficiency for Emissions from | |
| | Chlorinating Aluminum | 440 |
| 20-1 | Thermally Dried Coal by Types of Drying Equipment, | |
| | 1958-1964 | 454 |
| 20-2 | Effluent Characteristics - Coal Preparation Plants | 458 |
| 21-1 | Particulate Emissions from the Manufacture of Carbon | |
| <u>.</u> | Black | 472 |
| 51-5 | Effluent Characteristics - Carbon Black | 4 7 3 |

List of Tables (Concluded)

Table

•

Title

Page

| 22-1 | Potential Sources of Specific Emissions from Oil | |
|----------------|---|----|
| | Refineries | 78 |
| 22-2 | Effluent Characteristics - Petroleum Refining 4 | 83 |
| 22-3 | Typical Plant Operating Conditions 4 | 85 |
| 22 -4 | A Summary of Performance Data of Precipitators in Fluid | |
| | Catalytic Cracking Application (1951-1962) 4 | 92 |
| 23-1 | Particulate Emissions, Mineral Acids 5 | 03 |
| 23-2 | Effluent Characteristics - Acid Manufacture 5 | 05 |
| 23-3 | Feasible Systems for Acid Mist Control 5 | 06 |
| 23-4 | Operating Characteristics of Phosphoric Acid Mist | |
| | Electrostatic Precipitators 5 | 14 |
| 24-1 | Estimated Municipal Incinerator Emissions 5 | 21 |
| 24-2 | Effluent Characterístics - Incineration 5 | 23 |
| 2 4- 3 | Air Pollution Control System Average Control Efficiency 5 | 24 |
| 24-4 | Distribution and Typical Economics Among Incinerators | |
| | and APC Concepts | 25 |
| 24-5 | Maximum Demonstrated Collection Efficiency of Incinera- | |
| | tor Control Equipment 5 | 26 |
| 24-6 | Relative In-Plant Space Requirements for Average Air | |
| | Pollution Control Systems 5 | 35 |
| 24-7 | Estimated Capital and Operating Costs for Two Control | |
| | Systems for an 800 Ton/Day Incinerator 5 | 35 |
| 24-8 | Refractory Furnace | 36 |
| 24-9 | Water-Cooled Furnace | 36 |
| 24-10 | Electrostatic Precipitators Installed on Municipal | |
| | Incinerators in North America 5 | 38 |
| 24-11 | Basic Design Elements of European Electrostatic | |
| | Precipitators | 38 |
| 24-12 | Peabody Scrubber Performance on Flue-Fed Apartment | |
| | Incinerators | 43 |
| 2 4-1 3 | Performance and Cost of Devices Installed on Apartment | |
| | Incinerator | 44 |
| | | |

-

List of Figures

Figure

<u>Title</u>

Page

| 3-1 | Efficiency Curves for Various Types of Dust Collecting | |
|----------------|--|-----|
| | Equipment | 14 |
| 4-1 | Average Size Distributions of Outlet Fume - Kraft Mill | |
| | Recovery Furnace | 26 |
| 4-2 | Effect of Humidity on Particle Resistivity | 31 |
| 4-3 | Conditioning of a Weak Acidic Dust by Strong Bases | 33 |
| 4-4 | Laboratory Conditioning Tests, Sulfuric Acid Fume with | |
| | Fly Ash | 33 |
| 6-1 | Nomograph for Estimating Particulate Emissions From Coal | |
| | Combustion (Without Air Pollution Control Equipment) . | 50 |
| 6 - 2 · | Precipitator Purchase Cost (FOB) as a Function of Gas | |
| | Volume Treated (Period 1965 - 1969) | 65 |
| 6-3 | Precipitator Erected Cost as a Function of Gas Volume | |
| | Treated (Period 1965 - 1969) | 66 |
| 6 -4 | Plant Fly-Ash Disposal Investment | 68 |
| 6-5 | Plant Fly-Ash Disposal Cost for 1967 | 69 |
| 6-6 | Effect of Sulfur Content of Coal on Collecting Area | |
| | Required in Electrostatic Precipitator | 70 |
| 6-7 | Multiclone Collection Efficiency - Fly Ash | 71 |
| 7-1 | Particulate Size from Rock Processing Operations | 85 |
| 8-1 | Alfalfa Dehydrating Process Flow Diagram | 103 |
| 8-2 | Flow Diagram of U.S. Department of Agriculture Cotton | |
| | Gin, Stoneville, Mississippi | 105 |
| 8-3 | In-Line Air Filter - Cotton Gin | 109 |
| 9-1 | A Composite Flow Diagram for a Steel Plant | 114 |
| 9-2 | Particle Size Distribution by Weight of Sintering | |
| | Machine Dust | 127 |
| 9-3 | Resistivity of Different Dusts in the Same Atmosphere | |
| | vs. Temperature | 128 |
| 9-4 | Resistivity in Different Atmospheres vs. Temperature | 128 |
| 9 - 5 | Electrical Resistivity of Sintering Machine Dust | 129 |
| 9-6 | Resistivity of Open-Hearth Furnace Fume Under Varying | |
| | Conditions of Temperature and Moisture in Gas | 130 |
| 9-7 | Apparent Resistivity of Fume from Open-Hearth Furnace | 130 |
| 9-8 | Apparent Resistivity of Fume from Open-Hearth Furnace | 131 |
| 9-9 | Apparent Resistivities of Metallurgical Dusts | 131 |
| 9-10 | Electrical Resistivity of Red Oxide Fume from Various | |
| | Oxygen-Blown Steelmaking Processes | 132 |
| 9-11 | Resistivity vs. Gas Temperature for BOF Furnace Dust | 133 |
| | | |

List of Figures (Continued)

Figure

Title

Page

| 9-12 | Estimated Installed Cost (1968) of Air-Pollution-Control Fourment as Related to Different Steel-Making | |
|------|---|-------------|
| | Processes | 140 |
| 9-13 | Estimated Annual Operating Costs for Air-Pollution- | |
| | Control Equipment for Steel-Making Process | 141 |
| 9-14 | Estimated Annual Operating Costs Plus Capital Charges | |
| | and Depreciation for Air-Pollution-Control Equipment | |
| | for Steel-Making Processes | 142 |
| 9-15 | Estimated Installed Capital Costs of Air-Pollution- | |
| | Control Equipment Installed on Electric-Arc Steel- | |
| | Making Furnaces | 143 |
| 9-16 | Estimated Installed Capital Costs of Air-Pollution- | |
| | Control Equipment Installed on Open-Hearth Furnaces | 144 |
| 9-17 | Estimated Installed Capital Costs of Air-Pollution- | |
| | Control Equipment Used in Sinter and Pellet Plants | 145 |
| 9-18 | Estimated Annual Operating Costs for Air-Pollution | |
| | Control Equipment Used in Sinter and Pellet Plants | |
| | (Depreciation and Capital Charges are Not Included | 146 |
| 9-19 | Estimated Capital and Annual Operating Costs for Air- | |
| | Pollution-Control Equipment Used on Scarfing Machines | |
| | (Depreciation and Capital Charges are Not Included in | |
| | the Operating Costs) | 14 7 |
| 9-20 | Range of Estimated Operating Costs for Air-Pollution- | |
| | Control Equipment/Net Ton of Raw SteelOpen-Hearth | |
| | Furnaces, BOFS, and Electric Furnaces (Two-Furnace | |
| | Operations) | 148 |
| 9-21 | Effect of Water Rate on Output Dust Loading for a | |
| | Venturi Scrubber Handling Blast-Furnace Gas | 153 |
| 9-22 | Effectiveness of Gas Cleaning by a Fixed-Orifice Scrubber | |
| | and a Variable-Orifice Scrubber When Gas-Flow Rate is | |
| | Varied | 154 |
| 9-23 | Operating Characteristics of a Blast-Furnace Venturi | |
| | | 154 |
| 9-24 | Relationship of Electrostatic Precipitator Collecting | |
| | Surface to Collection Efficiency for Open-Hearth | |
| | Emissions (315,000 acfm) | 156 |
| 9-25 | Relationship Between Clean-Gas Dust Loading and Pressure | |
| | Drop for a Wet Scrubber on an Open-Hearth Furnace | |
| | (Oxygen Lancing Used During the Refining Period) | 158 |
| | | |

xvi

List of Figures (Continued)

Figure

.

.

<u>Title</u>

Page

| 9-26 | Typical Side-Draft and Roof-Tap-Hood Systems for Electric-Arc Eurpaces | 166 |
|----------------|---|-----|
| 10-1 | Scurces of Dust Emissions, Cement Plants. | 172 |
| 10-2 | Typical Particle Size Range of Cement Kiln Dust | 181 |
| 10-3 | Resistivity of Cement Kiln Dust Under Varying Conditions | |
| | of Temperature and Moisture in Gas | 182 |
| 10-4 | Dependence of Specific Electrical Dust Resistance on | |
| | Gas Temperature for Various Dusts | 182 |
| 10-5 | Typical Laboratory and Field Resistivities of Cement | |
| | Kiln Dusts | 183 |
| 10-6 | Laboratory Resistivities of One Cement Kiln Dust Sample | |
| | For Various Gas Moisture Contents | 184 |
| 11-1 | Composite Flow Diagram - Forest Products Industry | 190 |
| 11-2 | Electrical Resistivity of Salt Cake | 200 |
| 11-3 | Electrical Resistivity of Sodium Sulfate as a Function | |
| | of Moisture in Gas at 300°F | 201 |
| 11-4 | Particle-Size Efficiency Curve TE Washer-Black Liquor | |
| | Recovery Furnace | 210 |
| 11 - 5 | Control Method Costs for 99.9% Efficiency Electrostatic | |
| | Precipitator Replacing an Existing Precipitator - | |
| | Recovery Boiler | 218 |
| 11-6 | Control Method Costs for 99.5% Efficiency Electrostatic | |
| | Precipitator Replacing an Existing Precipitator - | |
| | Recovery Boiler | 219 |
| 11-7 | Control Method Costs for 99.0% Efficiency Electrostatic | |
| | Precipitator Replacing an Existing Precipitator - | |
| | Recovery Boiler | 220 |
| 11-8 | Control Method Costs for Packed Tower Added to Smelt- | |
| | Dissolving Tank Vent | 223 |
| 11 - 9 | Control Method Costs for Orifice Scrubber Added to Smelt- | |
| | Dissolving Tank Vent | 224 |
| 11 -1 0 | Control Method Costs of Mesh Pad Added to Smelt- | |
| | Dissolving Tank Vent | 225 |
| 11-11 | Control Method Costs for Fresh Water Venturi Added to | |
| | Lime Kiln - 99.0% Lime Solids Collection | 228 |
| 11-12 | Control Method Costs for Fresh Water Venturi Added to | |
| | Lime Kiln - 99.9% Lime Solids Collection | 229 |
| 11-13 | Control Method Costs for 99.0% Efficiency Electrostatic | |
| | Precipitator Added to an Existing 90% Efficiency Dust | |
| | Collector Coal-Fired Power Boiler | 231 |

List of Figures (Continued)

Figure

Title

Page

| 11-14 | Control Method Costs for 90.0% Efficiency Electrostatic Precipitator Added to an Existing 90% Efficiency | |
|----------------|---|-----|
| | Dust Collector Coal-Fired Power Boiler | 232 |
| 11-15 | Sulfite Pulping Process, Ammonia-Base Recovery | 234 |
| 11- <u>1</u> 6 | Sulfite Pulping Process, Magnesia-Base Recovery | 235 |
| 12-1 | Simplified Flowsheet for Lime and Limestone Products | 240 |
| 12-2 | Flow Diagram of a Modern Hydrated Lime Plant from Ground | |
| | Quick Lime Feed Silos Through to Bulk Hydrate Storage | |
| | Silos and Bagging Department | 241 |
| 12-3 | Dependence of Specific Electrical Dust Resistance on Gas Temperature for Line Shaft Kiln Dust | 247 |
| 12 1 | Compon Smolting - Simplified Flor Disgram | 050 |
| 13 0 | Copper Smerting - Simplified flow Diagram | 200 |
| 13.3 | Apparent Posistivity of Lord Type from Sintering Plant | 200 |
| 13 4 | Repairing resistivity of Lead Fune from Scholing Fight . | 200 |
| 10-4 | of Tomponeture and Moisture in Cas | 067 |
| וא ה | Apparent Pagistivity of Losd Type from Losd Plast Typeso | 201 |
| 13-6 | Apparent Resistivity of Lead Tume from Slag Freatment | 201 |
| 10-0 | Plant | 268 |
| 13-7 | Typical Flowsheet of Pyrometallurgical Lead Smelting | 274 |
| 13-8 | Zinc Smelting Flow Diagram | 278 |
| 13-9 | Dust Composition vs. Roasting Temperature in Zinc | |
| | Frocessing | 282 |
| 13-10 | Diagram of the Bayer Process | 267 |
| 13-11 | Aluminum Cell (Prebaked Anode Type) | 288 |
| 13-12 | Prebake | 289 |
| 13-13 | Horizontal Soderberg | 289 |
| 13-14 | Vertical Soderberg | 289 |
| 13-15 | Schematic Drawing of Cross-Sectional View of the New | |
| | Sieve-Plate Gas Scrubber | 293 |
| 13-16 | Purification Installation for Cell Gases | 293 |
| 13-17 | The Floating Bed Scrubber Developed for Horizontal Stud | |
| | Soderberg Cell Exhausts | 295 |
| 13-18 | Roof Scrubbers | 298 |
| 14-1 | Ceramic Clay Manufacturing Processes | 304 |
| 14-2 | Refractories Manufacture Flow Diagram | 307 |
| 15-1 | Flow Diagram of Phosphate Rock Storage and Grinding | |
| | Facilities, Noting Potential Air Pollution Sources | 314 |
| 15-2 | Flow Diagram Illustrating Wet-Process Phosphoric Acid | |
| | Plant | 316 |

xviii

List of Figures (Continued)

Figure

<u>Title</u>

Page

| 15-3 | Flow Diagram of Normal Superphosphate Plant, Noting | |
|---------------|---|-------------|
| | Potential Air Pollution and Sources | 319 |
| 15-4 | Flow Diagram for Production of Run-of-Pile and Granular | |
| | Triple Superphosphate, Noting Potential Air Pollution | |
| | Sources | 321 |
| 15-5 | Flow Diagram of Diammonium Phosphate Plant, Noting | |
| | Potential Air Pollution Sources | 323 |
| 15-6 | Flow Diagram of the Slurry Granulation Process in the | |
| | Manufacture of Fertilizer, Noting Potential Air | |
| | Pollution Sources | 324 |
| 15-7 | Flow Diagram of the Process for Manufacture of Ammonium | |
| | Nitrate, Noting Pctential Air Pollution Souces | 3 27 |
| 15-8 | Sketch of Manufacturing Process for Crystalline Urea | |
| | Product | 330 |
| 15 - 9 | Sketch of Manufacturing Process for Prilled or Shotted | |
| | Urea Product | 331 |
| 16-1 | Asphalt Batch Mix Plant | 343 |
| 16-2 | Asphalt Continuous Mix Plant | 343 |
| 16-3 | Test Data on Air Pollution Control Equipment Serving Two | |
| | Hot-Mix Asphalt Paving Plants | 348 |
| 16-4 | Effect of Drum Gas Velocity on Dust Emission | 350 |
| 16-5 | Effect of Scrubber Water-Gas Ratio on Stack Emissions | |
| | at Average Aggregate Fired Rate in the Dryer Feed | 353 |
| 16-6 | Schematic Drawing of an Asphalt Roofing Felt Saturator . | • 355 |
| 18-1 | Particle Size Ranges for Dusts from Cold- and Hot-Blast | |
| | Cupolas | 387 |
| 18-2 | Apparent Resistivity of Dust and Fume in Plant A | 388 |
| 18 - 3 | Apparent Resistivity of Dust and Fume in Plant B | 388 |
| 19-1 | Apparent Resistivity of Zinc Fume from Slag Fuming Plant | 412 |
| 19-2 | Apparent Resistivity of Zinc Fume from Melting Plant | 412 |
| 19-3 | Diagram Showing One Bank of a Belgian Retort Furnace | 4 30 |
| 19 -4 | Diagram of a Distillation-Type Retort Furnace | 432 |
| 19-5 | Diagram of a Muffle Furnace and Condenser | 433 |
| 20-1 | Pressure-Type Fluidized-Bed Thermal Coal Dryer, Showing | |
| | Component Parts and Flow of Coal and Drying Gases | 450 |
| 20-2 | Exhausting-Type Fluidized-Bed Thermal Coal Dryer, Showing | |
| | Component Parts and Flow of Coal and Drying Gases | 451 |
| 20-3 | Schematic Drawing Showing Component Parts of Flash-Drying | |
| | Unit | 4 52 |
| 20-4 | Schematic Sketch of Screen-Type, Thermal Coal-Drying Unit | 453 |

List of Figures (Continued)

Title

Figure

Page

| 20-5 | Typical Particle-Size-Analysis Curves for Material Going | |
|---------------|---|-------------|
| | to Cyclones (Coal Thermal Dryers) | 4 59 |
| 20-6 | Particle Size Distribution of Effluent | 461 |
| 20-7 | Venturi Scrubber Performance on Coal Dryer Effluent | 4 61 |
| 21-1 | Flow Diagram of Oil-Furnace Process | 4 6? |
| 21-2 | Flow Diagram of Gas-Furnace Porcess | 4 67 |
| 21-3 | Flow Diagram of Channel Process | 4 68 |
| 21-4 | Flow Diagram of Thermal Process | 4 69 |
| 22-1 | Flow Diagram of Fluid Cracking Unit | 4 81 |
| 22-2 | Electrical Resistivity of Dust from Catalytic Cracking | |
| | Unit | 4 84 |
| 22-3 | Schematic Flow for Precipitator Installed After Power- | |
| | Recovery Turbine | 486 |
| 22-4 | Schematic Flow for Precipitator Installed After CO Boiler | 4 87 |
| 22-5 | Relationship Between Quantity of Catalyst Carryover and | |
| | Particle Size | 4 88 |
| 22-6 | Calculated Stack Losses as a Function of Particle-Size | |
| | Distribution of Cyclone Carryover | 489 |
| 22-7 | Particle-Size Stack Loss Distribution Compared to Cyclone | |
| | Carryover Particle Size | 490 |
| 23-1 | Simplified Flow Diagram of Typical Lead-Chamber Process | |
| | for Sulfuric Acid Manufacture (Based on Use of Elemental | |
| | Sulfur as the Raw Material) | 4 97 |
| 23-2 | Sulfuric Acid Manufacture by the Contact Process | 4 98 |
| 23-3 | Sulfuric Acid Concentrator, Drum Type | 500 |
| 2 3-4 | Flow Diagram for Typical Thermal-Process Phosphoric Acid | |
| | $Plant \dots \dots$ | 509 |
| 23-5 | Effect of Gas Velocity on Phosphoric Acid Recovery in | |
| | Pilot-Plant Packed Tower | 513 |
| 23-6 | Collection Efficiency of Venturi Scrubber as a Function | |
| | of Particle Size for Phosphoric Acid Mist | 513 |
| 24-1 | Effect of Underfire Air Rate on Furnace Emission | 520 |
| 24-2 | Electrical Resistivity of the $< 74 \mu$ Fraction of | |
| | Particulate Emission from the Furnace at 6% Water Vapor | 527 |
| 24-3 | Air Pollution Control Systems Total Installed Costs | 528 |
| 24-4 | Air Pollution Control Systems Annual Operating Costs | 529 |
| 24-5 | Air Pollution Control Systems Annual Operating Costs | 530 |
| 2 4- 6 | Air Pollution Control Systems Annual Operating Costs | 531 |

TABLE OF CONTENTS (Concluded)

List of Figures (Concluded)

| Figure | Title | Page |
|--------|---|------|
| 24-7 | Total Annual Operating Cost vs. Particulate Removal Efficiency, 150 Tons/Day Plant; 1, 2, and 3 Shift Operation | 533 |
| 24-8 | Total Annual Operating Cost vs. Particulate Removal Efficiency, 150 and 300 Tons/Day Plant; 2 Shift | |
| 24-9 | Operation | 534 |
| 21 0 | Air Pollution Control Equipment | 541 |

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CHAPTER 1

INTRODUCTION

This handbook is presented as a part of the documentation for a NAPCA sponsored study, conducted at Midwest Research Institute, of particulate air pollution from stationary sources. The objective of the study was to identify, characterize, and quantify the particulate air pollution problem in the United States. This document delineates the kind and number of stationary particulate sources, the chemical and physical characteristics of both the particulates and carrier gas emitted by specific sources, and the status of current control practices. Details of the methodology employed to obtain the data reported in this handbook are presented in the final report for the project.

The first three chapters present general background information pertaining to source emission factors and emission rates, effluent characteristics, and control technology. The chapter on emission factors and rates (Chapter 2) outlines the methods used to calculate the total tonnage emitted by individual sources, and presents a ranking, on a tonnage emitted basis, of industrial sources of particulate pollutants. Chapter 3 highlights the general aspects of control equipment available for use on a source of particulate pollution. Distinguishing characteristics and general areas of application and ranges of performance of control devices are summarized in this chapter. Chapter 4 discusses some of the more important chemical and physical properties of particulates and carrier gas emitted by industrial sources. The discussion is focused primarily on the relationship of the effluent properties to control device selection and/or design. Chapter 5 presents a coding key for the tables of effluent characteristics presented in Chapters 6 - 24.

The remaining chapters (Chapters 6 - 24) present discussions of the major industrial sources of particulate pollutants. The industrial categories were selected on the basis of the ranking of tonnage emitted outlined in Chapter 2. The chapters on industrial sources delineate the production process, emission sources, emission rates, chemical and physical properties of the effluents, and control practices and equipment for each industrial category. Appendix A presents general cost information for control equipment. Miscellaneous emission data for minor sources are summarized in Appendix B. This handbook constitutes a reference source for available information on the distinguishing features of the various particulate pollution sources and should be of value to air pollution regulatory agencies, control equipment manufacturers, and industrial concerns.

CHAPTER 2

EMISSION FACTORS AND RATES

2.1 INTRODUCTION

To assess the relative contributions of stationary sources of particulate air pollution, the major types and quantities of particulate pollutants emitted must be determined. Methods based on source emission factors are generally used to calculate quantities of particulates emitted for individual sources. Material balances and outlet grain loadings can also be used for these calculations.

The emission factor for stationary sources is a statistical average of the rate at which pollutants are emitted from the processing or burning of a given Quantity of material. Ideally, emission factors should be related to aspects of system design, operating practices, and material processed to permit a definitive statement as to the total emissions characterizing a given source or plant producing a specified product. Unfortunately, the numerous and expensive stack testing studies needed to completely characterize a source have not generally been performed. Recourse must be made to existing data, and general comments presented on the probable influence of variables on emission factors. In some cases, especially industrial sources, the emission factor may be based upon tests conducted on only one installation or a few installations.

The source emission factors used in this handbook were compiled from an extensive literature survey and stack sampling data provided by air pollution control agencies and individual industrial companies. In most cases, a single number is presented for the emission factor for a specific source. These source emission factors are, in our judgment, the most accurate currently available. Details of the analysis of all available data for each specific source are presented in the final report for this project. $\frac{1}{2}$

The industrial categories discussed in Chapters 6 - 24 were chosen from a ranking of sources based on the total tonnage of particulates emitted/year. The ranking of sources on the basis of tonnage emitted and its development are discussed in the following section.

2.2 EMISSION RATES OF INDUSTRIAL SOURCES

Important particulate pollutant sources based on the total tonnage emitted/year are presented in this section. The ranking was obtained by first listing possible sources and then investigating in detail a large enough segment to account for more than 99% of the total emissions on a mass basis.

Several different methods were used to calculate the total tonnage emitted by individual sources. These methods included the use of emission factors (both controlled and uncontrolled), material balances, and outlet grain loadings. The primary method used for establishing the tonnage emitted by an industry utilized uncontrolled emission factors. Total tonnage emitted by a given source was determined from four quantities: (1) an emission factor for the uncontrolled source; (2) the total tonnage processed/year by the source; (3) the efficiency of control equipment used: and (4) the percentage of production capacity equipped with control devices The mathematical equation for the calculation is:

$$E = \frac{(P)(e_f)(1-C_c \cdot C_t)}{2,000}$$
(1)

where E = total particulate emissions for a source, tons/year

P = total production for the industry, tons/year

- e_f = emission factor for uncontrolled source, pounds/ton
- C_c = average efficiency of control equipment used in the industry for the specific source
- C_t = amount of application of control in the industry (on a production capacity basis) for the specific source

 $C_{c}C_{t} = net control$

Production figures were obtained primarily from government statistics. Efficiency of control equipment was determined from literature sources and information obtained from discussions with industrial contacts The extent of application of control equipment in a given industry was found to be, in most cases, unobtainable from the open literature. There some information as to the number of plants that have control equipment, b no information as to the production capacity of these plants or to the plants that do not have control equipment. Industry surveys were used to secure information on extent of control. Details of these surveys and the emission calculations are given in Reference 1.

Table 2-1 presents a ranking of important stationary industrial sources of particulate pollutants. The stationary sources represented in Table 2-1 were ranked by calculating the emissions from the primary pieces of processing equipment such as kilns, furnaces, reactors, and dryers. In several cases, we have included emissions for "secondary sources" which include crushing operations, materials handling, stockpiles, etc. The calculations involving these secondary sources are in general much less accurate than those involving the primary processing equipment because data on secondary sources are meager or nonexistent. The emission quantities listed for these secondary sources are at best order of magnitude calculations, and it is possible that secondary sources. Total emissions for an industry were obtained as a sum of the emissions from primary and secondary sources.

The leading sources are stationary combustion processes, crushed stone, agriculture and related operations, iron and steel, and cement. Emissions from residential and commercial combustion sources, field burning, and slash burning are not included in the totals shown in Table 2-1 for the stationary combustion processes, agricultural operations, and forest products categories. However, emissions from these processes are included in the individual chapters discussing these industries.

The reliability of the emission quantities in Table 2-1 was assessed by evaluating the reliability of each factor in Equation (1). The quantity of data available, the spread of the data, and the source of the data were considered in the evaluation. A reliability factor, ranging from 1 to 5 with 1 being the most reliable, was assigned to each factor. A composite rating, shown in the last column of Table 2-1, was then determined by averaging the ratings of the individual terms. In those cases where the emissions were calculated by a method other than Equation (1), a reliability rating was assigned directly to the final emission quantity.

More detailed discussions of manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for each industry category are presented in Chapters 6 - 24.

TABLE 2-1

MAJOR INDUSTRIAL SOURCES OF PARTICULATE POLLUTANTS (Based on 1968 production data)

| | Source | Annual Tonnage P | Enission Factor Lb/Ton | Efficiency <u>b</u> / of Control Ce | Application ¹ / of Control C _t | Net ^{c/} Control ^C c ^{•C} t | Emistions Tons/Yr E | Relimoility Rating[/ |
|---|---|-----------------------------------|---------------------------------------|---|--|--|---------------------------|-------------------------|
| | 1. Fuel Combustion | · | | | | | | |
| | A. Coal | | | | | | | |
| | 1. Electric Utility | | | | | | | |
| | a. Pulverized | 258,400,000 tons of coal | 16A=190 ^d / 1b/ton of coal | 0.92 | 0.97 | 0.89 | 2,710,000 | 1 |
| | b. Stoker | 9,900,000 tons of coal | 13A=146 lb/ton of coal | 0,80 | 0.87 | 0.70 | 217,000 | 1 |
| | c. Cyclone | 28,700,000 tons of coal | 3A=35 lb/ton of coal | 0.91 | 0.71 | 0.64 | 182,000 | 1 |
| | | | | Total from | Electric Utilit | y Coal | 3,109,000 | |
| | 2. Industrial boilers | | 1 | | | | | |
| | a. Pulverized | 20,000,000 tons of ceal | 16A=170 [©] / 1b/ton of coal | 0.85 | 0.95 | 0.81 | 322,000 | 5 |
| | b. Stoker | 70,000,000 tons of coal | 13A-133 lb/ton of coal | 0.85 | 0.62 | 0.52 | 2,234,000 | 5 |
| | c. Cyclone | 10,000,000 tons of coal | 3A-31 lb/ton of coal | 0.82 | 0.91 | 0.75 | | 2 |
| | | | | Total from | n Industrial Coal | | 2,595,000 | |
| | B. Fuel Oil | 0 | | | | | | |
| | 1. Electric Utility | 7.18 x 10^9 gal. | 0.010 lb/gai | 0 | 0 | 0 | 36,000 | 2 |
| | 2. Industrial | 0 | | | | | | |
| | a. Residual | 7.51 x 10^9 gal. | 0.023 1b/gal | 0 | 0 | 0 | 87,000 | 2 |
| | b. Distillate | 2.36 x 10^9 gal. | 0.015 lb/gal | 0 | 0 | 0 | 18,000 | 5 |
| | | | | Total from | Fuel Oil | | 1 41, 000 | |
| | C. Natural Gas & LPG | 6 | | | | | | |
| | 1. Electric Utility | $3.14 \times 10^{\circ}$ mil. scf | 15 1b/mil. scf | 0 | 0 | 0 | 24,000 | 2 |
| თ | 2. Industrial | 9.27 x 10° mil. sef | 18 lb/mil. scf | 0 | 0 | 0 | 84,000 | 2 |
| | | | | Total from | ı Natural Gas & I | PG | 108,000 | |
| | | | Total f | rom Utility an | d Industrial Fue | l Combustion | 5,953,000 | |
| | 2. Crushed Stone, Sand & Gravel | | | | | | | |
| | A. Crushed Stone | 681,000,000 | 17 | 0,80 | 0.25 | 0.20 | 4.554.000 | 4 |
| | B. Sand & Gravel | 918,000,000 | 0.1 | | | 0 | 46,000 | 4 |
| | | | | Total from | Crushed Stone, | Sand & Gravel | 4,600,000 | |
| | 3. Operations Related to Agriculture | | | | | | | |
| | A. Grain Elevators | 177.000.000 tons grain handled | | 0.70 | 0.40 | 0.28 | 1,700,000 | • 3 |
| | B. Cotton Gins | 11.000.000 bales | 12 1b/bale | 0.80 | 0.40 | 0.32 | 45,000 | 2 |
| | C. Feed Mills | | | | | | | |
| | 1. Alfalfa Mills | 1,600,000 tons dry meal | 50 lb/ton dry meal | 0.85 | 0.50 | 0.42 | 23,000 | 2 |
| | 2. Mills Other Than | | | | | | | |
| | Alfalfa | 8,364,000 tons | 1% of production | 0.85 | 0.50 | 0.42 | 49,000 | 2 |
| | | | | Total from | Listed Agricultu | ral Operations | 1,817,000 | |

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| | | Annua) Tonnage | Factor Lb/Ton | Efficiency ^b / of Control | Application ⁸ of Control | Net ^c / Control | Emissions Tons/Yr | Reliacilįty |
|----|--|---|--------------------------------------|---|--|-------------------------------|----------------------|-----------------------|
| | Source | P | er | Cc | C_t | Cc'Ct | <u> </u> | Rating ^f / |
| | 4 Tron and Steel | | | | | | | |
| | A Ore Crushing | 82,000,000 tons of one | 2 lb/ton of one | 0 | 0 | 0 | 82,000 | 4 |
| | R. Materials Wandling | 131,000,000 tons of steel | 10 lb/ton of steel | 0.90 | 0 35 | 0 32 | 446,000 | 4 |
| | C Pallat Dianta | 50,000,000 tons of select | | 0.50 | 0.55 | 0.52 | 80,000# | 4 |
| | C. Feilet Flants | 50,000,000 tons of perfects | | | | | 00,000* | - |
| | D. Sinter Fiants | SI,000,000 cons of sinter | 20 lb/top of sister | 0.90 | 1.0 | 0.90 | 51 000 | 2 |
| | 2. Cruching Concess | | | 0.50 | 1.0 | 0.90 | 56,000 | 2 |
| | Z. Grusning, Screening, Etc | | 22 ID/ con of sincer | 0.50 | 1.0 | 0.50 | 30,000 | 2 |
| | E. Coke Manufacture | 1 700 000 have a financial | 000 15/6 | 0 | 0 | 0 | 170,000 | 2 |
| | 1. Beenive | 1,500,000 tons of coal | 200 lb/ton of coal | 0 | 0 | 0 | 130,000 | 2 |
| | 2. By-Product | 90,000,000 tons of coal | | 0 | U | U | 90,000 | 2 |
| | 5. Fushing & Quenching | 91,500,000 tons of coal | U.46 10/ton of coal | | | 0.00 | 21,00) E9,000 | 3 |
| | F. Blast Furnace | as, and, our cons of from | 150 Ib/con of from | 0.33 | 1.0 | 0.55 | 30,000 | 2 |
| | G. Steel Furnaces | CE 000 (00 toos data 1 | 17.15/4-0.44 | 0.07 | 0 43 | 0.40 | 777 000 | 2 |
| | 1. Open Hearth | 5,800,000 tons of steel | 17 10/ton of steel | 0.97 | 0.41 | 0.40 | 337,000 | 2 |
| | 2. Basic Oxygen | 48,000,000 tons of steel | 40 lb/ton of steel | 0.99 | 1.0 | 0.99 | 10,000 | 2 |
| | 5. Electric Arc | 16,800,000 tons of steel | 10 1b/ton of steel | 0.99 | 0.79 | 0.78 | 18,000 | 2 |
| | H. Scarfing | 131,000,000 tons of steel | 3 lb/ton of steel | 0.90 | 0.75 | 0.68 | 63,000 | 3 |
| | | | | Total from | n Iron and Steel | | 1,442,000 | |
| | 5. Cement | | | | | | | |
| | A. Wet Process | 43,600,000 tons of cement | | | | | | |
| | 1. Kilns | ,-, , | 167 lb/ton of cement | 0.94 | 0.94 | 0.88 | 435,000 | 1 |
| -7 | 2. Grinders Dryers, etc. | | 25 lb/ton of cement | 0.94 | 0.94 | 0.88 | 65,000 | 3 |
| | B. Dry Process | 31.000.000 tons of cement | | | | | , | • |
| | 1 Kilne | bijooojooo kond or centro | 167 lb/ton of coment | 0.94 | 0.94 | 0.88 | \$10.000 | 1 |
| | 2 Grinders Druces etc. | | 67 lb/ton of coment | 0.94 | 0.94 | 0.00 | 124,000 | |
| | L. Grinders, pryers, ecc. | | | Total fro | n Cement | 0.00 | 934.000 | 5 |
| | | | | | | | ··· , ··· | |
| | 6. Forest Products | | | | | | | |
| | A. Wigwam Burners | 27,500,000 tons of waste | 10 lb/ton of waste | 0 | 0 | 0 | 132,000 | 2 |
| | B. Pulp Mills | | | | | | | |
| | 1. Kraft Process | 24,300,000 tons of pulp | | | | | | |
| | a. Recovery Furnace | | 150 lb/ton of pulp | 0.92 | 0.99 | 0.91 | 164,000 | 2 |
| | b. Lime Kilns | | 45 lb/ton of pulp | 0.95 | 0.99 | 0.94 | 33,000 | 2 |
| | c. Dissolving Tanks | | 5 lb/ton of pulp | 0.90 | 0.33 | 0.30 | 42,000 | 3 |
| | 2. Sulfite Process | 2,500,000 tons of pulp | | | | | | |
| | a. Recovery Furnace | 833,000 tons of pulp | 268 lb/ton of pulp | 0.92 | 0.99 | 0.91 | 10,000 | 3 |
| | 3. NSSC Process | 3,500,000 tons of pulp | | | | | | |
| | a. Recovery Furnace | 1,167,000 tons of pulp | 24 lb/ton of pulp | 0.92 | 0.99 | 0.91 | 1,000 | 3 |
| | b. Fluid-Bed Reactor | 525,000 tons of pulp | 533 lb/ton of pulp | 0.70 | 1.00 | 0.70 | 42,000 | 3 |
| | 4. Bark Boilers | | | | | | 82,000 | • 3 |
| | C. Particleboard, etc. | | | | | | 74.0004 | • 4 |
| | | | | Total fro | m Forest Products | | 580,000 | • |
| | 7. Lime | | | | | | - | |
| | A. Crushing, Screening | 28,000,000 tons of rock | 24 lb/ton of rock | 0.80 | 0.25 | 0.20 | 264 000 | 3 |
| | B. Rotary Kilns | 16,200,000 tons of lime | 180 lb/ton of lime | 0.93 | 0.87 | 0.81 | 224 000 | 2 |
| | | | / | | | | L | c |
| | C. Vertical Kilns | 1,800,000 tons of lime | 7 lb/ton of lime | 0.97 | 0.40 | 0.39 | 4 000 | 2 |
| | C. Vertical Kilns D. Materials Handling | 1,800,000 tons of lime 18,000,000 tons of lime | 7 lb/ton of lime S lb/ton of lime | 0.97 0.95 | 0.40 0.80 | 0.39 0.76 | 4,000 | 2 |

TABLE 2-1 (Continued)

| Annual TonnagePactorEfficiency EfficiencyApplications ControlMetry ControlEmissions TonsageSource P $c_{\rm C}$ $c_{\rm C}$ $c_{\rm C}$ $c_{\rm C}$ $c_{\rm C}$ $c_{\rm C}$ $E^{\rm missions}$ 8. Primary Nonferrous Metals A Aluminum1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg13,000,000 tons of bauxite 5,840,000 tons of aluminum6 lb/ton of aluminum 200 lb/ton of aluminum $$ $$ 0.900 3 a. H. S. Soderberg600,000 tons of aluminum 0.000 tons of aluminum144 lb/ton of aluminum 0.64 0.400 1.0 0.40 $35,000$ 2 b. V. S. Soderberg700,000 tons of aluminum 0.000 tons of aluminum144 lb/ton of aluminum 0.64 0.64 1.00 0.64 $10,000$ 2 c. Prebake 2. Reverb. Purace $1,755,000$ tons of aluminum $142,000$ 10 0.64 1.0 0.64 $20,000$ 2 B. Copper 2. Roasting $170,000,000$ tons of orc $1,437,000$ tons of copper 2 lb/ton of cru 26 lb/ton of Cu 0.85 1.0 0.85 $7,000$ 3 c. Prebake $4.$ Converters $1,437,000$ tons of copper 2 lb/ton of Cu 0.95 0.85 0.81 $29,000$ 3 c. S. Materials Handling $1,437,000$ tons of copper 2 lb/ton of Cu 0.95 0.85 0.81 $33,000$ 3 c. Converters $1.437,000$ tons of copper 2 lb/ton of Cu 0.95 0.85 0.81 $33,000$ 3 </th <th>Source 8. Primary Nonferrous Metals A. Aluminum 1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg b. V. S. Soderberg</th> | Source 8. Primary Nonferrous Metals A. Aluminum 1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg b. V. S. Soderberg |
|--|---|
| Source p Lb/ton of Control of Control < | Source 8. Primary Nonferrous Metals A. Aluminum 1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg b. V. S. Soderberg |
| Source p cr Cc Ct Ct <th< th=""><th>8. Primary Nonferrous Metals A. Aluminum 1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg b. V. S. Soderberg</th></th<> | 8. Primary Nonferrous Metals A. Aluminum 1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg b. V. S. Soderberg |
| 8. Primary Nonferrous Metals A. Aluminum 1. Grinding of Bauxite 13,000,000 tons of bauxite 0.80 8,000 3 2. Calcining of Hydroxide 5,040,000 tons of aluminum 104 lb/ton of aluminum 0.90 58,000 3 3. Reduction Cells a. H. S. Soderberg 800,000 tons of aluminum 144 lb/ton of aluminum 0.40 1.0 0.64 10,000 2 b. V. S. Soderberg 700,000 tons of aluminum 64 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 c. Frebake 1,755,000 tons of aluminum 10 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,500,000 tons of ore 2 lb/ton of cu 0.90 0.35 0.32 11,000 4 B. Copper 1 10 lb/ton of cu 0.90 0 0 100,000 3 3,000 3 3. Reverb. Furnace 1,437,000 tons of copper 168 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 206 lb/ton of Cu | Primary Nonferrous Metals Aluminum |
| A. Aluminum 1. Grinding of Bauxite 15,000,000 tons of bauxite 6 lb/ton of bauxite 0.80 8,000 3 2. Calcining of Hydroxide 5,840,000 tons of alumina 200 lb/ton of alumina 0.80 8,000 3 3. Reduction Cells a. H. S. Soderberg 800,000 tons of aluminum 144 lb/ton of aluminum 0.40 1.0 0.40 35,000 2 b. V. S. Soderberg 700,000 tons of aluminum 144 lb/ton of aluminum 0.64 1.0 0.64 10,000 2 c. Prebake 1,755,000 tons of aluminum 63 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,500,000 tons of or 2 lb/ton of aluminum 0.90 0.35 0.52 11,000 4 Deprimary Aluminum 10 lb/ton of aluminum 0.64 1.0 0.65 7,000 3 B. Copper 1 0re Grushing 170,000 tons of copper 160 lb/ton of Cu 0.85 0.81 28,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 < | A. Alumpinum 1. Grinding of Bauxite 2. Calcining of Hydroxide 3. Reduction Cells a. H. S. Soderberg b. V. S. Soderberg |
| 1. Grinding of Bauxite 13,000,000 tons of bauxite 6 lb/ton of bauxite 0.80 8,000 3 2. Calcining of Hydroxide 5,840,000 tons of alumina 200 lb/ton of alumina 0.90 58,000 3 3. Reduction Cells a. H. S. Soderberg 800,000 tons of aluminum 144 lb/ton of aluminum 0.40 1.0 0.40 35,000 2 b. V. S. Soderberg 700,000 tons of aluminum 144 lb/ton of aluminum 0.64 1.0 0.64 10,000 2 c. Prebake 1,755,000 tons of aluminum 61 b/ton of aluminum 0.64 1.0 0.64 10,000 2 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.90 0.35 0.32 11,000 4 B. Copper 1 170,000,000 tons of copper 168 lb/ton of Cu 0.95 0.85 7,000 3 2. Roasting 575,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 | Grinding of Bauxite Calcining of Hydroxide Reduction Cells a. H. S. Soderberg b. Y. S. Soderberg |
| 2. Calcining of Hydroxide 3. Reduction Cells 5,840,000 tons of alumina 200 lb/ton of alumina 0.90 58,000 3 3. Reduction Cells a. H. S. Soderberg 800,000 tons of aluminum 144 lb/ton of aluminum 0.40 1.0 0.40 35,000 2 b. V. S. Soderberg 700,000 tons of aluminum 84 lb/ton of aluminum 0.64 1.0 0.64 10,000 2 c. Prebake 1,755,000 tons of aluminum 63 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,300,000 tons of ore 2 lb/ton of aluminum 0.90 0.35 0.32 11,000 4 b. Copper 1. Ore Crushing 170,000,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 33,000 3 5. Materials Handling 1,437,000 tons of copper 235 lb/ton of Cu 0.90 0.35 0.32 5,000 3 6. Zinc 1. 0re Crushing 18,000,000 tons of ore 2 lb/ton of ore <td> Calcining of Hydroxide Reduction Cells a. H. S. Soderberg b. V. S. Soderberg </td> | Calcining of Hydroxide Reduction Cells a. H. S. Soderberg b. V. S. Soderberg |
| a. H. S. Soderberg 800,000 tons of aluminum 144 lb/ton of aluminum 0.40 1.0 0.40 35,000 2 b. V. S. Soderberg 700,000 tons of aluminum 84 lb/ton of aluminum 0.64 1.0 0.64 10,000 2 c. Prebake 1,755,000 tons of aluminum 63 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 5. Copper 10 lb/ton of aluminum 10 lb/ton of aluminum 0.90 0.35 0.32 11,000 4 B. Copper 10 lb/ton of cre 0 0 0 170,000 3 2. Roasting 575,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 700,03 3 4. Converters 1,437,000 tons of copper 235 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zinc 1 1.0 creshing </td <td>a. H. S. Soderberg</td> | a. H. S. Soderberg |
| b. V. S. Soderberg 700,000 tons of aluminum 84 lb/ton of aluminum 0.64 1.0 0.64 10,000 2 c. Prebake 1,755,000 tons of aluminum 63 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.90 0.35 0.32 11,000 4 B. Copper 1 10 lb/ton of cue 0 0 0 170,000 3 2. Roasting 170,000,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zinc 1.0 re Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 0 18,000 3 2. Roasting < | h V S Soderberg |
| c. Prebake 1,755,000 tons of aluminum 63 lb/ton of aluminum 0.64 1.0 0.64 20,000 2 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.90 0.35 0.32 11,000 4 B. Copper 1 0 re Crusbing 170,000,000 tons of ore 2 lb/ton of ore 0 0 0 170,000 3 2. Roasting 575,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 33,000 3 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zinc 1 Total from Primary Copper 243,000 243,000 3 243,000 3 2. Roasting 18,000,000 tons of ore 2 lb/ton of ore 0 0 0 18,000 3 2. Roasting | o. v. b. Doderberg |
| 4. Materials Handling 3,300,000 tons of aluminum 10 lb/ton of aluminum 0.90 0.35 0.32 11,000 142,000 B. Copper 1. Ore Crusbing 170,000,000 tons of ore 2 lb/ton of ore 0 0 0 170,000 3 2. Roasting 575,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 5. Materials Handling 1,437,000 tons of copper 205 lb/ton of Cu 0.95 0.85 0.81 33,000 3 6. Zinc 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 0 18,000 3 2. Roasting 163,000 tons of zinc 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 3 2. Roasting 765,000 tons of zinc <td< td=""><td>c. Prebake</td></td<> | c. Prebake |
| B. Copper 142,000 1. Ore Crushing 170,000,000 tons of ore 2 lb/ton of ore 0 0 170,000 3 2. Reasting 575,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 235 lb/ton of Cu 0.95 0.85 0.81 33,000 3 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zinc Total from Primary Copper 243,000 243,000 3 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 2. Roasting | 4. Materials Handling |
| B. Copper 1. Ore Crusbing 170,000,000 tons of ore 2 lb/ton of ore 0 0 170,000 3 2. Reasting 575,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 235 lb/ton of Cu 0.95 0.85 0.81 33,000 3 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zine Total from Primary Copper 1. Ore Crushing 18,000,000 tons of core 2 lb/ton of ore 0 0 0 18,000 3 2. Roasting 16,000,000 tons of zine 2 lb/ton of ore 0 0 0 18,000 3 c. Zine 1 30,000 tons of zine 2 lb/ton of ore 0 0 0 18,000 3 a. Fluid-bed 765,000 tons of zine 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 | |
| 1. Ore Crushing 170,000,000 tons of ore 2 1b/ton of ore 0 0 0 170,000 3 2. Reasting 575,000 tons of copper 168 1b/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 1b/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 235 1b/ton of Cu 0.95 0.85 0.81 23,000 3 5. Materials Handling 1,437,000 tons of copper 10 1b/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zine Total from Primary Copper 245,000 245,000 3 2. Roasting 18,000,000 tons of ore 2 1b/ton of ore 0 0 18,000 3 2. Roasting 1.0 Te Crushing 18,000,000 tons of zine 2,000 1b/ton of Zn 0.96 1.0 0.98 15,000 3 a. Fluid-bed 765,000 tons of zine 2,000 1b/ton of Zn 0.98 1.0 0.95 4.000 3 b. Room, multiphearth 153,000 tons of zine 333 1b/ton of Zn 0.85 1. | B. Copper |
| 2. Reasting 575,000 tons of copper 168 lb/ton of Cu 0.85 1.0 0.85 7,000 3 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 235 lb/ton of Cu 0.95 0.85 0.81 23,000 3 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zinc Total from Primary Copper 245,000 3 2. Roasting 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zn 0.96 1.0 0.98 15,000 3 b. Romm, multipherath 153,000 tons of zinc 2,000 lb/ton of Zn 0.98 1.0 0.95 4000 3 | 1. Ore Crushing |
| 3. Reverb. Furnace 1,437,000 tons of copper 206 lb/ton of Cu 0.95 0.85 0.81 28,000 3 4. Converters 1,437,000 tons of copper 235 lb/ton of Cu 0.95 0.85 0.81 33,000 3 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.95 0.85 0.81 33,000 3 6. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 Total from Primary Copper 243,000 C. Zinc Total from Primary Copper 243,000 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 2. Roasting a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zn 0.96 1.0 0.98 15,000 3 b. Boom, multiphearth 153,000 tons of zinc 333 lb/ton of Zn 0.85 1.0 0.85 4.000 3 | 2. Roasting |
| 4. Converters 1,437,000 tons of copper 235 lb/ton of Cu 0.95 0.85 0.81 33,000 3 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 Total from Primary Copper 243,000 C. Zinc 1 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 2. Roasting a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 3 b. Romm, multichearth 153 000 tons of zinc 333 lb/ton of Zn 0.85 1.0 0.85 4.000 3 | 3. Reverb. Furnace |
| 5. Materials Handling 1,437,000 tons of copper 10 lb/ton of Cu 0.90 0.35 0.32 5,000 4 C. Zinc Total from Primary Copper 243,000 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 2. Roasting a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 3 | 4. Converters |
| Total from Primary Copper 243,000 C. Zinc 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 0 18,000 3 2. Roasting a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 3 b. Bonn, multi-bearth 153,000 tons of zinc 333 lb/ton of Zn 0.85 1.0 0.85 4,000 3 | 5. Materials Handling |
| C. Zinc 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 2. Reasting a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zin 0.98 1.0 0.98 15,000 3 b. Roum, multi-bearth 153,000 tons of zinc 333 lb/ton of Zin 0.85 1.0 0.85 4,000 3 | |
| 1. Ore Crushing 18,000,000 tons of ore 2 lb/ton of ore 0 0 18,000 3 2. Reasting | C. Zinc |
| 2. Roasting a. Fluid-bed 765,000 tons of zine 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 3 b. Ropp. multi-hearth 153,000 tons of zine 333 lb/ton of Zn 0.85 1.0 0.85 4,000 3 | 1. Ore Crushing |
| a. Fluid-bed 765,000 tons of zinc 2,000 lb/ton of Zn 0.98 1.0 0.98 15,000 3 b. Ropp. multi-hearth 153,000 tons of zinc 333 lb/top of Zn 0.85 1.0 0.85 4,000 3 | 2. Roasting |
| b. Ropp. multi-hearth 153,000 tons of zinc 333, b/top of zn 0.85 1.0 0.85 4,000 3 | a. Fluid-bed |
| | b. Ropp, multi-hearth |
| 3. Sintering 612,000 tons of zinc 180 lb/ton of Zn 0.95 1.0 0.95 3,000 3 | 3. Sintering |
| 4. Distillation 612,000 tons of zinc 15,000* 4 | 4. Distillation |
| 5. Materials Handling 1,020,000 tons of zinc 7 lb/ton of Zn 0.90 0.35 0.32 4 | 5. Materials Handling |
| Total from Primary Zinc 57,000 | |
| D. Lead | D. Lead |
| 1. Ore Crushing 4,500,000 tons of ore 2 lb/ton of ore 0 0 0 4,000 3 | 1. Ore Crushing |
| 2. Sintering 467,000 tons of lead 520 lb/ton of lead 0.95 0.90 0.86 17,000 3 | 2. Sintering |
| 3. Blast Furnace 467,000 tons of lead 250 lb/ton of lead 0.85 0.98 0.83 10,000 3 | 3. Blast Furnace |
| 4. Dross Reverb. Furnace 467,000 tons of lead 20 lb/ton of lead 0.50 2,000 3 | 4. Dross Reverb. Furnace |
| 5. Materials Handling 467,000 tons of lead 5 lb/ton of lead 0.90 0.35 0.32 1,000 4 | |
| Total from Primary Lead 34,000 | 5. Materials Handling |
| | 5. Materials flandling |

.

Total from Primary Nonferrous 476,000

| | Source | Annual Tonnage P | Emission Factor Lb/Ton | Efficiency ^{b/} of Control C | Application ^B / of Control | Net ^c / Control _C _c .C _t _ | Enissions Tons/Yr E | Reliability Rating |
|---|----------------------------------|-------------------------------------|--------------------------------|---|--|--|---------------------------|-----------------------|
| | 9. Clay | | | | | | | |
| | A. Ceramic | | | | | | | |
| | 1. Grinding | 4,722,000 tons | 76 1b/ton | 0.80 | 0.75 | 0.60 | 72,000 | 3 |
| | 2. Drying | 7,870,000 tons | 70 1b/ton | 0.80 | 0.75 | 0.60 | 110,000 | 3 |
| | B. Refractories | | | | | | | |
| | 1. Kiln-Fired | | | | | | | |
| | a. Calcining | 688,000 tons | 200 lb/ton | 0.80 | 0.80 | 0.64 | 25,000 | 3 |
| | b. Drying | 1,032,000 tons | 70 lb/ton | 0.80 | 0.80 | 0.64 | 13,000 | 3 |
| | c. Grinding | 3,440,000 tons | 76 lb/ton | 0.80 | 0.80 | 0.64 | 47,000 | 3 |
| | 2. Castable | 550,000 tons | 225 lb/ton | 0.90 | 0.85 | 0.77 | 14,000 | 3 |
| | 3. Magnesite | 120,000 tons | 250 lb/ton | 0.80 | 0.70 | 0.56 | 7,000 | 3 |
| | 4. Mortars | | | | | | | |
| | a. Grinding | 120,000 tons | 76 1b/ton | 0.80 | 0.75 | 0.60 | 2,000 | 3 |
| | b. Drying | 120,000 tons | 70 1b/ton | 0.80 | 0.75 | 0.60 | 2,000 | 3 |
| | 5. Mixes | 249,000 tons | 76 1b/ton | 0.80 | 0.75 | 0.60 | 4,000 | 3 |
| • | C. Heavy Clay Products | | Ba a 4 | 0 -0 | | | | - |
| | 1. Grinding | 4,740,000 tons | 76 lb/ton | 0.80 | 0.75 | 0.60 | 72,000 | 3 |
| | 2. urying | 7,110,000 tons | 70 IB/ton | 0.80 | 0.75 | 0.60 | 99,000 | 3 |
| | | | | Total Iron | i Ciay | | 467,000 | |
| 1 | 0. Rentilizer and Phosphate Rock | | | | | | | |
| - | A. Phosphate Rock | 41.300.000 tons of rock | | | | | | |
| Q | 1. Drving | | 12 lb/ton | 0.94 | 1.0 | 0.94 | 14.000 | 2 |
| | 2. Grinding | | 2 lb/ton | 0.97 | 1.0 | 0.97 | 1,000 | 2 |
| | 3. Materials Handling | | 2 lb/ton | 0.90 | 0.25 | 0.22 | 30,000 | 4 |
| | 4. Calcining | 8,260,000 tons | 40 lb/ton | 0.95 | 1.0 | 0.95 | 8,000 | 3 |
| | B. Fertilizers | | | | | | • | |
| | 1. Ammonium Nitrate | 2,800,000 tons of granules | | | | | 28,000 | F 4 |
| | 2. Urea | 1,000,000 tons of granules | | | | | 10,000 | F 4 |
| | Phosphates | | | | | | | |
| | a. Rock Pulverizing | 17,000,000 tons of rock | 6 lb/ton of rock | 0.80 | 1.0 | 0.80 | 10,000 | 2 |
| | b. Acid-Rock Reaction | 4,370,000 tons of P ₂ 05 | 48 lb/ton of P ₂ 05 | 0.95 | 0.95 | 0.90 | 9,000 | 2 |
| | c. Granulation and Drying | 3, | | | | | | |
| | etc. | 18,100,000 tons of granules | 195 1b/ton | 0.95 | 0.95 | 0.90 | 169,000 | 2 |
| | d. Materials Handling | | | | | | 18,000 | • 4 |
| | e. Bagging | 9,000,000 tons of granules | | | | | 4,000 | * 4 |
| | 4. Ammonium Sulfate | 2,700,000 tons of granules | | | | | 27,000 | * 4 |
| | | | | Total from | m Fertilizers and | d Phosphate Bock | 328,000 | |
| , | 11 Acobalt | | | | | | | |
| | A Daving Matorial | 251 000 000 tone of material | | | | | | |
| |). Drivers | cor,oco,oco cous or anternar | 32 lb/ton of material | 0.97 | 0 99 | 0.96 | 161.000 | 2 |
| | 2. Secondary Sources | | 8 lb/ton of material | 0.97 | 0.99 | 0.96 | 40,000 | 2 |
| | B. Boofing Material | 6.264.000 tons of asphalt | o service of material | 0.01 | 0.05 | v. 50 | 40,000 | Ľ |
| | 1. Blowing | -,, | 4 lb/ton of asphalt | | | 0.50 | 3,000 | 4 |
| | 2. Saturator | | | | | | 14.000 | * 4 |
| | | | | Total fro | m Asphalt | | 218.000 | - |
| | | | | | • • • | | | |

TABLE 2-1 (Continued)

| | | Emission | . / | , | , | | |
|---------------------------------|------------------------------|----------------------------|----------------|----------------------------|-----------------------------|-----------|-------------|
| | Annual | Factor | Efficiencyb∕ | Application ^a / | Net ^C / | Emissions | |
| | Tonnage | Lb/Ton | of Control | of Control | Control | Tons/Yr | Reliability |
| Source | P | <u>e</u> r | C _e | C_t | $\underline{c_c \cdot c_t}$ | <u> </u> | Rating1/ |
| | | | | | | | |
| 12. Ferroalloys | | | | 1 00 | 0.00 | 1 000 | <u> </u> |
| A. Blast Furnace | 591,000 tons of ferroalloy | 410 lb/ton ferroalloy | 0.99 | 1.00 | 0.99 | 1,000 | 2 |
| B. Electric Furnace | 2,119,000 tons of ferroalloy | 240 lb/ton ferroalloy | 0.80 | 0.50 | 0.40 | 150,000 | 5 |
| C. Materials Handling | 2,710,000 tons of ferroalloy | 10 1b/ton ferroalloy | 0.90 | 0.35 | 0.52 | 9,000 | 4 |
| | | | Total from | Ferroalloys | | 160,000 | |
| 13. Iron Foundries | | | | | | | |
| A. Furnaces | 18,000,000 tons of hot metal | 16 lb/ton of metal | 0.80 | 0.33 | 0.27 | 105,000 | 5 |
| B. Materials Handling | | | | | | | |
| 1. Coke, Limestone, etc. | | 5 lb/ton of metal | 0.80 | 0.25 | 0.20 | 37,000 | 3 |
| 2. Sand | 10,500,000 tons of sand | $0.3 \ lb/ton \ of \ sand$ | 0 | 0 | 0 | 1,000 | 3 |
| | | | Total from | Iron Foundries | | 143,000 | |
| | | | | | | | |
| 14. Secondary Nonferrous Metals | | | | | | | |
| A. Copper | | | | | | | |
| 1. Material Preparation | | 075 12 / 100 01 01 00 | • | 0 | | 43,000 | |
| a. wire Burning | Stop tons insulated wire | 2/5 1b/ton of vire | 0 | 0 | 0 | 41,000 | 3 |
| 0. Sweating Furnaces | 007 000 tons scrap | 13 10/ton of serap | 0.95 | 0.20 | 0.19 | | 7 |
| C. Blast Furnaces | 287,000 tons scrap | 30 lb/ton of serap | 0.90 | 0.75 | 0.68 | 2,000 | 3 |
| 2. Smelting & Refining | 1,170,000 tons scrap | 70 Ib/ton of scrap | 0.95 | 0.60 | 0.57 | | 2 |
| B. Alumninum | | | Total from | Secondary Coppe | er | 60,000 | |
| 1. Sweating Furnaces | 500.000 tons scrap | 32 lb/ton of scrap | 0.95 | 0.20 | 0.19 | 6,000 | 4 |
| 2. Refining Furnaces | 1,015,000 tons scrap | 4 1b/ton of scrap | 0.95 | 0.60 | 0.57 | 1,000 | 3 |
| 3. Chlorine Fluxing | 136,000 tons C1 used | 1,000 1b/ton Cl used | | | 0.25 | 51,000 | 4 |
| | | | Total from | Secondary Alum: | inuma | 58,000 | |
| C. Lead | | | | | | , | |
| 1. Pot Furnaces | 53,000 tons scrap | 0.8 lb/ton of scrap | 0.95 | 0.95 | 0.90 | | |
| 2. Blast Furnaces | 119,000 tons scrap | 190 lb/ton of scrap | 0.95 | 0.95 | 0.90 | 1,000 | 2 |
| 3. Reverb. Furnaces | 554,000 tons scrap | 100 lb/ton of scrap | 0.95 | 0.95 | 0.90 | 3,000 | 2 |
| | | - | Total from | Secondary Lead | | 4,000 | |
| D. Zinc | | | | - | | | |
| 1. Sweating Furnaces | | | | | | | |
| a. Metallic Scrap | 52,000 tons of scrap | 12 lb/ton of scrap | 0.95 | 0.20 | 0.19 | | |
| b. Residual Scrap | 210,000 tons of scrap | 30 lb/ton of scrap | 0.95 | 0.20 | 0.19 | 3,000 | 3 |
| 2. Distillation Furnace | 233,000 tons Zn recovered | 45 1b/ton of zinc | 0.95 | 0.60 | 0.57 | 2,000 | 3 |
| | | | Total from | Secondary Zinc | | 5,000 | |
| | | | | | | | |

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Total from Secondary Nonferrous Metals 127,000

| Source | Annual Tonnayc P | Brission Factor Lb/Ton f | Efficiency $\frac{b}{c_{c}}$ | Application <u>u</u> / of Control C _t | Het ^c / Control C _c ·C _t | Emissions Tons/Yr E | Reliability |
|----------------------------|--|---|------------------------------|--|---|---------------------------|-----------------|
| 15. Coal Cleaning | 17 (000 000 br | | | | | | |
| A. Thermal Dryers | 75,000,000 tons dried | | | 1.0 | | 94,000# | 2 |
| 16. Carbon Black | | | | | | | |
| A. Channel Process | 71,000 | 2,300 | 0 | 0 | 0 | 82.000 | 1 |
| B. Furnace Process | | | | | - | , | - |
| 1. Gas | 156,000 | | | 1.00 | | 5,000* | 5 |
| 2. 011 | 1,180,000 | | | 1.00 | | 6,000* | 2 |
| | | | Total from | Carbon Black | | 93,000 | |
| 17. Petroleum | | | | | | | |
| A. FCC Units | 1.19 x 10 ⁹ bb1. of feed | | | 1.0 | | 45,000# | 3 |
| 18. Acids | | | | | | | |
| A. Sulfuric | | | | | | | |
| 1. New Acid | | | | | | | |
| a. Chamber | 1,000,000 tons of 100% H2SO4 | 5 1b/ton of 100% H ₂ SO ₄ | | · 0 | 0 | 2,000 | 1 |
| b. Contact | 27,000,000 tons of 100% H ₂ SO ₄ | 2 lb/ton of 100% H ₂ SO4 | 0.95 | 0.90 | 0.85 | 4,000 | 5 |
| 2. Spent-Acid Concentrator | s 11,200,000 tons of spent acid | 30 lb/ton of spent acid | 0.95 | 0.85 | 0.80 | 8,000 | 4 |
| B. Phosphoric | · · · · · · · · · · · · · · · · · · · | | | | | | |
| 1. Thermal Process | 1,020,000 tons of P ₂ 05 | 134 lb/ton of P_2O_5 | 0.97 | 1.0 | 0.97 | 2,000 | 1 |
| | | | Total fro | om, Acids | | 16,000 | |
| | | | | | | | |
| | | | | | | | |

TOTAL FROM MAJOR INDUSTRIAL SOURCES 18,056,000

* See specific industry section of Volume I for method of calculating quantity emitted.

 a/ Application of Control is defined as that fraction of the total production which has controls.
 b/ Efficiency of Control is defined as the average fractional efficiency of the control equipment, prorated on the basis of production capacity.
 c/ Net Control is defined as the overall level of control, and is the product of the application of control multiplied by the efficiency of control. $\overline{d_{je}}$ Average Ash Content of Coal Used, determined by phone survey (see Volume I - Section 5):

| | (d) | (e) |
|-------------|-------------|------------|
| Type Boiler | Elec. Util. | Industrial |
| Pulverized | 11.9% | 10.6% |
| Stoker | 11.2% | 10.2% |
| Cyclone | 11.8% | 10.3% |

f/ Reliability rating is indicative of the reliability of the Emissions quantity. Ratings range from 1 to 4 with 1 being the most reliable.

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1. "Particulate Pollutant System Study, Vol. I, Mass Emissions," Midwest Research Institute, NAPCA Contract No. CPA 22-69-104, May 1971.

CHAPTER 3

CONTROL EQUIPMENT

3.1 INTRODUCTION

Equipment available for the control of particulate matter consists of cyclones, wet scrubbers, electrostatic precipitators, and fabric filters. Afterburners may also be used for removal of combustible gases and particulates. The chapters in this handbook discuss the application, advantages, and disadvantages of these devices in each of the major industrial categories of particulate pollution.

The preliminary consideration in selection of the different types of devices is probably most dependent on the volume of gas to be treated. Knowing this, rough cost estimates can be made on the basis of cost figures and equations presented in Appendix A.¹/ Appendix A includes figures illustrating purchase cost, installed cost, and annualized cost of operation plus equations for annual operating and maintenance costs. It should be borne in mind that these costs can vary considerably for any specific application, as is noted in some of the chapters of this handbook.

Specifications for a particular application require considerably more information than gas volume. Particle and carrier gas characteristics are needed including particle size concentration (average and range), particle size distribution, particle density, particle resistivity, gas flow rate, gas temperature and moisture content, and other important properties such as corrosivity or flammability.

The usual objective of installing pollution control equipment is concerned with the quantity or concentration of particulate matter that will be emitted. Therefore, the specifications will usually stipulate the maximum allowable emissions as a quantity in 1b/hr or as a concentration in grains/scf. This will set the efficiency for which the control equipment must be designed, based on given inlet conditions. An indication of the relative efficiency of various collection devices, as a function of particle size, is shown in Figure 3-1.3/ These curves were obtained using one standard test dust which compares to a typical fly ash.

The opacity of the emission is usually also an important aspect of the equipment performance. Opacity is related to the outlet concentration



Figure 3-1 - Efficiency Curves for Various Types of Dust Collecting Equipme

of the particulate matter. It should be remembered that the finer particles, which are the most difficult to collect, affect the light scattering properties of the stack effluent. This is one of the reasons that the inlet particle size distribution is so important. If the control equipment must provide a clear stack, the outlet concentration to be specified may be lower than would otherwise be required. The maximum permissible concentration for fly-ash emissions from power plants is of the order of 0.02 - 0.03 grain/scf for the discharge to be invisible. $\frac{4}{}$ Maximum concentrations for other industry effluents are presented in some of the industry chapters of this handbook.

A brief description of each of the general types of control devices is presented below to acquaint the reader with each and to point out those industries and processes that utilize each type. A more complete description of each of the devices and treatment of theoretical considerations may be found in References 1, 2 and 3 plus many of the references given in the bibliographies following each industry chapter.

3.2 CYCLONES

Cyclonic collectors are round conically shaped vessels in which the gas stream enters tangentially and follows a spiral path to the outlet. The spiral motion produces the centrifugal forces that cause the particulate matter to move toward the periphery of the vessel and collect on the walls and fall to the bottom of the vessel.

The centrifugal force is the major force causing separation of the particulate in a cyclone separator. This force (F_c) is equal to the product of the particulate mass (M_p) and centrifugal acceleration (V_p^2/R) , where V_p is the particle velocity and R is the radius of motion (curvature).

$$\mathbf{F}_{c} = (\mathbf{M}_{p})(\frac{\mathbf{V}_{p}^{2}}{\mathbf{R}})$$

The centrifugal forces cause the particles to move outward toward the wall of the cyclone. However, this movement of the particle through the gas stream is opposed by frictional drag on the particle caused by the relative motion of the particle and gas. The frictional drag (F_f) is directly proportional to the product of (C_f) , a drag coefficient, the projected cross-sectional area of the particle (A_p) , particle density (p), the square of the particle velocity relative to the gas stream (V_r^2) , and an inverse function of the acceleration due to gravity (g).

$$F_{f} = (C_{f})(A_{p})(p)(V_{r}^{2})/2g$$
The centrifugal and frictional forces, plus the force of gravity, combine to determine the collection efficiency. This collection efficiency increases with:

- (1) dust particle size
- (2) particle density
- (3) gas velocity
- (4) cyclone body length
- (5) smoothness of cyclone wall

Although efficiency increases with increasing gas velocity, this is at a lower rate than that at which the pressure drop increases. For a given cyclone and dust combination, an optimum velocity exists, beyond whic turbulence increases more rapidly than separation efficiency, and efficienc decreases. l'

The cyclonic collectors are generally of two types: the large diameter, lower efficiency cyclones, and the smaller diameter, multitube high-efficiency units. The larger cyclones have lower efficiencies especially on particles less than about 50 μ . However, they have low initial cost and usually operate at pressure drops of 1-3 in. of water. The multitube cyclones are capable of efficiencies exceeding 90% but the cost is higher and their pressure drop is usually 3-5 in. of water. They are also more susceptible to plugging and erosion.

The larger cyclones are often used as a part of the process when the gas stream is heavily laden with part of the product such as in coal dryers, alfalfa dehydrators and milling operations. They are widely used in grain elevators, sawmills, asphalt plants and detergent manufacture.

3.3 WET SCRUBBERS

Wet collectors use water "sprays" to collect and remove particula matter. There are many variations of wet collectors but they may generally be classified as low or high energy scrubbers. Low energy scrubbers of 1-6 in. of pressure drop may consist of simple spray towers, packed towers or impingement plate towers. Water requirements may run 3-6 gal/1,000 cu ft. of gas and collection efficiencies can exceed 90-95%. The lower energy scrubber finds frequent application in incinerators, fertilizer manufacturing, lime kilns, and iron foundries.

The high energy scrubber, or Venturi, imparts high velocity to the gas stream by means of converging-diverging duct section, and contacts the stream with injected water. The high velocities provide increased collection efficiency, up to 99.5%, but the pressure drop may range from 10-60 in. of water. This requires a draft fan with high power input. The Venturi scrubber is often used in conjunction with steel furnaces, pulp mills and foundry cupolas.

The wet scrubbers can provide high collection efficiency but may involve treatment of liquid wastes with settling ponds. They also saturate the gas stream and produce a resultant steam plume.

The principal mechanisms involved in wet scrubbing are: (1) increasing the size of the particles by combination with liquid droplets thereby increasing their size so they may be collected more easily, and/or (2) trapping them in a liquid film and washing them away.

Dust collection efficiency is believed by some investigators to be directly related to contacting power and the properties of the particulate matter. Contacting power is that portion of useful energy expended in producing contact of the particulate matter with the scrubbing liquid, as well as in producing turbulence and mixing in the scrubber device. The contacting power represents the kinetic energy or pressure head loss across the scrubber, kinetic energy or pressure head drop of the scrubbing liquid, and other forms of energy dissipated in the gas stream such as sonic energy or energy supplied by a mechanical rotor. This means that the higher the power imput, the higher is the efficiency. However, the efficiency is also a function of the particulate matter properties and the smaller particles require higher power input than larger particles. $\underline{1}/$

3.4 ELECTROSTATIC PRECIPITATORS

The operating principle of electrostatic precipitation requires three basic steps:

- (1) Electrical charging of the suspended particulate matter.
- (2) Collection of the charged particulate matter on a grounded surface.
- (3) Removal of the particulate matter from the collecting surfaces by mechanical scrubbing or flushing with liquids.

The electrical charging is accomplished by passing the suspended particles through a high-voltage, direct-current corona. Peak voltage

requirements usually range from 30 to 100 kilowatts. Gas velocities range from 3 to 15 ft/sec. This low linear velocity promotes deposition and minimizes re-entrainment. However, this also means that the precipitators will be large in size, or cross-sectional area, to achieve the low gas velocities. Uniform flow distribution is also an important factor that must be considered in design of ductwork.

The collection efficiency of electrostatic precipitators is expressed by the Deutsch equation as: 2^{2}

$$E = 1 - \ell - WA/Q$$

where

- w = migration velocity of dust particle toward the collecting electrode, ft/sec
- A = area of collecting electrode, ft^2

E = weight fraction of dust collected

Q = gas flow rate, acf/sec

This equation shows the exponential relationship of efficiency to the area of the collecting electrode. Thus, moderate increases in collector efficiency for an existing unit may require a rather large increase in collecting surfaces.

The proper operation of an electrostatic precipitator is dependent on the electrical resistivity of the particles. Pre-conditioning with water sprays may be required to impart beneficial resistivity character to the particles. Proper control of operating voltages must also be provided if efficient particulate removal is to be maintained. The precipitator generally has high initial cost but it is capable of high collecti efficiency, exceeding 99%, at a pressure drop less than 0.5 in. of water.

Electrostatic precipitators have been used extensively for many years to reduce particulate emissions from coal-fired power plants. These units handle very large gas volumes with low pressure drops. They have also been applied in steel mills to clean the gases from blast furnaces and basic oxygen furnaces, and in cement plants, pulp mills, and sulfuric acid plants.

3.5 FABRIC FILTERS

Fabric filter systems, i.e., baghouses, usually consist of tubular bags made of woven synthetic fabric or fiberglass, in which the dirty gases pass through the fabric while the particles are collected on the upstream side by the filtering action of the fabric. The dust retained on the bags is periodically shaken off and falls into a collecting hopper for removal.

Fabric filters usually provide very high collection efficiencies, exceeding 99.5%, at pressure drops usually ranging from 4-6 in. of water. The amount of filter area required is often based on an air-to-cloth ratio of 1.5-3.0 cu ft/min of gas/sq ft of cloth. The maximum operating temperature for a baghouse is 550° F using fiberglass bags. However, there may also be a minimum temperature limitation so as to maintain the gas temperature 50° F to 75° F above the dew point. Inlet dust loadings range from 0.1 to 10.0 grains/cu ft of gas. Higher concentrations in some industries are removed by a precleaning device, such as a low efficiency cyclone.

Baghouses do provide the high collection efficiency at moderate pressure drop but initial cost is relatively high especially when precooling systems are required. The baghouses also may be large and take up considerable space. They frequently entail high maintenance costs for bag replacement. However, replacement of bags need not impair baghouse operation if the unit is compartmented so that one section can be taken out of service for maintenance while the others continue to operate.

The baghouse has found wide application in many industries, including mining operations, food processing, grain elevators, soap and detergents, plastics manufacture and numerous others. Some of the industries that employ large baghouse operations are carbon black, cement, electric arc furnaces, foundry cupolas and nonferrous smelting operations.

3.6 MIST ELIMINATORS

One of the most commonly used type of mist eliminators is the mesh filter which consists of an evenly spaced knitted wire or plastic mesh, usually mounted in horizontal bed. Rising mist droplets strike the wire surface, flow down the wire to a wire junction, coalesce, and flow to the bottom surface of the bed, where the liquid disengages in the form of large droplets and returns by gravity to the process equipment. $\frac{1}{2}$

Operating pressure drop is usually less than 1 in. of water with gas velocities of 10 to 15 ft/sec. Advantages in the use of this type of collector are low initial cost, low maintenance, high removal efficiency and recovery of valuable products without dilution. $\frac{1}{}$ However, these units should not be used in services where the material can cause plugging of the mesh unless provision is made for flushing out accumulated solids.

Another type of mist eliminator consists of packed beds of fibers. These may operate at velocities ranging from 5 to 90 ft/sec and, therefore, have correspondingly higher pressure drops of 5 to 15 in. of water. Collection efficiencies may be in excess of 99% on particles. $\frac{1}{2}$

Other types of mist eliminators are impingement baffle mist eliminators and packed bed mist eliminators which may not achieve efficiencies as high as those discussed above but do prevent loss or carryover of larger droplets.

3.7 AFTERBURNERS

Afterburners are gas cleaning devices which use a furnace for the combustion of gaseous and particulate matter. Combustion is accomplished either by direct flame incineration or by catalytic combustion.

The disposal of particulate matter by combustion is limited to residuc-free vapors, mists and particulate matter which is readily combustible, as well as to particle sizes which require short furnace retention time and small furnace size. Afterburners are usually used to dispose of funes, vapors, and odors when relatively small volumes of gases and low concentrations of particulate matter are involved.¹

Advantages of the direct flame incineration afterburner include: (1) high removal efficiency of submicron odor-causing particulate matter; (2) simultaneous disposal of combustible gaseous and particulate matter; (3) compatibility with existing combustion equipment; (4) relatively small space requirements; (5) simple construction; and (6) low maintenance.

Disadvantages include: (1) high operational costs including fuel and instrumentation; (2) fire hazards; and (3) excessive weight.

Advantages of the catalytic afterburner include: (1) reduced fuel requirements; and (2) reduced temperature, insulation requirements and fire hazards. Disadvantages of catalytic afterburners include: (1) high initial cost; (2) sensitivity to catalytic poisoning; (3) inorganic particles must be removed and organic droplets must be vaporized before combustion to prevent damage and plugging of the catalyst; and (4) catalysts may require frequent reactivation.

Afterburner systems have been used successfully in many processes including asphalt blowing and saturating, paint baking, coffee roasting, food processing, Kraft paper manufacture, paint and varnish cooking and wire enameling.

The use of afterburners in conjunction with paint baking operations may allow recirculation of the combustion gases to the oven or recovery by heat exchangers. Fuel savings from the use of heat of combustion of the paint solvent vapors may be large enough to provide a 50%return on investment in the case of catalytic combustion.¹/

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- Sargent, Gordon D., "Dust Collection Equipment," <u>Chemical Engineering</u>, January 1969.
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CHAPTER 4

EFFLUENT CHARACTERISTICS

4.1 INTRODUCTION

The severity of the problems associated with sources of particulate air pollution is dependent on the total amount or rate of emission and the physical and chemical characteristics of the emissions. Furthermore, the intelligent selection or design of dust collection equipment must be based on particle and carrier gas characteristics.

Important effluent characteristics which define the objectionable aspects of a pollution source include: (1) particle size distribution; (2) toxicity; (3) corresivity; (4) solling potential; and (5) optical properties. Particle and carrier gas properties that are important for control device selection or design include: (1) particle size distribution and shape; (2) particle density; (3) electrical resistivity; (4) volumetric flowrate; (5) gas temperature; and (6) humidity.

Some of the more important particulate and carrier gas characteristics are discussed in more detail in the following sections. The discussion will focus primarily on the relationship of the effluent properties to control device selection and/or design.

4.2 PARTICULATE CHARACTERISTICS

4.2.1 Particle Size

Information on particle size distribution in the gas stream is important in the proper selection of gas cleaning equipment. Particles larger than about 10 μ may be removed in inertial and cyclone separators and simple, low-energy wet scrubbers. Particles smaller than 10 μ require either high-efficiency (high-energy) wet scrubbers, fabric filters, or electrostatic precipitators.

Particle size in general cannot be specified uniquely by a single parameter. For irregular dust particles, the average dimension along three mutually perpendicular axes may be used, or the diameter of a sphere having the same volume or the same surface area as the particle may be chosen. Obviously, the more irregular the shape of the particles, the greater will be the variations in equivalent diameters. For extremely irregular particles like plates, rods, or stars, some other measure, such as specific surface or settling rate, will usually be more significant. In many gas cleaning processes the settling velocity has direct physical meaning, independent of particle structure, and is preferred to equivalent diameter.

Determination of particle size cannot be unique except for the special case of spherical particles. For all other cases, the results will depend on the experimental method used. Methods for determining particle size and particle size distribution may be classified as follows:

4.2.1.1 Sieve Analysis: Used for relatively coarse particles above 44 μ , corresponding to a 325 mesh screen.

4.2.1.2 <u>Microscopic Analysis</u>: The maximum resolving power of optical microscopes permits determination of particles down to about 0.5 μ . The much greater resolution of electron microscopes extends this lower limits about 0.01 μ .

4.2.1.3 <u>Sedimentation Analysis</u>: This method is based on measure ment of settling rate of particles in fluids. It gives settling velocities directly and equivalent diameters indirectly, based on known or assumed laws of the flow resistance or drag of the particles. Stokes' diameter is determined by this method, which is useful for particles in the range of about 0.5 to 50 μ .

4.2.1.4 <u>Elutriation Analysis</u>: This method is based on separatic of particles in vertically rising fluids. Fine particles above a certain size cutoff point are carried upward with the rising fluid, and coarser particles below the cutoff point fall to the bottom of the elutriation cham ber. A series of graded elutriation chambers may be used to separate particles into a series of size classes.

4.2.1.5 <u>Centrifugal Analysis</u>: Similar in principle to sedimenta tion but uses centrifugal forces, which may be as high as one million times gravity in the best ultracentrifuges. This extends the lower particle size limit down to giant molecules, or to about 0.01 μ .

4.2.1.6 <u>Impaction Methods</u>: Particles are deposited on a plate surface by impaction from an air jet. A series of graded impactors, the so-called cascade impactor, may be used to separate particles into size classes.

4.2.1.7 <u>Photometric Methods</u>: These methods are based on scatter ing or absorption of light, both of which depend on particle size. This method is most useful for fine particles below a few microns in size. Lowe limit by the best techniques is about 0.03 μ for monodisperse or uniform particle size dispersions. 4.2.1.8 <u>Miscellaneous Methods</u>: Gas absorption methods, air permeability, X-ray diffraction.

No universal method or apparatus for particle size determination is possible, even in principle. For gas-cleaning applications, the sedimentation and elutriation methods have very definite advantages because they give results in terms of settling velocity or Stokes' diameter. But these methods usually necessitate redispersion of collected particle samples, which may be difficult, and any agglomerates present in the original aerosol cannot be reproduced in the particle size equipment. Another problem connected with sizing of industrial aerosols is the difficulty of procuring representative samples from the field because of the very large gas flows and variable conditions that characterize most industrial gas-cleaning situations.

The Bahco centrifugal dust classifier is used extensively for routine measurements by control device manufacturing companies. This instrument uses a form of centrifugal elutriation. Dust is fed into an air stream in the annular space between parallel rotating plates and in each stage the dust is divided into two fractions, one deposited on the periphery of the wheel and the other carried forward. By varying the air velocity a number of fractions can be collected. Instruments of this type require careful adjustment to ensure a good separation. \underline{L}

Generally, the purpose of a particle size measurement is to discover the true frequency distribution of particle size. The observed distribution serves as basic data from which may be derived cortain representative constants, for example, the median size. Modified relative frequency distributions can also be obtained by transformation; for example, percent by weight from percent by number. Adequate presentation of data is important to facilitate utilization.

Tabular and graphical forms can be used. A table can list size versus one of many ways of expressing distribution; for example, size frequency or size cumulation. It is essential to specify which weighting process is employed since distributions are generally radically different .(e.g. number-size and weight-size distributions).⁵/

Graphical methods for presenting size distributions are: (1) histograms, (2) size frequency curves and (3) cumulative plots. Cumulative plots are used extensively and their interpretation and comparison can be enhanced by using the generally applicable log-normal distribution plot or one of its modifications. $\frac{5}{}$ Figure 4-1 illustrates a log-normal distribution plot bution plot for particulates emitted from a kraft pulp mill recovery furnace.



Figure 4-1 - Average Size Distributions of Cutlet Fume - Kraft Mill Recovery Furnace

Log-normal size distributions are defined by two parameters: (1) the intercept of the cumulative curve with the 50% probability mean diameter, and (2) the polydispersity factor (geometric deviation) defined as:

Polydispersity factor = $\frac{\text{intercept at 50\% probability}}{\text{intercept at 15.87\% probability}}$

A completely monodisperse aerosol has a polydispersity factor of

Figure 4-1 shows that 50% of the outlet fume is composed of particles smaller than 1.4μ in diameter. The polydispersity factor is 4.2.

Comprehensive discussions of particle size measurement, interpretation, and application are given in References 1, 5 and 6. Readers interested in more detail are directed to these sources.

4.2.2 Particle Shape

one.

As noted above, particle size analysis does not account for the multiplicity of particle shapes. Particle shapes of aerosols are of many types, from simple spheres to complex stars and chainlike aggregates. Fogs, mists, and some smokes are composed of spherical liquid or tarry droplets. Many fly ash particles, produced in the combustion of pulverized coal, are hollow spheres or cenospheres, frequently with much smaller satellite particles attached to their surfaces. Dust particles usually are irregular in shape as the result of multiple fractures that occur in crushing or grinding. Many metallurgical fumes have a starlike or platelike shape; others are needlelike and tend to form agglomerated chains.

Particle shape and surface condition influence handling characteristics, chemical reactivity, adsorption potential, and flammability limits among other particulate properties.

4.2.3 Solids Loading

Solids loading is a measure of particulate concentration in the gas stream. While it is not strictly a particulate property, it is included in this category for ease of discussion. Solids loading or grain loading is usually expressed in grains per cubic foot (l grain = 1/7,000 lb). Grain loading and particle size often dictate the choice of control equipment. Very high grain loadings might require the use of a series control device configuration to meet air pollution regulations (i.e., cyclone followed by an electrostatic precipitator or a baghouse).

4.2.4 Electrical Properties

The most important electrical properties of particulates are their electric charge and conductivity. Practically all natural or industrial dusts are electrically charged to an appreciable degree. The fractions of positively and negatively charged dust are generally equal, so that any given dust suspension is, as a whole, electrically neutral.

4.2.4.1 Particle Resistivity: In the electrical precipitation method for gas cleaning, the particle deposits on the collection surfaces of precipitators must possess at least a small degree of electrical conductivity. Theory and experience indicate that the critical or minimum value of particle conductivity for normal precipitator performance is about 0.5 x 10^{-10} inverse ohm-cm, or as more commonly expressed, a maximu resistivity of 2 x 10^{10} ohm-cm (measured in situ).

In precipitator operation, high particle resistivity is usually manifested by disturbed electrical conditions in the form of excessive sp ing with moderately lowered voltages, or by excessive current with greatl lowered voltages. These effects in turn cause loss of precipitator efficiency, the loss in performance increasing with resistivity. When resist ity exceeds about 10^{11} ohm-cm it becomes very difficult to achieve reason able efficiencies with precipitators of conventional design. Special typ of precipitators must then be used, or, more commonly, measures must be taken to reduce resistivity.<u>3</u>/

There are a number of factors and combinations of factors which influence the apparent resistivity of particulates. Among those particle characteristics which may be important are particle size distributions, shape, particle temperature, surface energy characteristics, packing configuration, and chemical composition. Carrier gas characteristics includchemical composition and temperature.

Most liquid particles and certain types of solid particles are intrinsically conducting and, therefore, cannot cause difficulty because of high resistivity. Most of the dusts and fumes in industrial precipitation applications, however, originate from furnace, smelting, drying, or calcining operations and are composed of silicates, metallic oxides, and similar inorganic compounds. Many of these materials in the pure dry state are among the best insulators known and, therefore, might be expect to cause trouble in precipitators. However, moisture and chemical impurities present in the gases and adsorbed on the particles provide at least part of the trace conductivity required. In other cases the gas temperatmay be sufficiently high to ensure adequate conductivity in the particles by the temperature conduction effect. Low moisture, absence of certain specific chemical impurities, and temperatures in the range of 250°F to 450°F are likely to cause high resistivity particles. $\frac{3}{2}$

4.2.4.1.1 Conduction mechanisms: The electrical conductivity of a bulk layer of particles depends on both surface and volume factors. In surface conduction, electrical charges are carried in the surface moisture and chemical films adsorbed on the particles. These films usually differ both physically and chemically from the interiors of the particles owing to adsorption phenomena. Volume conduction, or the motions of electrical charges through the interiors of the particles. Volume conduction also involves ancillary factors, such as compression of the particle layer, particle size and shape, and surface properties. $\frac{3}{2}$

Volume conduction in semi-insulating mineral particles may be either ionic or electronic. The most common examples of ionic conductors are metallic halides, such as sodium chloride or silver bromide, and are of little importance in electrical precipitation. Electronic conduction occurs in many materials, such as metallic oxides and silicates, which are of primary interest in industrial gases. For the metallic oxides and the silicates the resistance to volume conduction decreases with rising temperatures in the following manner:

 $\rho = A \exp E/kT$

where $\rho = resistivity$

- A = constant
- E = electron activation energy
- k = Boltzman's constant
- T = temperature

Volume conduction is thought to be the predominant mode at temperatures above approximately 300-350°F. At lower temperatures, volume conduction becomes insignificant. It appears that the volume conductivity of dusts and fumes is caused by temperature excitation of internal electrons. Field measurements confirm the increase in particle conductivity and the improved performance of precipitators collecting these materials at higher temperatures.

Surface conduction usually predominates for semi-insulating particles in the temperature range below about 300°F. As previously noted, conduction at these lower temperatures occurs primarily through adsorbed moisture and chemical films on the particles. Moisture is present naturally in most industrial gases controlled by electrical precipitation in amounts ranging from a few up to about 50%. Conduction in the surface moisture films appears to be electrolytic or ionic in character, with the proton-jump mechanism being the predominant mechanism for transfer of charge.³/

Figure 4-2 illustrates the effect of temperature and humidity on particle resistivity. The influence of temperature on volume resistivity of a typical layer of collected particles is shown by the straight line in Figure 4-2 labeled "bone dry." In the presence of certain conditioning agents the total resistivity becomes a function of the conditioning agent and temperature. This combined surface-volume conduction relationship is illustrated by the lower two curves in Figure 4-2 with water as the conditioning agent.

4.2.4.1.2 <u>Conditioning methods</u>: Control of particle resistivity by conditioning of the carrier gases plays an important role in electrical precipitation practice. Although the term <u>conditioning</u> usually implies the addition of chemicals or moisture to the flue gases, it is used here in a broader context and includes temperature and composition control.

Conditioning of gases by steam injection, water sprays, or wetting of raw materials to reduce particle resistivity is widespread, particularly where the natural moisture content of the gas is low and the temperature relatively high. Moisture also is favorable in raising the dielectric strength and reducing the viscosity of the gas. Conditioning by humidification is always more effective at low temperatures. At room temperature, for example, most dusts and fumes may be effectively conditioned by only 1% to 2% moisture in the gas, but 10% to 20% may be needed at 200°F to 300°F.3

Chemical conditioning agents may be effective in minute concentrations. A good example occurs in the fine cleaning of the exhaust gas in the powdered-catalyst petroleum-cracking process used widely in the production of high-octane gasoline. In the first full scale operation of this process, it was found that recovery of the valuable aluminum silicate catalyst dust in the electrical precipitator was hampered by high resistivity of the particles. Ammonia was found to be a highly effective chemical conditioner, and it was added to the precipitator gas in the proportion of only 1 part in 60,000 which was sufficient to drop the dust resistivity from 5 x 10¹¹ to 10^{10} ohm-cm, and to raise precipitator efficiency from 96% to 99.8%.3/

Moisture appears to be essential to the effectiveness of chemical conditioning agents. In general, the action of the conditioner increases with the amount of moisture in the gas and with decreasing temperature of the gas. Water vapor is therefore frequently referred to as a primary conditioning agent and chemicals are considered secondary conditioning agents. The effects of conditioning on particulate resistivity are shown in



Figure 4-2 - Effect of Humidity on Particle Resistivity

Figures 4-3 and 4-4. The addition of a small amount of ammonia reduces the resistivity of a powdered catalyst by a factor of about 100, and the addition of diethylamine reduces resistivity by a factor of 10^3 to 10^6 (Figure 4-3). Figure 4-4 illustrates the effects of SO₃ conditioning on fly ash resistivity. Resistivity is plotted in terms of the percent of sulfuric acid fume added, with gas temperature as a parameter.<u>3</u>/

4.2.4.1.3 <u>Resistivity measurement</u>: Because of conduction modes and their dependence on operating conditions, particle resistivities measure directly in plant flues are preferable to those measured in the laboratory. Gaseous environments usually cannot be duplicated feasibly in the laboratory In the in-situ measurements, the phenomenon of surface conduction usually predominates because of the presence of conditioners in the flue-gas stream. In the laboratory, these conditions are usually not present and conduction is by the volume mode. When in-situ measurements are compared to laboratory measurements, the in-situ resistivity is frequently 2 to 3 orders of magnitude lower. This discrepancy is most severe with fly ash. Laboratory measurements of fly ash resistivity have very little fundamental meaning, and the only meaningful measurements are those made in situ. Essentially all electrical resistivity data currently available in the literature have been determined under laboratory conditions. A more detailed discussion of particle resistivity is presented in References 2 and 3.

4.2.4.2 <u>Electrostatic Attraction</u>: Electrostatic attraction is also important in fabric filtration. Precipitation on the filter will resul from electrostatic forces drawing particles and filter elements together when either or both possess a static charge. These forces may be either direct, when both particle and filter are charged, or induced, when only one is charged. Such charges are usually not present unless deliberately introduced during the manufacture of the fiber. Electrostatics assist filtration by providing an attraction between dust and fabric, and also affect particle agglomeration, fabric cleanability, and collection efficiency

The type and quantity of charge acquired by a filter medium is a function of the filter type and the method of charging. The rate at which a fabric loses its charge is also an important consideration. This depends not only on the conductivity of the fibers but also on the humidity of the gases passing through the filter. Thus fabrics which are poor conductors retain a charge much longer than good conductors. In humid conditions a fabric acquires a surface film of moisture which also acts as a conductor.

Charges are induced in fabrics by friction, and the type and exten of charging that a particular material acquires relative to others can be measured by charging a series of materials in the same way. The usual technique consists of placing a strip of the material on an insulated ring and rubbing it with a strip of the reference fabric which is mounted on an



1

Figure 4-3 - Conditioning of a Weak Acidic Dust by Strong Bases. Catalyst clay dust from a powdered catalyst petroleum-cracking process, $310^{\circ}F^{3}/$



Figure 4-4 - Laboratory Conditioning Tests, Sulfuric Acid Fume with Fly $Ash^{3/2}$

insulating rotating disc. The charge on the test strip is measured after a standarized number of turns of the charging disc, and again after a set period (frequently 2 min.) to find the rate of charge leakage. The maxim charge, measured immediately after charging, enables the materials to be placed in relation to one another in a triboelectric series (Table 4-1).7

٠,

Dust particles can be arranged into a similar series relative t one another and to filter fabrics. This arrangement can assist in the sel tion of filter fabrics with the most favorable charge characteristics for both particle collection and particle release, if the particles are to be removed by shaking, vibration or blowing.

Particles can be placed in one of three categories: Those which acquire a charge and do not agglomerate (Class I); those that acquire a charge and agglomerate (Class II), these being the active classes; and those which are not affected by the charge on the filter (Class III), being inactive. The active groups are divided into fine and coarse particles. Coarse particles do not present a problem in filtration as they are easily collected on the surface layers of the fabric, usually form a loose cake, and are easily shaken off. Fine particles are much more difficult to collect because they tend to penetrate the filter medium and often leal through. By selecting a highly charged filter medium, fine particles in Class II will be agglomerated, their collection improved, and they should form a loosely agglomerated cake on the fiber filter surface. If the filhas a high rate of charge loss under these conditions, cake release will also be assisted.<u>8</u>/

Several dusts in the various categories have been experimentally investigated and their properties are listed in Table $4-2.\frac{7}{.8}$

4.2.5 Moisture Content

Moisture content influences both selection of control equipment and particle characteristics. Particle resistivity, flammability, and handling characteristics are strongly influenced by moisture content.

4.2.6 Toxicity

Toxicity charactertistics of particulates and carrier gases defi important health aspects of particulate emissions. The toxicity aspects of the particulates might dictate the use of a control device where it wou not otherwise be required.

TABLE 4-1

TRIBOELECTRIC SERIES FOR FABRICS⁷



Note: Polystyrene, Saran and Vinyon are at the far negative end of the series.

| RELATIONS OF FAB | RIC REQUIREMENTS | TO DUST PROPERTIE | S AND DUST IN THE CATE | CORIES LIST | <u>ED</u> 7/ |
|--|----------------------------------|---|---|------------------------------|---|
| Dust Classification | IA | IB | IIA | IIB | <u>111</u> |
| Relative particle size Electrostatic properties Agglomerating tendencies | Fine Active Little or none | Coarse Active Little or none | Fine Active Positive | Coarse Active Positive | Fine and coarse Inactive |
| Criteria for filtration: Leakage High flow low∆p | P _x Consta/ | Const <u>a</u> / P _m | P_x to P_c^2 P_x | P_x to P_c^2 P_x | Fabric Construction dictates performance |
| Criteria for cleaning: Leakage control Ease of cake removal | D _e D _h | Const <u>a</u> / D _h | P_x to P_c^2 D _h | P_x to P_c^2 D_h | |
| Material | Calcium Calcium Silicate | Flux Calcined Diatomaceous Earth Commercial Finished Cement Ball Clay | Processed Natural Diatomaceous Earth Wheat Starch Taconite Zinc oxide Fume Nickel furnace fume Magnesite Cellulose Acetate Molybdic oxide Sugar | Carbon SRF | Kaolin |

36

a/ Fabric construction determines property.
 b/ Requires low density, rapidly agglomerating dust forming large aggregates.

TABLE 4-2

4.2.7 Wettability and Solubility

These properties can affect dust separation in wet scrubbers, although they are generally only second-order effects. In general, wetting is the term applied to the phenomenon of a liquid adhering to a solid. Wettability depends upon the nature of the substance involved, and is related to boundary surface energies. In principle, wetting occurs when the adhesion energy between solid and liquid is greater than, or equal to, the cohesion energy of the liquid.

The determination of wettability is difficult in the case of morphologically heterogeneous dusts. Recent studies in Germany have indicated that a wettability trend can be expressed in terms of the velocity of rise of a liquid in capillaries of powders and the total time required for a liquid to rise a certain height. $\frac{4}{}$ Table 4-3 summarizes rates of rise and total wetting times for several dust samples using water as the liquid phase. The results indicate that the rates of rise and the wetting times differ greatly for individual dusts. Highest wettability is shown by dust from sludge of a wet scrubber operating in the cleaning room of a foundry. In contrast, the wetting properties of dust samples from the hotblast cupola furnaces and the boiler soot are very poor. $\frac{4}{}$

Subsequent investigations, conducted with a test setup in which dust particles could be shot at individual droplets of water at different velocities, indicated that wettability did not markedly affect the efficiency of wet scrubbing. It was repeatedly shown that, regardless of particle type and velocity, a dust particle hitting the water droplet was always retained by the latter, even if the droplet was greatly deformed by the particle. $\frac{4}{}$ These results indicate, at least for the dust studied, that wetting behavior of particles in wet scrubbing is of secondary importance.

4.2.8 Flammability or Explosive Limits

These factors influence selection of control equipment and define handling hazards. Ignition and explosion behavior of dust is affected by electrostatic charging, chemical composition, the size and state of the solid surface, moisture content, and dust thermal properties. Carrier-gas temperature, pressure, and chemical composition also affect these limits.

4.2.9 Chemical Composition

Particulate and carrier-gas chemical composition exerts an influence on choice of control and auxiliary handling equipment. Composition also influences electrical properties, toxicity, reactivity, wettability, and most other particle properties.

TABLE 4-3

RATES OF RISE AND TOTAL WETTING TIMES <u>MEASURED AT DIFFERENT DUST SAMPLES</u> (Sample cross section: 0.50 cm², sample height: 0.5 cm, liquid: distilled water)

| | | Rate of | Total | |
|-------------------------------------|---------------------------------|-----------------------|------------------------|--|
| Origin of dust | Density (g/cm ³) | Rise (cm/sec)º10-3 | wetting time (sec.) | |
| Boiler (largely soot) | 2.57 | 4.46.10 ⁻³ | ca. 51,000 | |
| Hot-blast cupola furnace (basic) | 2.44 | 9.48·10 ⁻² | ca. 6,800 | |
| Hot-blast cupola furnace (acid) | 2.68 | 0.226 | 1,153 | |
| Cold-blast cupola furnace | 2.71 | 5.98 | 148 | |
| Swing grinding shop | 3.17 | 25.72 | 63.6 | |
| Blast furnace | 4.68 | 46.80 | 21.7 | |
| Boiler | 2.30 | 96.32 | 12.6 | |
| Sand preparation (sludge) | 2.51 | 192.58 | 6.14 | |

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4.2.10 Handling Characteristics

Particle handling and flow properties influence dust separation equipment and auxiliary devices for dust collectors. Powder flow properties result from a combination of a number of factors including transmission of external and body forces through the system, particle size and shape distribution, ruggedness and resilience of the particles, cohesion, adhesion of particles to surfaces, and adsorbed films especially of water.

Particle shaking properties are very important for the design of auxiliary devices for dust collectors and for the further treatment of separated dust. These properties include:

- (1) Shakedown Weight specific weight of highest packing density
- (2) Angle of Repose angle at which piled dust begins to slide
- (3) Slide Angle angle at which dust begins to slide on a base.

Shakedown weight exceeds the free bulk weight by a factor of 1.2 to 1.4; angle of repose lies between 25 degrees to 55 degrees and sliding angle between 35 degrees to 65 degrees. Both angles are influenced by particle size, moisture content of dust, particle shape, and cohesion and adhesion forces.

The abrasive behavior of dust characterizes its mechanical effect upon a surface with which it comes into contact. In gas cleaning, the inner walls of pipe conduits are subject to the highest abrasion. This dust property cannot be expressed by merely giving its hardness, since hardness expressed as resistance to the penetration of foreign bodies cannot be determined for dust particles. Furthermore, abrasive behavior is also affected by the shape and size of particles and their specific weight.

The corrosive characteristics of the particulates can influence the choice of gas-cleaning equipment, and, in many cases, dictate the materials of construction.

4.3 CARRIER-GAS CHARACTERISTICS

4.3.1 Volume Flowrate, Pressure, Temperature, and Composition

Control equipment choice and size are dictated by these parameters. The gas temperature also exerts an influence on particle resistivity, moisture content, and flammability limits. Pressure and composition affect flammability limits.

4.3.2 Corrosive Properties

Carrier-gas corrosive properties primarily influence selection of equipment construction materials.

4.3.3 Optical Properties

The optical properties of aerosols are of importance in connection with gas cleaning and air pollution, because the degree of pollution is commonly judged by visual appearance of stack discharge or of the atmosphere itself. Visual appearance is subjective and is associated with the observer character of the sky, and physical character of the stack discharge.

Optical density is closely related to the visual appearance of the stack exhaust plume. The extinction coefficient is a function of the number of particles per unit volume, the particle size, shape, and size distribution.

4.3.4 Odor and Toxicity

Particulate and carrier-gas odor properties are secondary factors. Concentrations below toxic or harmful levels are primarily a problem from the standpoint of complaints from nearby residents. Malodorous gases and vapors include mercaptans, phenolic compounds, naphthenic acids, organic sulfides, nitrogen bases, aldehydes, and ammonia.

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CHAPTER 5

PRESENTATION OF EFFLUENT DATA FOR SPECIFIC INDUSTRIES

Effluent data for specific sources in the major industrial categories listed in Table 2-1, Chapter 2, are presented in tabular form in Chapters 6 - 24. Only numerical data are given in these tables. Table 5-1 is provided as a coding key for the tables of effluent characteristics in Chapters 6 - 24.

⁴³ Preceding page blank

TABLE 5-1

CODING KEY FOR TABLES OF EFFLUENT CHARACTERISTICS

- I. General Note: All data for uncontrolled sources unless otherwise noted.
- II. Specific Notes:
 - A. Particulates
 - 1. Particle size;

x < y, x > y.

x = weight %, y = particle size (μ) .

Measuring technique noted. If no notation is listed, measuring technique was not reported or is unknown.

- 2. Solids loading: grains/scf, unless otherwise noted.
- 3. Chemical composition:

solids - wt. % (unless otherwise noted).

- 4. Particle density: g/cm^3 .
- 5. Electrical resistivity: ohm-cm, laboratory measurements unless otherwise noted.
- 6. Moisture content: wt %, unless otherwise noted.
- 7. Toxicity:
 - a) N.T. not toxic.
 - b) numerical value threshold limit, mg/m^3 .

8. Solubility:

s. - soluble.

- s. sl. slightly soluble.
 - ⁴⁵ Preceding page blank

TABLE 5-1 (Concluded)

d. - decomposes.

- Wettability, hygroscopic, flammability, handling, optical, and oder characteristics: only a descriptive comment generall given; if numerical value is presented, units will be indicate
- B. Carrier Gas
 - 1. Flow rate: flow-rate data presented in two forms:
 - a) thousands of standard cubic feet per minute, M scfm, unless otherwise noted.
 - b) thousands of standard cubic feet per ton of product processed, M/sof/ton, unless otherwise noted.
 - 2. Temperature: °F.
 - 3. Moisture content: vol %, unless otherwise noted. Dew point is in °F if listed under moisture content.
 - 4. Chemical composition: vol %, unless otherwise indicated.
 - 5. Toxicity:
 - a) N.T. not toxic.
 - b) numerical value threshold limit, mg/m^3 .
 - 6. Corrosivity, odor, flammability, and optical properties: only a descriptive comment generally given; if numerical value is presented, units will be indicated.

CHAPTER 6

STATIONARY COMBUSTION PROCESSES

6.1 INTRODUCTION

More than 29 million stationary combustion sources are currently in operation in the United States: (1) electric-utility power-generating plants, (2) industrial power plants and process heaters, and (3) spaceheating units. Coal, cil, and gas are burned in a wide variety of equipment. $\frac{1}{2}$

Particulate emissions vary widely from unit to unit because processes, practices, and fuels all affect emission levels. For each fuel, several different processes are used for stationary combustion. Coal-fired electric generating plants utilize pulverized, cyclone, and stoker-fired boilers. Burners, combustion chambers, draft systems, heat transfer characteristics, and combustion controls of industrial units may vary widely. Steam, hot water, and warm air furnaces are in common use for domestic heating.

Stationary combustion sources are divided into electric utility, industrial, and commercial and residential groups for a more detailed discussion in the following sections.

6.2 ELECTRIC UTILITIES

The production of power by the combustion of coal, fuel oil, and gas contributes large quantities of particulates, sulfur oxides and nitrogen oxides to the atmosphere. Coal-fired units are the dominant source of particulate emissions. Particulate emissions from oil-fired power boilers are about 1% of emissions from similar coal-fired equipment. Use of natural gas as a fuel nearly eliminates particulate emissions. Since emissions depend so strongly on the type of fuel burned, discussion of emission rates, effluent characteristics, and control practices is presented for each fuel type in succeeding paragraphs.

6.2.1 Fuel Type

6.2.1.1 <u>Coal-Fired</u>: The modern coal-fired electric generating plant is comprised of a boiler, generator, condenser, coal handling equipment, dust collection and disposal equipment, water handling and treatment facilities, and heat recovery systems such as economizers and air heaters. Boilers in present-day usage include cyclone, pulverized, and stoker types with pulverized fuel boilers comprising nearly 90% of the total.

Pulverized fuel boilers utilize coal ground to a size such that about 70% passes 200 mesh. The coal and preheated combustion air are direct-fired into the boiler as determined by the steam requirements. The coal-air ratio is automatically regulated to give optimum combustion for all load conditions. Boilers are classified as horizontal, vertical, or tangential, depending upon the firing position of the burbers.2/

Pulverized coal-fired boilers are also classified as either wet bottom or dry bottom, depending on the operating temperature and ash-fusion temperature. In wet-bottom boilers, the temperature is maintained above the ash-fusion temperature so the slag is molten and can be removed from the bottom as a liquid. Dry-bottom boilers operate at temperatures below the ash-fusion point, and the ash is removed in a solid state.²/

Cyclone boilers operate with much coarser coal, typically 95% minus 4 mesh. The heater is a water cooler cylinder with combustion air introduced tangentially. Combustion occurs at temperatures sufficiently high to melt a high percentage of the ash which is discharged through slag tap openings.

Less than 5% of the coal consumed in electric-generating plants is burned in stoker boilers. A variety of stoker units exist, but spreaderstoker units have the highest steam output rates.³/ The spreader-stoker unit combines suspension and fuel-bed firing; the stoker mechanism feeds from the hopper onto a rotating flipper mechanism, which in turn throws the fuel into the furnace. Because the fuel is burned partly in suspension and partly on the grate, the fuel bed is thin, and response to fluctuations in load is rapid. The grates are either stationary or continuous moving from the rear to the front. Vibrating, oscillating, traveling, and chain grates are used for moving the fuel toward the ash-receiving pit.³/ Fly-ash reinjection is also practiced in many plants.

6.2.1.2 <u>Oil-Fired</u>: Compared to coal-fired units, oil-fired electric-generating plants emit a minor amount of particulate matter to the atmosphere. The rates of emissions from these units are affected by variable operating conditions and by the nature of the fuel used.

Two different basic designs of furnace are used in oil-fired plants: tangentially and horizontally fired. The tangentially fired unit is built so that the flame is propagated in a cylindrical form. The unit is constructed to produce a spiral upward motion of the flame and combustion products around the walls of the cylindrical firebox. The tangentially fired unit is a relatively new and infrequently used design. $\frac{4}{2}$ Horizontally fired units are usually fired at right angles to the walls of the firebox, but may be fired at various angles. They may be fired on one or more sides, or from the bottom of the firebox. The firebox may be square, rectangular, or cylindrical. Horizontal firing tends to concentrate the hot gases in the center of the firebox.

6.2.1.3 <u>Gas-Fired</u>: Natural gas is also utilized in power plants. Particulates and oxides of sulfur emissions are insignificant compared with those of other fossil fuels. Control equipment has not been required for natural gas combustion equipment.

6.2.2 Emission Rates

6.2.2.1 <u>Coal-Fired</u>: The emission rate of particulate matter from a coal-fired furnace is related to many factors, mainly gas velocity, particle size, particle density, fuel-burning rate, combustion efficiency, flue gas temperature, furnace configuration, coal composition and size, and the initial state of the raw coal.

The following variables are thought to be the most important in relation to particulate emissions: $\underline{3}/$

- 1. Amount of ash in the coal;
- 2. Method of burning the coal;
- 3. Rate at which the coal is burned.

For any specific furnace, coal-ash content is the dominant variable. Other conditions remaining fixed, the fly-ash emission will be approximately proportional to the ash content of the coal. The heating value of the coal is related to its ash content. Figure 6-1 presents a noncograph for estimating particulate emissions from coal combustion. $\underline{3}/$

The method of burning the coal influences particulate emission rates. When coal is thrown or blown into a furnace, combustion takes place in suspension. As the pieces of coal burn, they get smaller, and thus their chance of being exhausted with stack gases is increased. When coal is pushed or pulled into a furnace to form a bed, the coal or ash has less chance of being entrained by the flue gases because of impingement onto larger particles. When coal is introduced tangentially into a cylinder, such as in the cyclone furnace, the burner acts as a cyclone separator and thus reduces emission of larger particles.³/

As the velocity of the gases passing through the furnace increases, larger particles of ccal and ash are carried out of the furnace. The velocity



Figure 6-1 - Nomograph for Estimating Particulate Emissions From Coal Combustion (Without Air Pollution Control Equipment)<u>3</u>/

of the gases is directly proportional to the firing rate of a given furnace; thus, the size of the particle and rate of emission should be a function of the firing rate. In a similar manner, the excess air, pressure, and temperature are related to the particulate emissions in that they control the gas velocity. $\frac{3}{2}$

Emission rates for the various types of coal-burning units are summarized in Table 6-1. As would be expected, over 90% of the emissions are from pulverized coal-fired boilers. The influence of firing method is clearly shown, as the emission factor for cyclone units is 20 to 25% of that for pulverized and stoker units.

6.2.2.2 <u>Oil-Fired</u>: The particulate loading of stack gases depends primarily upon the efficiency of combustion and the rate of build-up of boiler deposits. Poor mixing, low flame temperatures, and short residence time in the combustion zone cause larger particles, higher combustible content, and higher particulate loadings. $\frac{4}{}$ The degree of atomization has an important effect on particulate emissions. Low-pressure atomization produces larger fly-ash particles and a higher particulate loading. $\frac{4}{}$ High-pressure atomization (400 psig or greater) produces smaller particles, fewer cenospheres, and lower particulate loadings. $\frac{4}{}$

The soot-blowing operation markedly increases the particulate loading in the stack gases. An increase of 1.7 to 3.3 times the normal emission level has been reported during soot blowing. $\frac{4}{2}$

Emission rates for oil-fired units are summarized in Table 6-1. Farticulate emissions are estimated at 36,000 tons/year.

6.2.2.3 <u>Gas-Fired</u>: Meager data exist on particulate emissions from gas-fired units. Table 6-1 summarizes available information. Particulate emissions are estimated to be 24,000 tons/year.

6.2.3 Characteristics of Effluents from Electric Generating Plants

6.2.3.1 <u>Coal-Fired</u>: The chemical and physical characteristics of effluents from coal-fired electric generating plants are summarized in Table 6-2. Farticulates from pulverized coal furnaces are larger in size than those from cyclone furnaces. There is also a rather large variation in particle size for each furnace. Furnace design, operating conditions and coal composition undoubtedly influence the size of emitted particulates. Outlet grain loadings from pulverized furnaces generally exceed those from cyclone furnaces.

TABLE 6-1

PARTICULATE EMISSIONS FUEL COMBUSTION IN STATIONARY SOURCES

| | _ | | Amount of Fue | 21 | Emission | Efficiency of Control | Application of Control | Net Control | Emissions |
|------|------|-----------------------|------------------|-----------------|-----------------|--------------------------|---------------------------|---|-----------------|
| | So | urce | Burned | ⊷ | Factor | (° _e) | (c_t) | $\frac{(c_c \cdot c_t)}{c_c \cdot c_t}$ | (tons/yr) |
| т. | Coa | ı | | | | | | | |
| | Α. | - Electric Utility | | | | | | | |
| | | 1. Pulverized | 258,400,000 t | tons | 16 A* | 0.92 | 0.97 | 0.89 | 2,710,000 |
| | | 2. Stoker | 9,900,000 | | 13 A | 0.80 | 0.87 | 0.70 | 217,000 |
| | | 3. Cyclone | 28,700,000 | | 3 A | 0.91 | 0.71 | 0.64 | 182,000 |
| | | 0 | | | | То | tal from electric | utilities | 3,109,000 |
| | в. | Industrial | | | | | | | |
| | | 1. Pulverized | 20,000,000 | | 16 A | 0.85 | 0.95 | 0.81 | 322,000 |
| | | 2. Stoker | 70,000,000 | | 13 A | 0.85 | 0.62 | 0.52 | 2,234,000 |
| | | 3. Cyclone | 10,000,000 | | 3 A | 0.82 | 0.91 | 0.75 | 39,000 |
| | | • | | | | To | tal from industri | ial units | 2,595,000 |
| | c. | Residential and | 20,000,000 | | 5 A | | | | 300,000 |
| | | Commerical | , , | | | То | tal from coal | | 6,004,000 |
| | | | | | | | | | |
| 11. | Fu | el Oil | | | | | | | |
| | Α. | Electric | 7,180,000,000 e | gal. 10 | 1b/1,000 gal. | | | | 36,000 |
| | | Utilities | | | | | | | |
| | | | | | | • | | | |
| | B. | Industrial | | | | | | | |
| | | 1. Residual | 7,510,000,000 g | gal. 23 | 1b/1,000 gal. | | | | 87,000 |
| | | 2. Distillate | 2,360,000,000 g | g al. 15 | 1b/1,000 gal. | | | | 18,000 |
| | | | | | | | | | - |
| | C. | Residential and | 36,550,000,000 € | gal. 8 | 1b/1,000 gal. | | | | 146,000 |
| | | Commercial | | | | Т | otal from fuel oi | .1 | 287,000 |
| | | | | | | | | | |
| III. | . Na | atural Gas and | | | | | | | |
| | | LPG | | | , | | | | |
| | A | . Electric | 3,143,143,000 m | nil. 15 | lb/mil cu ft | | | | 2 4,00 0 |
| | | utilities | cu. ft. | | | | | | |
| | | | | | | | | | |
| | В | . Industrial | 9,270,000 m | nil. 18 | lb/mil cu ft | | | | 84,000 |
| | | | cu. ft. | | | | | | |
| | | | | | | | | | _ |
| | С | . Residential and | [6,250,000 m | nil. 19 | 15/mil cu ft | | | | 59,000 |
| | | Commercial | cu. It. | | | Т | otal from natural | gas | 167,000 |
| | | | | | | | | | _ |
| | | | Total | f for fuel | combustion, sta | ationary sour | ces | | 6,458,000 |

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TABLE 6-2

EFFLIENT CHARACTERISTICS STATIONARY COMPUSTION PROCESSES

A. Particulate (Part I)

| Source | Particle Size | Solids Loading | Chemical Composition | Particle Density | Electrical <u>Resistivity</u> | Moisture Content | Toxicity |
|--|--|---|---|---|--|---------------------------|---------------------|
| Electric Generating Flants | | | | | | | |
| Coal Fired Type of boiler Pulverized | 25 < 10, 49 < 20, 79 < 44 | | | | | | |
| Vertical[#] Corner* Pront wall horizontal⁴ Norizontal⁴ Norizontal⁴ Signa (Second Second Secon | BAHCO Analysis 305 CF 69 Mea- aurements in following range 6-20 < 3, 12-32 < 5, 28-56 < 10, 42-79 < 20, 61-93 < 40 <u>Most Probable</u> <u>Fistribution</u> 15 < 3, 25 < 5, 42 < 10, 65 < 20, 81 < 40 | 4.7-4.8** 2.9-3.7; avg. 3.5 2.4-2.5 2.9-4.9; avg. 3.9 1.02-5.6 Mean: 5.5 | <u>Sypical 71y Aah</u> : S10 ₂ : 17-64 avg. 43, Pa ₂ O ₃ : 2-36 avg. 15, Al ₂ O ₃ : 3-36 avg. 24, CaO: 0.1-27 avg. 4, NgO: 0.1-35 avg. 1.0, Ng ₂ O: 0.3-4 avg. 0.9 <u>Ignition Less</u> C.4-356 avg. 0.3 <u>Fmall Anounts</u> TiC ₂ : K ₂ O, FeC, P ₂ O ₅ , SO ₃ Polynuclear hydro- catbons (see Table 6-3 for datailed data) | Bulk Density 30-50 1k/ft3 Particle Density 0.5-3.0, avg. 2.3 Particle shape varies widely. May be minute spheres, slivers, or spoagy, lace- like entities. | Varies from 10 ⁶ -10 ²³ | 0.23 (avg. 30 samples) | N.T., but aridir |
| b. Cyclone* | 72 < 10, 37 < 20, 95 < 44 <u>BAHCC Analysis</u> 20-72 < 3,avg. 40 < 5; 40-36 < 10, avg. 65 < 10; 70-99 < 20, avg. 81 < 20, 81-100 < 40, avg. 92 < 40 | 0.2-3.2 Nean: 0.85 | | | | | |
| Stoker Spreader stoker* Underfeed stoker | 11 < 10, 23 < 20, 42 < 44 7 < .0, 15 < 20, 50 < 44 | 1.5-2.3; EVg. 1.5 0.05-0.2 | | | | | |
| d. Unspecified boiler type | $\begin{array}{l} \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \begin{array}{l} \hline \end{array} \\ \hline \end{array} \end{array} \\ \hline \end{array} \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \end{array} \\ \hline \end{array} \end{array} \\ \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \\ \hline \end{array} \\ \\ \hline \end{array} \\ \\ \end{array} \end{array} \\ \hline \end{array} \\ \end{array} \end{array} \\ \hline \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \\ \end{array} \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \end{array} \\ \\ \end{array} \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \end{array} \\ \\ \end{array} \end{array} \\ \end{array} \\ \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \\ \end{array} \\ \end{array} \\ \end{array} \\ \end{array} $ \\ \rule \rule \\ \end{array} \end{array} \\ \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \end{array} \end{array} \\ \\ \end{array} \\ \end{array} | | | | | | |

See Coding Key, Table 5-1, Chapter 5, p. 45, for units for individual effluent properties. # Partial and full load tests (partial load ~ 75% load); 30-50 excess wir. #Corrected to 12% CO₂, dry basis.
TABLE 5-2 (Continued)

A. Particulate (Part I, Concluded)

| Source | Particle Size | Solide Loading | Chemical Composition | Particle Density | Electrical Resistivity | Moisture Content | Texicity |
|--|---------------|--|--|--|---------------------------|---------------------|---------------------|
| Biestric Generatin Plants (Conclude | ng ed) | | | | | | |
| II. Oil Fired | | | | | | | |
| a. Typical cpe | ration 90 < 1 | 0.013=0.2, avg. 0.05, most common value - 0.03= 0.035 | Fly Ash: See Table 6-6 for detailed data | 2.5 Particle shape varies, many small spheres | | | N.T., but acidic |
| b. Soot Blowing | 6 | 0.13-0.19 | | | | | |
| Industrial Purnace | el | 0.01-0.265, avg. 0.083 | | | | | |

A. Particulate (Part II)

| | Source | Solubility | Wettability | Hygroscopic <u>Characteristics</u> | Flammability or Explosive Limits | Handling Characteristics | Optical Properties |
|----------|--------------------------|---|------------------|---------------------------------------|-------------------------------------|---|---|
| Ele P | ctric Generati; lants | 1 4 | | | | - | |
| Ι. | Ccal-Fired | Contains H ₂ C soluble components | Difficult to wet | | | Difficult to handle, ag- gomerates | Color varies from light tan or grey to various shades |
| | | | | | | Internal Friction Angle 420-590 µ = 25.1° 295-420 µ = 25° | of black |
| | | | | | | 250-295 µ = 20.3 | |
| | | | | | | 149-250 µ - 18.1-24.2" | |
| | | | | | | 105-149 µ - 16.3-23.6* | |
| | | | | | | 74-105 µ = 14.2-22" | |
| | | | | | | 0-44 µ = 1.1° | |
| | | | | | | External Friction Angle | |
| | | | | | | (with aluminum) | |
| | | | | | | 420-590 ja = 16.7" | |
| | | | | | | 250-005 | |
| | | | | | | 149-250 u + 13.28 4° | |
| | | | | | | 105-149 u - 20.5-24" | |
| | | | | | | 74-105 u - 14.6-27.3° | |
| | | | | | | 44- 74 µ + 12+16.6" | |
| | | | | | | C- 64 µ - 16.4-15.3* | |
| | | | | | | Cobesion | |
| | | | | | | 205 400 | |
| | | | | | | 250-295 H = 5.4 | |
| | | | | | | 149-230 u = 3.5-20.5 | |
| | | | | | | 105-149 µ - 13.5 | |
| | | | | | | 74-105 y = 0.5-5.0 | |
| | | | | | | 44- 74 µ + 5.0-14.5 | |
| | | | | | | 0- 44 µ - 14.5-21 | |
| 11. | 011-Fired | 30-60% soluble solida | Difficult to wet | | | | |

TABLE 6-2 (Continued)

B. Carrier Gas

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| Source | Flow Rate | Temperature | Moisture Content | Chemica. <u>Composition</u> | Texicity | Corrosivity | Oder | Flammatility or Explosive Limits |
|---|---|-----------------------|----------------------------------|---|---------------------------------|-------------|------|-------------------------------------|
| Electric Generating Trunt | | | | | | | | |
| C.al Fired Type of Boiler B. Bulverized | | | | | | | | |
| . Vertical* | (a) 097-597 1vg, 350 (b) 362-434 avg. 400 | 245-289 avg 252 | 6. 4 | 20g = 12.5-12.6 0g = 6.2-8.6 Ng = balance CO = 15-17 ppm NO _X = 101-221 ppm SO ₂ = 1.450- 1.702 ppm SO ₂ = 46-66 ppm | 00g - 5 irritant 60 - 100 | | | |
| 2. Corner* | (a) 294-362 avg. 325 (b) 387-417 avg. 40? | 253-28₹ ∎vg 259 | 7.0-8.0 | 502 - 14.4-14.9 02 - 4.2-4.7 Ng - balance 00 - 11-49 pm NO _X - 393-526 ppm SO ₂ - 1,120- 1.150 ppm SO ₃ - 8-10 ppm | | | | |
| 3. Front wall* horizontal | (a) 254-369 avg. 292 (b) 378-394 avg. 386 | 244-257 avg 251 | 5.5 | CO ₂ - 13.7-13.6 C ₂ - 5.5-5.6 N ₂ - bslance CO - 5-17 ppz N ² N ₂ - 416-500 ppz SO ₃ - 7-11 ppz SO ₃ - 7-11 ppz | | | | |
| 4. Hericontally* cress4 | (3) 44-62 4vg. 53 (0) 392-399 avg. 395 | 314-*15 evg 514.5 | 6.5-6.8 ≊v _d . 6.7 | CC ₂ = 12.8-13.3 D ₂ = 5.9-6.0 N ₂ = balance CO = 44-69 ppm NO ₄ = 383-355 ppm SO ₂ = 3.560- 1.780 ppm SO ₃ = 6-10 ppm | | | | |
| b. ly.lon⊶ | (a) 654-858 avg. 501 (b) 538-643 svg. 50: | 245-273 avg 272 | 0.3-0.0 avg. 6.45 | 202 - 12:0-12:8 02 - 6:4-6:8 Ng - balance CC - no data NG _Q - 742-1:204 ppm SO ₂ - 1:350- 1:350 ppm SO ₃ - 13-21 ppm | | | | |
| e. Spreader stak≁ y ≉ | (s) 44-54 avg. 43 (b) 351-383 wyg. 367 | 396-426 nvg: - 411 | 7.4+7.9 avg. 7.5 | CDy - 12.1 Cg = 6.6-6.9 Kg = balance CO = 13-29 ppm NOg = 420 ppm SCg = 1.280- 1.380 ppm SOg = 52-59 ppm | | | | |
| II. Oi. Fired a. Herizontally fired | (a) 47-12,400 (b) 348-780 avg. 440 | 200-688 avg 315 | 6,6-9,5 ▲¥g 5.4 | $\begin{array}{l} CC_{2} = 5.9 - 15.4 \\ \textbf{avg.} = 11.7 \\ O_{2} = 0.7 - 15.2 \\ \textbf{avg.} = 4.2 \\ \textbf{K}_{2} = \textbf{balance} \\ SD_{2} = 118 - 0.200 \text{ ppm} \\ \textbf{avg.} = 857 \text{ ppm} \\ \textbf{avg.} = 857 \text{ ppm} \\ \textbf{avg.} = -857 \text{ ppm} \\ \textbf{avg.} = -19.5 \text{ ppm} \\ \textbf{avg.} = -15 - 800 \text{ ppm} \\ \textbf{avg.} = -15 - 800 \text{ ppm} \\ \textbf{avg.} = -414 \text{ ppm} \\ \textbf{(most common value} \\ \textbf{460} - 480 \text{ ppm} \\ \end{array}$ | | | | |
| b. Tangentisl | (a) 206-216 (b) 344-396 avg. 390 | 273 | 55 | CCp - 11.1-13.2 avg 14.7 O2 - 2.2-6.8 avg 4.3 NO _X - 160-400 ppm avg 260 ppm Mott commer. value, 180-260 ppm | | | | |

TABLE 6-2 (Concluded)

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B. Carrier Gas (Concluded)

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| Source | Flow Rate | Temperature | Moisture Content | Chemical Composition | Toxicity | Corrosivity | <u>Odor</u> | Flammac. Explosi: |
|---|--|--------------------|-----------------------|---|----------|-------------|-------------|----------------------|
| Industrial Furnace | | | | | | | | |
| Pressure atomizing | (a) 0.3-1.2 (b) 0.3-1.1 svg. 0.6 | 250-370 avg 310 | 3.0-9.8 evg 6.0 | $\begin{array}{l} CO_{22} = 3.9 - 12.4 \\ avg. = 5.6 \\ D_2 = 4.5 - 16.5 \\ svg. = 11.0 \\ CO = 0.002 = 0.01 \\ avg. = 0.002 \\ SO_2 = 98.355 \ pps \\ avg. = 214 \ pps \\ svg. = 2.5 \ pps \\ avg. = 34 - 128 \ pps \\ avg. = 50 \ pps \end{array}$ | | | | |
| 2. Steam stamijing | (a) 1.7-10 (b) 0.3-0.6 avg. 0.44 | 320-710 avg 548 | 6.3-12.7 avg 9.6 | CO2 - 4-8.2 avg 6.4 O2 - 7.8-24.0 avg 10.1 CO - 0.001-C.CC3 avg 0.CC1 SO2 - 7-700 pps avg 366 pps SO3 - 1.2-6.7 pps avg 4.2 pps NO2 - 15-368 pps avg 229 pps | | | | |
| Centrifugal atomizing | (a) 1.2-4.0 (b) 0.39-0.8 Avg. 0.53 | 240-500 Avg 373 | 4,4+8.2 avg. → 6.3 | $\begin{array}{c} CO_2 \ - \ 2.7 - 6.3 \\ avg. \ - \ 4.7 \\ O_2 \ - \ 3.8 - 16.2 \\ avg. \ - \ 12.7 \\ CC \ - \ C.001 - 0.02 \\ avg. \ - \ 12.7 \\ CC \ - \ C.008 \\ SG_2 \ - \ 11 - 102 \ ppm \\ avg. \ - \ 4.0 \ ppm \\ avg. \ - \ 4.0 \ ppm \\ avg. \ - \ 2.6 \ ppm \\ avg. \ - \ 2.7 \ ppm \\ avg. \ - \ 3.7 \ ppm \ avg. \ - \ 3.7 \ avg. \ - \ 3.7 \ avg. \ - \ 3.7 \ avg. \ avg$ | | | | |

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POLYNUCLEAR HYDROCARBON CONCENTRATIONS 5/ (Micrograms/10⁶ Btu Heat Input)ª/

| | | Type of Boiler Firing | | | | | | | | | |
|--------------------|----------|-----------------------|----------------|------------------------------|--------------------|--------------|--|--|--|--|--|
| | | Pulver | ized | | | | | | | | |
| Compound | Vertical | Corner | Front- Wall | Hori- zontally Opposed | Spreader Stoker | Cyclone | | | | | |
| Fluoranthene | 200 | 300 | 80 | 188 | 50 | 79 | | | | | |
| Pyrene | 155 | 140 | 180 | 91 | 105 | 1,025 | | | | | |
| Benzo(a)pyrene | 19 | 140 | 19 | 81 | < 20 | 223 | | | | | |
| Benzo(e)pyrene | | 86 | 23 | 265 | 30 | 39 5 | | | | | |
| Benzo(ghi)perylene | | 150 | 7 | 645 | | 1 9 8 | | | | | |
| Coronene | | 7 | | 56 | 5 | 6 | | | | | |
| Perylene | | 71 | | | | 37 | | | | | |

<u>a</u>/ After fly-ash collector during full-load operation. Average values for two tests at each unit. A blank indicates that the compound was not detected.

ELEMENTAL ANALYSES OF TOTAL PARTICULATES 4/ (Data in Percent)

| | <u>Test A</u> | <u>Test B</u> |
|---|---------------------------|-----------------------------|
| | Total solids from burning | |
| | PSa/400 cil (collected in | Total solids from burning |
| | a laboratory electrical | 4° API oil (collected in a |
| Elements | precipitator at 230°F) | glass filter sock at 300°F) |
| Carbon | 58 1 <u>b</u> / | 18 1 ^b / |
| Ether soluble | 2.3 | 4.4 |
| Hydrogen | 210 | - |
| Ash $(900°C)$ | 17 4 | 51 2 |
| Sulfates as SO- | T 9 E | 01.E |
| (incl. HoSO4) | 17.5 | 25.0 |
| Chlorides as Cl | • | 0.5 |
| Nitrogen as NO ₇ | - | 0.3 |
| Iron as Feg0z | 3.1 | 3.7 |
| Chromium as CrOp | 0.06 | 0.3 |
| Nickel as NiO | 1.8 | 13.2 |
| Vanadium as V ₂ C ₃ | 2.5 | 4.7 |
| Cotalt as CopOz | J.08 | 0.3 |
| Silicon as SiO ₂ | 0.6 | 9.7 |
| Aluminum as Al ₂ 03 | 1.6 | 14.9 |
| Earium as EaO | 0.4 | 0.1 |
| Magnesium as MgO | 0.2 | 0.7 |
| Lead as PbO | 0.1 | 0.2 |
| Calcium as CaO | 0.2 | 0.4 |
| Sodium as Na ₂ O | 0.9 | 3.0 |
| Copper as CuO | 0.01 | 0.25 |
| Titanium as TiO2 | - | 0.004 |
| Molybdenum as MoO ₂ | 0.02 | 0.03 |
| Boron as B203 | 0.01 | 0.1 |
| Manganese as MnO ₂ | 0.04 | 0.04 |
| Zinc as ZnO | _ | 0.06 |
| Phosphorus as P205 | 0.9 | - |
| Strontium as SrO | 0.04 | - |
| Titanium as TiO | 0.03 | - |

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<u>a</u>/ Pacific Standard.
 <u>b</u>/ Value probably includes minor amount of hydrogen.

Fly ash (particulate emitted from combustion process) is a heterogeneous material and is composed of a variety of shapes. Cenospheres, unburned carbon particles, and mineral matter are the principal components. Percentages of these constituents vary from sample to sample, depending upon factors such as coal composition and furnace operation.

6.2.3.2 <u>Oil-Fired</u>: Table 6-2 presents data on the effluent characteristics of cil-fired electric-generating plants. Limited data were found on particle size distributions for particulate emissions from oil-fired units. The predominant size (over 90%) is less than 1μ . Size distribution will depend upon the degree of atomization of the oil, the efficiency of mixing, the number of collisions between fly-ash particles, the flame temperature, the design of the firebox, and the flue-gas path through the boiler to the stack. The lighter particles usually contain less carbon and are smaller in size.

The larger particles are skeletons of burned-out fuel particles, called cenospheres, which are hollow, black, coke-like spherical particles. $\frac{4}{}$ The smaller particles formed by the condensation of vapors are of regular shape and usually have a maximum dimension of about $0.01 \,\mu$. $\frac{4}{}$ Fuel atomization usually reduces the number of cenospheres.

6.2.3.3 <u>Gas-Fired</u>: No detailed data were found on emissions from gas-fired units. Particulates can be assumed to be less than 5μ in size, and gaseous emissions will contain O_2 , N_2 , CO_2 , SO_2 and NO_x .

6.2.4 Control Practices and Equipment for Electric-Generating Plants

6.2.4.1 <u>Coal-Fired</u>: The dust collectors used for coal-fired power plants are shown in Table 6-5 with their usual expected efficiency in Table 6-6.3/ Optimum expected performance of various types of cleaning systems is shown in Table $6-7\frac{1}{2}$.

A comparison of the cost of various types and combinations of control equipment is given in Table $6-8.6^{-1}$

The problem of particulate matter is not solved with its collection. The costly matter of disposal still remains. This cost ranges from 0.50 to 2.00/ton for most utilities. The average is about 0.74/ton.

6.2.4.1.1 <u>Electrical precipitators</u>: Electrical precipitators are used extensively in power plants. A recent survey shows that in recent years high-efficiency electrostatic precipitators are being installed almost exclusively.^{-/} Recent trends toward the use of low-sulfur coal may require increasing the capacity of the electrostatic precipitators. A reduction in the sulfur content of the coal is apt to increase fly-ash resistivity, thereby reducing the efficiency of existing electrostatic precipitators.^{6/}

DUST COLLECTORS FOR COAL-FIRED HEATING AND POWER PLANTS3/

| Collector Type | Collecting Action | Recommended Application | Efficiency Relative to Particle Size | Draft Loss, Inches of Water | Other Considerations |
|---|----------------------------------|---|--|--|---|
| Cinder trap | Gravity | Smaller plants with under- feed, vibrating, chain, and traveling-grate stokers | 30 to 40% for 45 µ and smaller; 75% or more for par- ticles over 45 µ | 0.1 to 0.5(nat- ural draft usu- ally sufficient) | Used mainly to eliminate cinder nuisance in im- mediate plant area. |
| Medium draft loss cyclone | Inertia | Smaller plants with very critical on- grate firing | Overallto 65%, 100% over 25-µ size | 0.4 to 1.5 | Abrasion may occur: made in variety of designs to fit job. |
| Single cyclone (large diameter) | Centrifugal force and inertia | On-grate firing at high rates and some spreader stokers | 50 to 90% for particles over 20 µ | 0.5 to 2.0 | Made in variety of designs. Care required to fit design to job. |
| Multicyclone (small diameter tubes) | Centrifugal force and inertia | Spreader stoker | 75 to 90% for particles over 10 µ | 2.0 to 6.0 | Abrasion may be a problem. |
| Wet scrubber | Inertia | Spreader stoker and pulverized-coal-firing units | 70 to 90%, de- pending on particle size; 75% over 2 μ | 13 to 20 | Caking and corrosion may be a problem, also water recovery. |
| Electrostatic precipitator | Electrical attraction | Pulverized-coal-firing unit | 85 to 99% - < 1 to 10 μ | 0.1 to 0.5 | Performance affected by resistivity of particles |
| Siliconized glass filter | Filtering | Pulverized-coal-firing units | 98 to 99% for < 1 to 44 μ | 1 to 6 | Exit temperature limited to 600°F. |

USUAL EXPECTED EFFICIENCY RANGES FOR <u>COMMONLY USED CONTROL EQUIPMENT</u> 3/ (Percent)

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| Type of Control Equipment | | | | | | | |
|---------------------------|---------------|------------|---------------|-------------------|--|--|--|
| | | High- | Low- | Settling Chamber, | | | |
| Type of Firing | Electrostatic | Efficiency | Resistance | Expanded | | | |
| or Furnace | Precipitator | Cyclone | Cyclone | Chimney Bases | | | |
| | | | | | | | |
| Cyclone | 65-99 | 30-40 | 20-30 | - | | | |
| | | | | | | | |
| Fulverized | 80-99.9 | 65-75 | 40-6 0 | - | | | |
| | | | | | | | |
| Spreader stoker | - | 85-90 | 70-80 | 20-30 | | | |
| | | | | | | | |
| Other stokers | - | 90-95 | 75-85 | 25-50 | | | |

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OPTIMUM EXPECTED PERFORMANCE OF VARIOUS TYPES OF GAS CLEANING SYSTEMS FOR STATIONARY COMBUSTION SOURCES4/

| | | Removal of | Uncontrolle | ed Particulate E | missions | (percent) | |
|-----------------------------|-------------|-------------------|------------------|---------------------|-------------|--------------------|----------------|
| | | | | | | Systems Develop | Under ment |
| | | Syst | tems in Open | ation | | 8-In. | |
| | _ | Large | Small | | _ | Pressure | _ |
| _ | Settling | Diameter | Diameter | Electrostatic | Stack | Drop | Fabric |
| Sources | Chambers | Cyclones | Cyclones | Precipitators | Sprays | Scrubbers | <u>Filters</u> |
| Coal-fired | | | | | | | |
| Spreader, chain grate, and | | | | | | | |
| vibrating stokers | 50 | 60 | 85 | 99.5 | 60 | 99+ | 99.5 |
| Other stokers | 60 | 65 | 90 | 99 5 | 80 | 99+ | 99 5 |
| o oner boner b | 00 | 00 | 50 | | 00 | 551 | 55.0 |
| Cyclone furnaces | 10 . | 15 | 70 | 99.5 | ъ/ | <u>b</u> / | ъ/ |
| | | | | | - | | - |
| Other pulverized coal units | 20 | 30 | 80 | 99.5 | <u>b</u> / | 99+ | 99.5 |
| Oil-fired | <u>5ª</u> / | 10 ^a / | ₃₀ a/ | 75.0 ^c / | ъ/ | ъ/ | ъ/ |
| | | | | | - | — | · _ · |

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<u>a</u>/ Efficiency estimated--not commonly used.
 <u>b</u>/ Insufficient data for estimate.
 <u>c</u>/ Designed for 99% efficiency when firing with coal.

TABLE 6-86/

AIR CLEANING EQUIPMENT INSTALLED COST BASED ON 1,000 MW UNIT (1968)

Furnish, Deliver, Erect (Supports and Flues not Included)

| | Mechanical (cyclone) (75%) | Electro- static Precip. (95%) | Electro- static Precip. (99%) | Comb. Mech- Electro. (95%) | Comb. Mech- Electro. (99%) | Comb. Electro- Mech. (99%) | Bag Filter |
|-----------------------------|----------------------------------|--|--|-------------------------------------|-------------------------------------|-------------------------------------|---------------|
| \$/MW at 300°F | \$ 730 | \$ 3,330 | \$ 5,200 | \$ 3, 830 | \$ 4,4 70 · | \$ 6,160 | \$ 7,650 |
| \$/lb_steam/hr at 300°F | 0.11 | 0.48 | 0.76 | 0.56 | 0.69 | 0.90 | 1.12 |
| \$/ton coal/hr at 300°F | 2,300 | 10,400 | 16,200 | 12,000 | 14,800 | 19,300 | 23,800 |
| \$/CFM flue gas at 300°F | 0.25 | 1.00 | 1.50 | 1.15 | 1.40 | 1.80 | 2.25 |
| \$/CFM flue gas at 700°F | 0.20 | 0.85 | 1.35 | 1.00 | 1.15 | 1.55 | |

For a 500-800 megawatt plant, an electrostatic precipitator with a design efficiency of 95%, treating 300°F flue gases and handling fly ash (which is relatively easy to collect) could be installed for a cost between \$800 and \$1,200/megawatt generating capacity. An electrostatic precipitator of 99% efficiency could be expected to cost between \$1,400 and \$2,200/megawatt of generating capacity.6/

Additional cost data, on the basis of volume flow rate, are given in Figures 6-2 and 6-3, and Table 6-9.2/ Data for fly ash disposal costs are given in Figures 6-4 and 6-5.

The relationship between the collecting area required in an electrostatic precipitator and the collection efficiency for coals of different sulfur content is shown in Figure 6-6. $\frac{9}{}$

6.2.4.1.2 Fabric filters: The principal objections to baghouse operation, that is, encrustation, blinding and deterioration of the cloth, can be overcome by injecting dry dolomite dust into the gas stream and ahead of the collection devices. Sulfur oxides react in the gas stream and on the surface of the bags to form calcium sulfate, a collectable solid. Bag filter installations are being tested with hopes of future application.¹

One prototype unit has been tested on an cil-fired boiler in California. This unit handles 820,000 cfm at 258°F, using a gas (ft³/min) to cloth (ft²) ratio of 6.5:1 along with an alkaline additive. This unit achieves high particulate and sulfur-trioxide collection efficiencies although a number of design and operating problems have been encountered. $\underline{11}$ /

The cost of a baghouse installation, including the additive handling system, has been estimated at $2.25/scfn.\frac{12}{}$

6.2.4.1.3 <u>Cyclones</u>: Multiple small-diameter cyclones are used on mechanical draft combustion units either as precleaners for electrostatic precipitators or as final cleaners. Efficiencies of well-designed units range from 90% for some stoker-fired units to 60% for coal-fired cyclone furnaces.

The efficiency of the cyclone or multicyclone collectors depends on size, shape, and density of the particles as well as other factors. It diminishes drastically in the range of 5 to 10 μ in size. The effect of particle size on collection efficiency at different pressure drops (inches of H₀O) is shown in Figure 6-7.<u>13</u>/



Figure 6-2 - Precipitator Purchase Cost (FOB) as a Function of Gas Volume Treated (Period 1965 - 1969)2/



Figure 6-3 - Precipitator Erected Cost as a Function of Gas Volume Treated (Period 1965 - 1969)2/

| | Gas Volume Range - Millions ACFM | | | | | | | | | |
|------------|----------------------------------|-----------------------|--------------|--------------|---------------------|-------------|-----------------------|--------------|--|--|
| Efficiency | 0-0.249 | | 0.250 | 0.250-0.499 | | 0-0.999 | > 1.00 | | | |
| Range (%) | FOB | Erected | FOB | Erected | FOB | Erected | FOB | Erected | | |
| 90.0-94.9 | 6 4. 7 (2) | 59.3 (1) | 33.8 (1) | 101.1 (6) | 25.2 (1) | 69.2 (2) | 25.8 (3) | No data | | |
| 95.0-98.9 | 75.4 (15) | 91.6 (5) | 61.1 (10) | 88.6 (12) | 37.1 (6) | 62.4 (9) | 31 <i>.</i> 6 (21) | 55.3 (16) | | |
| 99.0+ | 98.0 (4) | 20 4. 5 (5) | 62.7 (4) | 103.5 (5) | 44. 3 (9) | 82.7 (9) | 34.2 (23) | 55.5 (17) | | |

PRECIPITATOR COSTS (1965 - 1969)2/

Note: (a) Costs are cents/ACFM.

(b) Numbers in parentheses are sample size, i.e., no. of installation contract prices averaged to obtain indicated costs/ACFM (all precipitator manufacturers represented).



Figure 6-4 - Plant Fly-Ash Disposal Investment



Figure 6-5 - Plant Fly-Ash Disposal Cost for 1967



Figure 6-6 - Effect of Sulfur Content of Coal on Collecting Area Required in Electrostatic Precipitator

70



Figure 6-7 - Multiclone Collection Efficiency - Fly Ash. (As a function of particle size at pressure drops of 2 in., 3 in. and 4 in. of H₂O.)¹³/

6.2.4.1.4 <u>Wet scrubbers</u>: Sprays are used to a limited extent in the stacks of coal-fired units to control particulate emissions during soot blowing. The problems that limit the use of wet scrubbing include high corrosion rates, high or fluctuating pressure drops, adverse effects on stack gas dispersion, and waste disposal.

A turbulent contact absorber system has undergone testing for absorption of SO_2 in alkaline solution and simultaneous removal of fly ash for a coal burning power plant. With this system, fly ash collection efficiencies of 98% and overall SO_2 removal of 91% can be expected at wet scrubber pressure drops of about 4.5 in. w.g. For a generating capacity of 25 megawatt equivalent to 100,000 cfm of flue gases at 300°F, the investment and operating costs are approximately \$10/kw and \$1.17/ton of coal, respectively.<u>14</u>/

Two limestone injection SO_2 removal systems, designed by Combustic: Engineering, have been installed on operating boiler units. This design incorporates a marble-bed wet scrubber having < 6 in. of pressure drop and is guaranteed to remove 83% of the SO₂ and 99% of the particulate matter.<u>17</u>/

6.2.4.2 <u>Oil-Fired</u>: The combined ash and unburned particulates in exhaust gases from gaseous or liquid fuel combustion are not likely to exceed local air pollution control statutes. For instance, the efficient burning of a common heavy residual oil of 0.1% ash results in a stack gas concentration of only 0.030 grain/scf at 12% CO₂. Nevertheless, particulates from oil burning are still principally in the submicron range (0.4 μ), and are in sufficiently large concentration to cause perceptible light scattering.

The only air pollution control devices that have found ready acceptance on cil-fired power plant boilers are dust collectors used to control particulates during soot blowing. This equipment serves principally to collect particulate matter larger than 10 μ . Small-diameter multiple cyclones are the most common soot-control devices installed. The emission from an oil-fired unit without special collection equipment is comparable to a coal-fired unit of better than 99% collection efficiency.² The use of an electrostatic precipitator for particulate removal on an oil-fired steam generator was tested on a pilot unit and a prototype unit. Although control was outstanding on the pilot unit, stack emissions from the full-scale unit did not comply with opacity regulations. $\frac{15}{7}$

6.2.4.3 <u>Gas-Fired</u>: Control equipment has not been utilized on natural gas equipment.

6.3. INDUSTRIAL POWER GENERATION

Large industrial plants may generate their own electric power or process steam by the combustion of coal, fuel oil, and gas. Emissions from these combustion units parallel those discussed under electric utilities (Section 6.2) but are lower in total quantity because of a smaller quantity of fuel burned.

6.3.1 Fuel Type

6.3.1.1 <u>Coal-Fired</u>: The stoker-type boiler is the dominant unit used in industrial plants. Stoker units accounted for about 70% of the coal burned by industrial plants in 1968. Pulverized units (20%) and cyclone (10%) accounted for the remaining coal consumption. The pulverized and cyclone units are generally associated with larger industrial complexes, and are similar in design to those discussed under electric utilities.

Stoker units used include:

- 1. Spreader stoker,
 - a. Traveling grate
 - b. Stationary or dumping grate
 - c. Vibrating grate
 - d. Reciprocating grate
- 2. Chain or traveling grate,
- 3. Water-cooled vibrating grate,
- 4. Multiple retort underfeed, and
- 5. Bituminous Coal Research Automatic "Packaged".

Spreader-stoker units were described in Section 6.2.1.1. Traveling grate and chain-grate units have moving grates. These grates move from the front to the rear and carry coal from the hopper in front through a grate into the combustion zone. The fuel bed burns progressively to the rear, where the ash is continuously discharged. Older units with natural draft are fast disappearing; modern units have zone-controlled forced draft. Complete combustion-control systems are utilized and overfire air, especially in the front wall, is an aid to burning the volatiles in the fuel. $\frac{3}{}$

The water-cooled vibrating grate unit consists of a water-cooled grate structure on which the coal moves from the hopper at the front of the boiler through the burning zone by means of a high-speed vibrating mechanism automatically operated on a time-cycling control. As in the traveling grate, the fuel bed progresses to the rear, where the ash is continuously discharged. Forced air is zone-controlled and regulated, along with the complete coal and air system, through an automatic combustion-control regulator.³/

Multiple-retort underfeed boilers usually consist of several inclined retorts side by side, with rows of tuyeres in between each retort. Coal is worked from the front hopper to the rear ash-discharge mechanisms by pushers. The forced-air system is zoned beneath the grates by means of air dampers, and the combustion control is a fully modulating system. In the larger furnaces the walls are water-cooled, as are the grate surfaces in some units. Multiple-retort underfeed stokers are declining in use, giving way to spreaders and traveling-grate units.

The BCR automatic packaged boiler is a complete steam or hot water generating system, incorporating a water-cooled vibrating grate as the firing mechanism. Coal is delivered from the storage bin to a hopper from which it travels on the vibrating grate to the fuel bed. Ash is discharged automatically by means of a screw conveyor. The unit has completely automatic combustion controls so that coal feed to the hopper from the bin and ash discharge is coordinated with load conditions. Forced and induced draft fans are used. $\frac{3}{2}$

6.3.1.2 <u>Oil-Fired</u>: Large industrial complexes will use essentially the same design of furnace as is used in electric utility plants. These units are discussed in Section 6.2.1.2. Smaller industrial operations utilize lower capacity units with attendant lower flame temperatures. In many cases less attention is given to treatment of fuel and regulation of combustion air for small units. Neglecting either one often results in reduced combustion efficiency.⁴/ Boiler types used in smaller units are: (1) steam atomizing, (2) pressure atomizing, and (3) centrifugal atomizing. 6.3.1.3 <u>Gas-Fired</u>: No detailed information was found on gasfired units in industrial applications.

6.3.2 Emission Rates

6.3.2.1 <u>Ccal-Fired</u>: Emissions from coal-fired industrial units are affected by the same factors discussed in Section 6.2.2.1 for electric utility plants. Emission rates are summarized in Table 6-1. Emissions currently total about 2.6 million tons/year with stoker-fired units accounting for about 85% (2.2 million tons/year).

6.3.2.2 <u>Oil-Fired</u>: The fly ash loadings for industrial sources may be slightly higher than those for the larger electric-generating plants. Emission levels are dependent upon combustion efficiency and rate of build-up of boiler deposits. Table 6-1 summarizes emission levels for cil-fired industrial boilers. Current emissions are estimated at about 100,000 tons/year.

6.3.2.3 Gas-Fired: Meager data exist on emissions from gasfired units. Available information on emission rates is tabulated in Table 6-1. Particulate emissions are estimated to be about 85,000 tons/ year.

6.3.3 Characteristics of Effluents from Industrial Boilers

6.3.3.1 <u>Coal-Fired</u>: The characteristics of effluents from industrial coal-fired units would parallel those from electric-utility sources. Some differences in composition and particle size of the fly ash will occur because of the differences in boiler types employed in industrial plants.

6.3.3.2 <u>Oil-Fired</u>: Characteristics of emissions from oil-fired industrial boilers differ in minor respects from those of electric-utility boilers. Table 6-2 summarizes available data for these sources.

6.3.3.3 <u>Gas-Fired</u>: No detailed data were found on emissions from gas-fired boilers.

6.3.4 Control Practices and Equipment for Industrial Boilers

6.3.4.1 <u>Coal-Fired</u>: Control equipment for coal-fired industrial boilers is very similar to that employed by electric utilities. Cyclones, multiclones and electrostatic precipitators are used in both groups although the use of electrostatic precipitators has not been as prevalent for industrial boilers. The increased emphasis on reducing air pollution has apparently prompted many of the industrial coal-fired boiler operators to switch over to oil or gas. This route to control may be a simpler matter for the industrial operator than for the electric utility operator who is consuming larger quantities of fuel.

6.3.4.2 <u>Oil-Fired</u>: The use of control devices on oil-fired units is usually limited to periods when soot-blowing operations are in progress or in areas where restrictive legislation requires low particulate loadings and low opacity of stack effluents. Multiple cyclones and electrostatic precipitators have been used for these purposes. $\frac{4}{}$

6.3.4.3 <u>Gas-Fired</u>: Control equipment has not been utilized on natural-gas equipment.

6.4. COMMERCIAL, INSTITUTIONAL, AND RESIDENTIAL FURNACES

Commercial, institutional and residential furnaces are primarily used for space heating. The general character of emissions from these sources would parallel that of electric utility and industrial sources, with allowance made for differences in furnace types and operating procedures. In general, combustion efficiency will be lower in these units and outlet grain loadings higher as a result.

6.4.1 Fuel Type

6.4.1.1 <u>Coal-Fired</u>: Small stoker-type boilers are the main units used in commercial, institutional and residential operations. In some cases hand-fired equipment may be employed, but such installations are fast disappearing, and are being replaced with automatic firing.

Stoker units include:

- 1. Underfeed stokers,
 - a. Single retort (residential)
 - b. Multiple retort
- 2. BCR Auto Packaged, and
- 3. Small spreader stoker
 - a. Stationary or dumping grate
 - b. Water-cooled vibrating grate.

In the residential underfeed stoker, the coal is fed from a hopper or directly from the coal storage bin to the retort by a continuous, rotating screw. Coal rises into the firing zone from underneath: thus the term "underfeed firing". Air is delivered to the firing zone through tuyeres (grate openings), also from underneath the actively burning bed. The coal and primary air control is "all on" or "all off". Ash is removed as a clinker from a refractory hearth through the furnace firing door.

The general arrangement of the single retort unit for commercial and institutional use is similar to the residential unit, with "dead" plates replacing the refractory hearth. As sizes become larger, screw feeders are replaced by a mechanical ram, which feeds coal to pusher blocks that distribute the coal in the fire box. Ash is discharged by side-dump grates. Modulating combustion controls, i.e., variable control of both fuel and air rates, are often used. Forced draft is automatically regulated, and separate over-fire air systems are used, particularly when on-off controls are used. A bridge wall retains the coal over the stoker grates.³/

The multiple-retort, BCR automatic packaged boiler, and spreaderstoker units are described in Section 6.3.1.1.

6.4.1.2 <u>Oil-Fired</u>: Boiler types are similar to the small units discussed in Section 6.3.1.2.

6.4.1.3 <u>Gas-Fired</u>: No pertinent information is available on gasfired units for these installations.

6.4.2 Emission Rates

Data are meager on emissions from all types of units used in these facilities. In general, lower combustion efficiency than that experienced for utilities or industrial units is expected to lead to increased outlet grain loadings.

6.4.3 Characteristics of Effluents

No pertinent data on effluent characteristics were found for this class of furnaces.

6.4.4 Control Practices and Equipment

Control equipment is not generally used on these small furnaces. Reference 16 discusses the use of various combustion-improving devices to reduce emissions of smoke, carbon monoxide, nitrogen oxides, and total gaseous hydrocarbons from high-pressure atomizing-gun burners used in domestic oilfired furnaces. The devices (primarily improved nozzles) were designed to improve combustion in older inefficient furnaces. Laboratory tests indicated that the devices offer potential for reducing levels of pollutants.

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CHAPTER 7

CRUSHED STONE, SAND, AND GRAVEL INDUSTRIES

7.1 INTRODUCTION

The conversion of naturally occurring minerals into crushed stone sand, and gravel involves a series of physical operations. Quarrying, transportation, crushing, size classification, and drying are common to almost all mineral production procedures. Air pollution problems may be created by all of these operations. The dust emitted is usually a heavy dust released at ambient temperature, and these emissions can be considered to be a nuisance to the community. Processing methods, particulate emission sources, emission rates of individual particulate sources, the characteristics of source emissions, and control practices and equipment are discussed in the following sections.

7.2 CRUSHED STONE

7.2.1 Production Process

The initial step in the processing of crushed stone occurs at the quarry site. Rock and stone products are loosened by drilling and blasting from their deposit sites. Primary drilling, primary blasting, and secondary blasting or breakage comprise the principal steps in the quarry operation. The secondary blasting operation in many quarries is now either eliminated by better fragmentation during primary blasting, or by the use of "drop ball" cranes. Tractor-mounted air or hydraulic operated "rock-splitters" have proven satisfactory for some operations. 1/

The broken rock or stone is transported from the quarry to the processing plant. Transport is usually by truck or heavy earth moving equipment. The processing of stone includes such operations as drying, crushing, pulverizing, screening, and conveying. Primary crushers will normally reduce stone to 1-3 in. in size. Secondary crushers are used to reduce stone to sizes below 1 in. Following the processing operations, the stone or rock is loaded for shipment to the customer or sent to storage.

7.2.2 Emission Sources and Rates

Particulate emission sources in the crushed stone industry can be divided into two categories; first, sources associated with the actual

81

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quarrying, crushing, screening, and processing operations; and second, "fugitive" sources involving reentrainment of previously settled dust. These fugitive sources include vehicle traffic on temporary roads, transfer operations, and stockpiles.

The use of pneumatic drilling and cutting as well as the blasting and transferring can cause considerable dust formation at quarry sites. The transport of stone by vehicle creates dust from unimproved roads. No quantitative data is available on emission rates from these sources.

Rock processing operations (i.e., crushing, pulverizing, classifying) are potential dust sources. Dust is discharged from crushers and grind finlet and outlet perts. Factors affecting emissions include moisture content of the rock, type of rock processed, amount of rock processed, and type of crusher employed.

Some minerals require drying prior to processing. Dryers are usually direct-fired, either parallel or counter flow, rotary units. Particulate emissions from dryers can be significant, and the amount emitted varies with type of mineral processed, degree of drying, and dryer type.

A major "fugitive" dust source is stockpiles (i.e., windblown dust). Losses vary with size of stored material, density of material, moisture content, and wind speed.

Actual test data on emissions from the above sources are limited. The limited emission data are presented in Table 7-1. The factors used in estimating the particulate emissions from the crushed stone industry were obtained from Reference 2. Table 7-1 does not include dust blown from stockpiles. Stockpile losses due to wind ergsion have been estimated at 0.5% of finished product for crushed stone.²/ The potential amount of dust that could arise from stockpiles in crushed stone storage areas is about 3.1 million tons per year. Factors which would reduce this estimate are: (1) the amount of product which is loaded for shipment directly from processing without being sent to stockpiles; (2) the amount stored in bins and siles; and (3) amount of product which has sufficient moisture content at the time of discharge to stockpiles to inhibit the formation of dust by wind ergsion.

No estimate has been made of dust emissions from quarrying or from vehicle traffic over unpaved or paved plant roads.

7.2.3 Effluent Characteristics

Meager data exist on the physical and chemical properties of dust emitted in crushed stone operations. It is usually a heavy dust emitted at

TABLE 7-1

PARTICULATE EMISSIONS CRUSHED STONE, SAND AND GRAVEL

| | Source | Quantity of Material | Emission Factor | Efficiency of Control | Application of Control Ct | Net Control $C_c \cdot C_t$ | Emissions (<u>tons/year</u>) |
|-----|--|--|--------------------------------------|--------------------------|---------------------------------|-----------------------------------|-----------------------------------|
| Ι. | Crushed Stone | | | | | | |
| | A. Primary crusher | 681,000,000 tons (cement, lime & dolomite not | 0.5 lb/ton of rock ^a / | | | | |
| | B. Secondary crushing & screening | included) | 1.5 ^a /, | | | | |
| | C. Tertiary crushing & screening | | 6.0 ^a /, | | | | |
| | D. Fines milling | | 6.0ª/ | | | | |
| | E. Re-crushing & screening | | <u>1.05</u> / 15.0 ^a / | 0.80 | 0.25 | 0.20 | 4,100,000 |
| | F. Conveying, general screening, etc. | | 1.7 lb/ton of product | 0.80 | 0.25 | 0.20 | 454,000 |
| | G. Dryers | | | | | | |
| II. | Sand & Gravel - crushing and | | | | | | |
| | screening | 918,000,000 tons | 0.1 lb/ton of material | | | | 46,000 |
| III | . Quarrying | | | | | | |
| | A. Drilling | | | | | | |
| | B. Blasting | | | | | | |
| | C. Loading - unloading | | | | | | |
| IV. | In-Plant Vehicle Traffic | | | | | | |
| | | | Total for | C rus hed Stor | ne, Sand and (| Fravel | 4,600,000 |

 $\frac{a}{Pounds}$ / ton of rock through the primary crusher.

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b/ Listed emission factor is 5 lb/ton of rock re-crushed. Twenty percent of product is assumed to be re-crushed.

83

ambient temperatures. The majority is fairly coarse and contains some moisture. Figure 7-1 presents particle size data for the particulates emitted from a jaw crusher and a conveyor system.

7.2.4 Control Practices and Equipment

Control measures consist of wetting and sprinkling to minimize dusting and proper loading and evacuation to collect dust from crushing and screening equipment and transfer points. Cyclones and water spray chambers are the present chief means of collection of this dust. Bag filters or high efficiency water scrubbers are used in locations where stringent emission standards must be met.

7.2.4.1 <u>Quarry Operations</u>: There are many sources of dust associated with crushed stone operations and most of these are of the "fugitive" type. Blasting is one of these sources which occurs intermittently.

In conventional mining of coal, water-filled plastic bags are used for stemming dust emissions from blast holes. Their use in conjunction with an air-and-water blast results in a considerable reduction of the dust from blasting. $3^{/}$ This technique may be applicable to blasting operations in stone quarries.

A method of suppressing dust from dry percussion drilling in quarries and open pit mines has been developed. Water with an added wetting agent is introduced into the air used for flushing the drill cuttings from the hole. Dilution ratios range from 800 to 3,000 parts of water to one of surfactant. The proper amount of solution, about 7 gal/hr for a 3-1/2 in. dia. hole, causes the drill cutting to be blown from the hole as damp dust-free pellets. $\frac{3}{2}$

For primary blowing operations, it has been reported that initiation of detonation with multi-delay devices and the complete combustion of the explosive compound result in low dust emission. $\underline{l}^{/}$

7.2.4.2 <u>Transport Operations</u>: The loading and unloading of blasted stone also usually releases dust into the atmosphere. Wetting of the broken stone can effectively decrease the dust emission but this is not a common practice. Wetting the surface of a load in a transport vehicle will reduce windage loss during transport.

The transport of stone by vehicle creates airborne dust from unimproved roads. This can be minimized by frequent wetting of the road. Oiling or wetting with CaCl₂ can reduce the required frequency of wetting.



Figure 7-1 - Particulate Size from Rock Processing Operations2/

85

Unpaved plant roads can be a constant source of trouble in dry weather. Calcium chloride can be applied at a cost of approximately 0.15/sq yd treated/year. The principal problem with calcium chloride treatment of roads is corrosion of vehicle bodies and timing the applications relative to weather. Treating roads with oils of various types, at least once a month, will do an excellent job of controlling unpaved roads at a cost of approximately 0.10/sq yd treated/year. The use of water trucks with high velocity side flush can be used to control dust. However, the opinion has been expressed that the use of a water truck on unpaved roads in the hot summer is virtually a complete waste of time. $\frac{4}{2}$

7.2.4.3 <u>Crushing</u>, <u>Screening and Transfer Operations</u>: The simplest and least expensive means of controlling dust in a crushing and screening operation is through the use of wetting agents and fine water sprays at critical points.⁴/

The use of untreated water sprays for suppression of dust from handling and storing materials requires that approximately 5 to 8% moisture by weight be applied. However, when the water has been treated with a surface active agent the moisture addition required may be reduced to 0.5 to $1\%.5^{-/}$ Once the material has been adequately sprayed and dustproofed it may be conveyed through several transfer points without requiring further treatment.

Water sprays are used successfully to control dust at transfer and unloading points. Experimental use of a high expansion foaming agent reduced dust counts at belt-conveyor transfer points by $50\%.\frac{5}{2}$

Steam has been used to alleviate dust at transfer points of conveyors in coal preparation plants, etc. The effectiveness of dust suppression by steam is attributed to the reduced surface tension of hot water. $\frac{2}{}$

7.2.4.4 <u>Stockpiles</u>: Stockpiles of minus 3/16 in. material can be a dust problem in dry or windy weather. An economical solution to this problem is difficult to find.³/ Various mechanical means can be used to minimize dust as the product is dropped onto the pile.⁶/

Another approach to dust control is the use of chemical binders for application to the surface of stockpiles. The chemical coats the topmost particles with a thin film causing them to adhere to one another. As long as the crust remains intact the stockpile is adequately protected against windage losses. By adding a coloring agent to the binder, treated areas can be readily identified to detect those that may not have been coated properly. The normal rate of application is 1 gal/100 sq ft of surface area.5/ Application of water from sprinkler systems has also been found to be a method of reducing stockpile losses.1/

7.3 SAND AND GRAVEL

7.3.1 Production Process

The raw materials for sand and gravel plants may be dredged from a river or quarried and then transferred by vehicle to the crushing and screening equipment. Material is frequently washed prior to processing to obtain a product which meets users' specifications. Preliminary screening, prior to crushing, is also practiced in some plants. Wet and dry screening may be used. Following processing and classification, the material is loaded for shipment or stockpiled in storage areas.

7.3.2 Emission Sources and Rates

Particulate emission sources in sand and gravel processing parallel those in crushed stone preparation. The crushing, screening, and transfer operations can all generate significant quantities of dust. Emission rates are affected by moisture content of processed materials, degree of size reduction required, and type of equipment used for processing.

Observations from numerous plants indicate that a major source of dust, in addition to those associated with the plant equipment, is from vehicle traffic over unpaved roads or paved roads covered with dust. $\frac{8}{}$ Stockpile losses would also contribute to the dust burden. Stockpiles of fire sand would be susceptible to wind loss.

No information has been found on emission factors from sand and gravel plants. One sampling report, furnished by a state agency, listed overall emissions as 0.06 lb. of dust/"ton of material through the plant." This report listed the discharge of the secondary and reducing crushers and the elevator boot on the "dry side" as the dust sources. Seventy-five percent of the dust was estimated to come from the crushers. Based on this limited information, an overall emission factor of 0.1 lb. of dust/ ton of product was assumed for sand and gravel plants.

Table 7-1 summarizes the estimates of emission levels from sand and gravel plants. Table 7-1 does not include dust blown from stockpiles. Stockpile losses due to wind erosion have been estimated at 1% of finished product for sand and 0.5% for gravel.¹/ Most stockpiles are merely ground piles; however, silos and bins are also used. Potential "fugitive" dust emissions from stockpiles in sand and gravel plants are estimated to be about 6.5 million tons/year. No estimate has been made of dust emissions from quarrying or from vehicle traffic over unpaved or paved plant roads.

7.3.3 Effluent Characteristics

Limited data were found on the characteristics of effluents from sand and gravel plants. Stock sampling data for sand and gravel dryers, obtained from state control agencies, $\frac{9,10}{}$ indicated that outlet grain loadings ranged from 5.8 to 38 grains/ft³. Mass median particle size of the particulates emitted from the dryers varied from 3.5 to 9.4 μ .

7.3.4 Control Practices and Equipment

Specific information on control practices and equipment utilized in sand and gravel plants is limited. Since many of the operations parallel those of the crushed stone industry, similar control practices and equipment are undoubtedly employed.

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CHAPTER 8

OPERATIONS RELATED TO AGRICULTURE

8.1 INTRODUCTION

The agriculture industry as considered here includes such diverse operations as field burning, grain elevators, feed mills, and cotton gins. Obviously, emissions from these operations are highly variable.

Open burning of agricultural wastes is practiced in many areas as the most practical means of clearing the land of these wastes. This practice can contribute a high concentration of pollutants to the atmosphere. Grain handling facilities constitute a major dust problem in some urban areas. Furthermore, in less densely populated areas a grain facility may be a nuisance to people in the immediate vicinity. Cotton gins also present primarily a localized air pollution problem.

Various phases of the agriculture industry, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

8.2 AGRICULTURAL FIELD BURNING

Disposal of agricultural wastes is imperative because the refuse piles act as reservoirs of horticultural diseases and agricultural pests. Open burning is currently the most practical means of accomplishing this disposal.

Emissions into the atmosphere from the burning straw and stubble are characteristic of vegetative plant sources generally. Cellulose and lignin are the primary constituents of plants. Emissions consist of smoke, made up of carbon particles of varying sizes, ash, and certain gases. Most of the carbon particles are minute in size and indistinguishable without visual aid, while others are readily visible. The former are a major factor in reduced visibility, while the larger particles, which settle out more readily, are factors in soiling and deposits on property. The principal gases emitted are the organic hydrocarbons, carbon dioxide, carbon monoxide and oxides of nitrogen.¹ Open burning emissions are affected by many

⁹¹ Preceding page blank
variables including wind, ambient temperatures, moisture content of the fuel burned, size and shape of fuel, and compactness of fuel bed. Table 8-1 gives typical data for particulate emissions from rye-grass burns and Table 8-2 summarizes emission rates. It is estimated that agricultural field burning emits about 2.4 million tons of particulate/year.

TABLE 8-1

PARTICULATE EMISSIONS FROM RYE-GRASS BURNS1/

| Grass | Variable | | Low | Average | <u>High</u> |
|-----------|------------------------------|-------------------|------|---------|-------------|
| Annual | Suspended particulate, | mg/m ³ | 11.4 | 25.6 | 46.8 |
| Annual | Percent organic matter smoke | in | 13.3 | 37.4 | 63.9 |
| Ferennial | Suspended particulate, | mg/m ³ | 20.4 | 39.4 | 56.3 |
| Perennial | Percent organic matter smoke | in | 19.9 | 38.8 | 72.8 |

PARTICULATE EMISSIONS FROM OPERATIONS RELATED TO ACRICULTURE

| | Source | Quantity of Material | Emission Factor | Efficiency of Control C _C | Application of Control Ct | Net Control Cc·Ct | Emissions (tons/yr) |
|-----|--------------------------------------|--|--------------------------------|--|---------------------------------|-------------------------|------------------------|
| Ι. | Burning of Stubble | 280,000,000 tons of stubble | 17 lb/ton of stubble burned | 0.0 | 0.0 | 0.0 | 2,400,000 |
| II. | Grain Elevators | 177,000,000 tons of grain | | | | | |
| | A. Terminal Elevators | | | | | | |
| | 1. Shipping or Receiving | | 1 lb/ton of grain handled | | | | |
| | 2. Transferring, Conveying, e | t c . | 2 ib/ton of grain handled | | | | |
| | A Device | | 6 lb/ton of grain handled | | | | |
| | B Country Flevetors | | o iby con or grain hattired | | | | |
| |). Shimping or Receiving | | 5 lb/ton of grain bandled | | | | |
| | 2. Transferring, Conveying, et | te. | 3 lb/ton of grain handled | | | | |
| | 3. Screening and Cleaning | | 8 lb/ton of grain handled | | | | |
| | 4. Drying | | 7 lb/ton of grain handled | | | | |
| | | Total for Grain Elevators | | 0.70 | 0.40 | 0.28 | 1,700,000 |
| пι. | Cotton Gins | 11.000.000 bales | | | | | |
| | A. Trailer Unloading | | 5 lb/bale | | | | |
| | B. Cleaners | | 2 lb/bale | | | | |
| | C. Stick and Bur Machine plus Hul | ler | 3 lb/bale | | | | |
| | Front and Mote Discharge Stand | | • | | | | |
| | D. Lint Cleaner | | l lb/bale | | | | |
| | E. Condenser | | <u>l</u> lb/bale | | | | |
| | | Total for Cotton Gins | 12 | 0.80 | 0.40 | 0.32 | 45,000 |
| rv. | Peed Mills | | | | | | |
| | A. Alfalfa Dehydrators | 1,600,000 tons of dry mea | L | | | | |
| | 1. Primary Cooling Cyclone | • | ll lb/ton of dry meal | | | | |
| | 2. Secondary Cooling Cyclone | | 4 lb/ton of dry meal | | | | |
| | Air-Meal Separator | | | | | | |
| | a. Cyclone | | 47 lb/ton of dry meal | | | | |
| | b. Cyclone + Skimmer | | 9 lb/ton of dry meal | | | | |
| | 4. Pellet-Meal Separator | | 2 lb/ton of dry meal | | | | |
| | 5. Pellet Re-Grinder | | $\frac{2}{50}$ (or or dry mean | 0.05 | 0.50 | 0.40 | |
| | | Total for Alfalfa Dehydrators | 50 (as an average) | 0.85 | 0.50 | 0.42 | 25,000 |
| | B. Wheat Mill-Feeds | 4,490,000 tons | 1% of end product | | | 0.42 | 26,000 |
| | C. Gluten Feed and Meal | 1,515,000 tons | 1% of end product | | | 0.42 | 9,000 |
| | D. Ríce Mill-Feeds | 476,000 tons | 1 % of end product | | | 0.42 | 3,000 |
| | E. Brewers' Dried Grains | 336,000 tons | 1% of end product | | | 0.42 | 2,000 |
| | F. Distillers' Dried Grains | 447,000 tons | 1% of end product | | | 0.42 | 3,000 |
| | G. Dried Beet Pulp | 1,100,000 tons | 1% of end product | | | 0.42 | 6,000 |
| | | Total for Feed Mills Other Than Alfalf | 8. | | | | 49,000 |
| v. | Flour Mills | 112 lb. pe r c apita | | | | | |
| | | | | TOTAL FOR | LISTED OPERATIO | DNS | 4,217,000 |

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8.3 GRAIN ELEVATORS

Grain elevators are primarily transfer and storage units and are classified into two categories. These are the smaller more numerous country elevators and larger terminal elevators. In addition many elevator locations also contain feed manufacturing facilities. Particulate emissions occur because of the dry, light nature of most grains and the way they are handled via pneumatic and mechanical conveyors. A wide variety of grain-handling configurations are possible at elevator sites depending on the number and quantity of grains handled, and the amount of processing required. At grain elevator locations any or all of the following operations can occur:

> Receiving, transfer and storage Cleaning Drying Milling and grinding.

Receiving and transfer operations are accomplished by unloading the grain, usually by dumping into a bin followed by conveyor belt or pneumatic transfer. Cleaning operations are designed to eliminate impurities such as sticks, stones, and other foreign matter. Both screening and air classifiers are used to separate grain and foreign matter.

8.3.1 Emission Sources and Rates

Emissions from grain operations may be separated into those occurring at all elevators involving transfer losses, and those occurring at processing operations such as cleaning, drying, and grinding. Emissions are greatest at the loading and unloading areas, especially when these operations are carried out in the open. Falling or moving streams of particles inspirate a column of air moving in the same direction. When this moving mass of particles strikes an immovable object, the energy expended causes extreme air turbulence and a violent generation of dust occurs. This undesirable situation occurs when trucks and rail cars are dumped into deep hoppers and also when rail cars and the holds of ships are loaded.

Lesser sources of dust emissions in transfer operations are conveying equipment and storage bins. Belt conveyors have less rubbing friction than either screw or drag conveyors and generate less dust. Dust emissions usually occur at belt transfer points as materials fall onto or away from a belt. The discharge points of pneumatic conveying equipment are also potential sources of dust emissions. Storage bins vent dust-laden air from two sources. One source is air displaced during loading operations. As the incoming material falls freely from a spout at the top of the bin, dust is mixed with the air in the bin. The other source is air inspirated by the flow of incoming material.

Factors affecting emissions from grain elevator transfer operations include the types of grain, the moisture content of the grain (usually 10-20%), amount of foreign material in the grain (usually 5% or less), the amount of moisture in the grain at the time of harvest (hardness), the amount of dirt included with the grain during harvesting, and the degree of enclosure at loading and unloading areas. $2^{/}$

The grain processing operations may include wet and dry milling (cereals), flour milling, oil-seed crushing, and distilling. Wet milling by its nature is not conducive to major dust formation, although dust may escape from dryer cyclones. Dry milling, however, is somewhat more dusty in its operation. Most handling and transfer in these operations is pneumatic, allowing good dust control. Oil-seed crushing generally is not conducive to major dust generation, but losses can occur from extracting and drying operations and from cyclone collectors used on these operations. Grain distilling operations also are not conducive to major dust formation although particulates can escape during unloading of grains and be entrained in the gaseous discharge from cooling operations. The major problem with these operations is odor emissions.²/

Drying is usually accomplished in rotary, column, or shelf dryers using heated air as the drying medium. The material emanating from the dryers is generally not classified as dust but rather chaff or, in the case of corn, "beeswing." Although the particle size is large, it is extremely light and filmy. This material will carry for miles on a windy day if it is released from a source sufficiently high above the ground. $\frac{3}{2}$

Grinding may be done in a variety of devices in either a wet or dry state. Common devices used include hammer mills and rollers. Many of the large terminal elevators also process grain at the same location.

Factors affecting emissions from grain processing operations include the type of processing (wet or dry), the amount of grain processed, the amount of cleaning, the degree of drying and heating, the type of dryer, the amount of grinding, and the type of grain. $\frac{2}{}$

Emission rates for grain elevators are summarized in Table 8-2. Current particulate emissions total 1.7 million tons/year.

8.3.2 Effluent Characteristics

Available data on the chemical and physical characteristics of effluents from grain elevators are summarized in Table 8-3. Particulates emitted during railroad car loading of oats and wheat have a geometric mean size of 3.1 and 2μ . Grain dust presents a high explosive hazard.

8.3.3 Control Practices and Equipment

Air pollution from feed and grain mills consists entirely of dusts. These dusts, though varied, may be collected by inertial devices and fabric filters.

For receiving hoppers used for unloading, the best method of hooding is to exhaust air from below the dump grating to a fabric filter or cyclone-filter combination. $\frac{4}{}$ One of the most difficult to control emission sources is that occurring when grain is poured into the hold of a ship. $\frac{5}{}$

The duct work for a dust-collection system generally is sized based on the volume of air necessary for each hood inlet and pickup point, and a base velocity of 4,000 ft/min in the duct. Velocities of < 3,500 ft/min will permit settling of dust in long horizontal ducts. If dust settles and accumulates in duct work, it provides a harborage and point of insect infestation. Careful attention should be given to design of duct work to avoid projections in the duct which will permit accumulation of dust and subsequent infestation by insects. $\frac{6}{2}$

One development reported in a recent $\operatorname{article}^{5/}$ is a completely enclosed belt conveyor. The basement of the storage elevator, which houses the conveyor, is kept under slight positive pressure so that no dust can leak from inside the conveyor.

6.3.3.1 <u>Cyclones</u>: Cyclones are used with great versatility in grain elevators and in feed mills. Nearly all cyclones are of the simple, low or medium efficiency types.

8.3.3.2 <u>Baghouses</u>: Fabric filters can provide high efficiency dust collection for most services associated with feed and grain operation. However, they do not find application in grain drying due to the high moisture content of the effluent gases from the dryer.

TABLE 9-3

EPPLIENT CHARACTERISTICS - OPERATIONS HELATED TO AGRECULTURE

A. Particulate (Part I)

| <u>So</u> 1 | urce | Particle Size | Solids Logding | Chemical Compositio | Particle Electrica n <u>Density</u> <u>Resistivi</u> | 1 Hoisture Ly <u>Content</u> | Texicity |
|--------------|---|--|--|--|--|---------------------------------|--|
| Ag | riculture Industry | | | | | | |
| 1. | Field burning a. Rye-grass field | Suspended particulates: mean particle size: 0.5 | 11-56• avg., 32.5 | Carbon, ash | | | |
| 2. | Grain alevators a. Railroad car loading | Optical: Data Geometric mean sige, 3.1 (1 test) Wheat: geometric mean sige, 2.1 (1 test) | 348- | See Table 8-4 for detailed composi- tica | 3.4 | | Grain dust fot consid- ered toxic, but may cause respiratory symptoms and skin rash on prolonged exposure |
| | b. Conveyor system (1 plant) | <u>Screen analysis:</u> 6.4 < 44, 25.6 < 74, 45 < 104 | | | | | |
| | c. Cleaning | | | Chaff, bran. weed seed, pollen. dirt, insect parts Chaff | | | |
| t | a. Drying | | 4-35 | Flour dust | | | |
| 4. | Fred mill a. Feed barley namermill | | | | 1.0 | | |
| 5. | Alfalfs dehydrating | | | | | | |
| | mill a. Primary cooling | | 0.1-0.2 | | | | |
| | cyclore b. Becondary cooling | Average equivalent | 0.1-0.4 | | 1.25 | | |
| | cyclone c. Air meal separator | Average equivalent Stokes' dia., 1.5-3 | 0.2-2.3 | See Table 8-5 for detailed compu- | 1.32 | | |
| | d. Pellet meal air | Average equivalent | 0.1-0.4 | Sition | 1.51 | | |
| | e. Pellet regrand air separator | Average Aquivalent Stokes' d'al, 3 | 1.7 | | 1.24 | | |
| 6. | Cotton ginning a. Gin | | 0.0019-0.55 (dependent upon seepling moint) | Trash. dust, lint. and pestimine residue | | | |
| | b. Incinerator | | P | Fly ash, smoke, Arsenic | | | Davie due 15 Anserie Content |
| ٨. | Particulate (Part II) | | | | | | |
| Sm | urce Sol: | ubility Wettability | Hygroscopic Characteristics | Flammability or Explosive limits | Handling Inspectation | Ortica: <u>Fropertie</u> | <u>s 0dry</u> |
| ^ () | riculture Industry | | | | | | |
| 1. | Field burning | | | | | | |
| 2. | Grain elevators | | | Grain dust presents a high explosive hazard | Grains are gennerally per abrative, sticky, or corrusive | : | |
| 3. | Cotton ginning a. Gin | | | | Festicile residues may be | | |
| | b. Incinerator | | | | COLLOSING | | Acrid |

See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.
 Milligrams per cubic meter.

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DABLE 8-3 (Concluded)

B. Carrier Gas

| ł | Sour | <u>te</u> | Flow Rate | Temperature | Noisture Content | Chemical Composition | Toricity | Corrosivity | Cdor | Flammability of Explosive limits | 다. 원 | |
|------------|--------------|-------------------------------------|--|--|--------------------------------------|---|----------|-------------|------|-------------------------------------|---------|--|
| Agr Da | icul dust | twre ry | | | | | | | | | | |
| 1. | 71+ 4. | ld burning Rye-grass field | | | | CO ₂ , CO, R ₂ , G ₂ , hydrocarbons, NO _X (see Tables 8-6, 8-7 for more de- tailed data) | 00+100 | | | | | |
| 2. | Ore 4. | in elevators Railroad car | | Ambient | | | | | | | | |
| | b. | londing Cleaning | Milo and malted barley cleaner (a) 2.6-3.7 (b) 6.8-40 | Ambient | | | | | | | | |
| | ¢. | Drying | | | | | | | | | | |
| 5. | Flo | ur mill | | | | | | | | | | |
| ♦ . | Fea A. | d mill Feed barley hazmermill | (a) 3.8 (b) 66 (1 mill) | | | | | | | | | |
| 5. | Alf | alfa dehydrat+ | | | | | | | | | | |
| | | Primary cool- ing cyclone | (a) 8-15 (b) 450-620 | Dry 5116, 340 Wet 5216, 152-175 | 0.174-0.48** daw point 144-172 | 0 ₂ , N ₂ , CO ₂ | | | | | | |
| | Ъ. | Becondary cool- ing cyclone | (a) 1.1-1.8 (b) 64-74 | Dry bulb, 125-140 Wet bulb, 85-67 | dew point 68-75 | | | | | | | |
| | c. | Air meal separator | (a) 2.5-6.4 (b) 168-250 | Dry bilb, 85-139 Wet bilb, 75-90 | 0.016-0.02** dew point 72-78 | | | | | | | |
| | d. | Pellet meal mir separator | (⊾) 3.8-4.9 (b) 100-120 | Dry bulb, 110-127 Wet bulb, 94-95 | 0.027-0.033** dew point 82-93 | | | | | | | |
| | | Pellet regrind separator | (m) 1.0 (b) 9.5 | Dry bulb, 120 Wet bulb, 90 | 0.024** dev point B2 | | | | | | | |
| 6. | Cot | ton ginning | | | | | | | | | | |
| | ∎. b. | Gin Incinerator | (b) 2.7-1.5 | | | Air CO2, CC, N2, D2, areanic compounds and other gates characteristic of cotton wate pyrolysis | | | | | | |

** Pounds/pound.

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ANALYSIS OF AIRBORNE DUST COLLECTED IN VICINITY OF RAILWAY CARS DURING LOADING

| | Percent by | Weight |
|-----------------------------------|------------|--------|
| | Oats | Wheat |
| Organic fraction | 82.2 | 87.2 |
| Inorganic fraction | 17.8 | 12.8 |
| Free silica in total dust | 8.0 | 7.4 |
| Free silica in organic fraction | 2.3 | 1.5 |
| Free silica in inorganic fraction | 5.7 | 5.9 |

TABLE 8-5

PARTICULATE AND PRODUCT ANALYSES (ALFALFA DEHYDRATING MILL)

| | Protein | Carotene |
|--|------------|-----------------|
| | Content | Content |
| Particulate Source pmpany A Air meal separator pmpany B Air meal separator pmpany A Pellet meal air separator pmpany B Pellet meal air separator pmpany C Pellet regrind air separator <u>Product</u> pmpany A, Pellets pmpany B, Pellets pmpany C, Meal | Percentage | <u>(IU/1b)*</u> |
| Company | | |
| company A | 01 02 | 107 000 |
| Air meal separator | 21.20 | 107,600 |
| Company B | | |
| Air meal separator | 21.60 | 77,300 |
| Company A | | |
| Pellet meal air separator | 18.90 | 88,900 |
| Company B | | |
| Pellet meal air separator | 19.25 | 84,900 |
| Company C | | |
| Pellet regrind air separator | 26.60 | 145,900 |
| Product | | |
| Company A Pollets | 15.0 | 100.000 |
| Company R. Pollota | 14 1 | 100,000 |
| Company D, Letters | | 30,000 |
| company c, meal | 17.5 | 132,000 |

* International Unit, IU, for carotene (pro-vitamin A) is defined as the biological activity of 0.6 μg of β-carotene.

YIELDS OF VARIOUS POLLUTANTS FROM GRASSES 1/ BURNED IN LABORATORY TOWER

| | | <u></u> | Poun | ls/Ton | of Gi | rass Burned | 1 | | C | NO_2 at |
|---------------|----------|-------------|-----------------|-----------|-----------------|-------------|----------------|----------|---------|------------|
| | Percent | | | | | Sat.ª/ | | | Balance | Temp. Peak |
| Grass | Moisture | Particulate | ^{CO} 2 | <u>co</u> | <u>C</u> | + Acet. | <u>Olefins</u> | Ethylene | (%) | (ppm) |
| | | | | Durit Se | arios | | | | | |
| | | | | DIY D | 51 T C 2 | | | | | |
| Blue | 5 | 16.5 | 2,786 | 147 | 18 | 3.3 | 3.1 | 2.4 | 107 | 72 |
| Perennial Rye | 6 | 12.0 | 2,483 | 104 | 14 | 2.1 | 3.2 | 1.4 | 100 | 49 |
| Bent | 2 | 14.0 | 2,557 | 124 | 14 | 2.1 | 2.0 | 0.9 | 98 | 21 |
| Annual Rye | 9 | 10.5 | 2,666 | 85 | 8 | 0.9 | 1.2 | 0.6 | 103 | 23 |
| Fescue | 9 | 13.0 | 2,737 | 122 | 12 | 2.5 | 2.4 | 1.2 | 107 | 45 |
| Orchard | 15 | 11.5 | 2,469 | 89 | 7 | 1.2 | 1.2 | 0.7 | 100 | 27 |
| | | | Dr | y-Gree | n Ser: | ies | | | | |
| Blue | 23 | 15.0 | 2,407 | 95 | 8 | 1.0 | 2.0 | ŀ.2 | 111 | 44 |
| Perennial Rye | 71 | 26.0 | 678 | 106 | 19 | 2.4 | 5.6 | 3.4 | 77 | 4 |
| Bent | 60 | 24.0 | 1,277 | 109 | 19 | 2.1 | 5.0 | 3.1 | 94 | 13 |
| Annual Rye | | | | | | | | | | |
| 1 | 20 | 9.0 | 1,855 | 56 | 4 | 0.4 | 1.0 | 0.6 | 103 | 37 |
| 2 | 55 | 11.0 | 969 | 60 | 6 | 0.8 | 2.4 | 1.8 | 102 | |
| Fescue | 66 | 17.0 | 925 | 77 | 9 | 1.2 | 2.6 | 1.8 | 94 | 8 |
| Orchard | | | | | | | | | | |
| l | 66 | 18.0 | 6 4 5 | 86 | 14 | 1.4 | 3.3 | 2.1 | 87 | 12 |
| 2 | 47 | 17.0 | 1,558 | 113 | 16 | 1.7 | 4.0 | 2.3 | 90 | 5 |

.

a/Without methane.

RESULTS OF SUMMER 1967 FIELD BURNS OF VARIOUS GRASSES 1/

| Burn | | Lb. Particulat | e/ Lb. CO/ | Lb. HC/ | Ambient Temp. | R.H. | Wind Speed |
|------------|---------------|----------------|------------|------------------|------------------|------|---------------|
| <u>No.</u> | Grass | Ton Fuel | Ton Fuel | Ton Fuel | <u>(°F)</u> | (%) | (mph) |
| 2 | Blue | 81.23 | 238 | 14.75 | 89.8 | 32 | 9 |
| 3 | Orchard | 15 .54 | 130 | 10.78 | 71.5 | 50 | 6 |
| 4 | Orchard | 8.47 | 140 | 11.18 | 90.2 | 24 | 6 |
| 5 | Perennial Rye | 10.23 | 133 | 10.68 | 70.5 | 61 | 3 |
| 6 | Red Fescue | 1.31 | 102 | 9.1 4 | 79.8 | 64 | 11 |
| 7 | Red Fescue | 12.65 | 120 | 9.90 | 88.0 | 34 | 0 |
| 9 | Perennial Rye | 8.78 | 118 | 9 .4 1 | 80.0 | 51 | 2 |
| 10 | Perennial Rye | 8.75 | 107 | 9.41 | 80.0 | 62 | 1 |
| 11 | Red Fescue | 5.24 | 126 | 10.02 | 84.0 | 64 | 12 |
| 12 | Annual Rye | 3.33 | 108 | 10.27 | 100.0 | 24 | 9 |

8.4 ALFALFA DEHYDRATING MILLS

Dehydrated alfalfa is a meal product dried rapidly by artificial means at temperatures above 212°F. The general method of operation is to harvest the alfalfa with a self-propelled or tractor-drawn chopping machine. The chopped alfalfa is then transported as quickly as possible to the dehydrating plant where it is dumped onto an automatic feeding device and fed into a dryer at a uniform rate. Practically all of the dryers are of the direct-fired, rotary type. The products of combustion leave the combustion chamber of the furnace (most units are gas- or oil-fired) at a . temperature in the neighborhood of 1800 to 2000°F. The chopped, wet alfalfa is discharged from the feeder into this hot flue-gas stream which is being pulled through the dryer by a fan at the outlet end. After passing through the rotating drum section, the moisture content of the material will be in the neighborhood of 7 to 9% and the flue-gas temperature will be 250 to 350° Customarily, the material is then blown to a primary cooling cyclone in which the dried material is separated from the now moisture-laden flue-gas stream. The effluent from this cyclone (Figure 8-1), usually billowing clouds of condensed steam, is the first of a series of atmospheric emissions from the alfalfa dehydrating plant.

From the primary cooling cyclone, the dehydrated alfalfa is passed through a secondary cooling cyclone, a grinder, and finally a third cyclone which collects the meal for bagging, bulk storage or pelletizing.

To minimize storage and shipping space requirements, the meal is often steam-extruded into pellets which are subsequently air cooled. The coolant air entrains small pellet chips and unpelletized meal. This particulate matter is then separated from the coolant air stream and recycled to the pelletizer. Separation is accomplished in a fourth cyclone, the pellet meal air separator, which constitutes a potential source of air contamination.

For formula feeds the pellets are reground, an operation found only in the larger dehydrating mills. This process consists of conveying the pellets from storage to a hammer mill, grinding the pellets into a meal, and pneumatically conveying the meal to the pellet regrind air separator, and thence to the blender, bagging equipment, or to bulk shipping facilities. The discharge from the pellet regrind air separator is a possible source of air pollution. $\underline{7}/$

8.4.1 Emission Sources and Rates

Objectionable emissions from alfalfa dehydrating plants include dust from the various separators, and odors from the volatile matter driven off the alfalfa with the moisture and combustion products emitted



Figure 8-1 - Alfalfa Dehydrating Process Flow Diagram7/

to the atmosphere.⁷/ Emission rates from alfalfa dehydrating plants are summarized in Table 8-2. Particulate emissions currently total about 23,000 tons/year.

8.4.2 Effluent Characteristics

Table 8-3 summarizes available data on the chemical and physical properties of effluents from alfalfa dehydrating plants. The average Stokes' diameter of emitted particulates ranges from 1.5 to 10μ .

8.4.3 Control Practices and Equipment

Alfalfa dehydrating operations are a source of pollution in some areas. The primary and secondary cooling cyclones, and air meal separators which are a part of the process, are the major pollution sources. Control equipment such as multitube collectors and bag filters has been used as auxiliary dust separators on the air meal separator. However, the cil additive that is sometimes used in the dehydrating process causes clogging of bag filters. Other methods suitable for control of effluents discharged to the atmosphere include incineration and electrical precipitation, but in general these are more costly than bag filter units. $\frac{7}{}$

8.5 COTTON GINS

Modern cotton ginning installations using pneumatic conveying equipment, air blast equipment, and seed cotton conditioning equipment have increased the output of normal ginning operations and improved cotton fiber quality. This gain in output has been accompanied by a major increas in the volume of air bearing lint and dust discharged to the atmosphere. Although the discharge of waste material to the atmosphere from an individual cotton ginning operation generally results in only a local air pollution problem, the number of such establishments and the gradual urban encroachment into the areas of ginning operations is sufficient to warrant consideration of their overall pollution potential. $\underline{8}/$

Figure 8-2 illustrates a flow diagram for a cotton gin used by the Department of Agriculture to study particulate emissions from ginning operations. This particular operation is considered to be representative of ginning operations in general.⁸/ The flow diagram indicates the following major sources of particulate emissions: unloading fan, six-cylinder cleaner, stick and bur machine, gin stand, separator No. 2, seven-cylinder cleaner, separator No. 3, and the condenser. The unloading fan supplies the air for the transfer of cotton from the storage bins or from a wagon to the first separator. These wastes are carried to the dust house by the



Figure 8-2 - Flow Diagram of U. S. Department of Agriculture Cotton Gin, Stoneville, Mississippi8/

moving air stream and consist mostly of sand, dirt, and other fine materials. The dust house is a tall structure open at top and sometimes also open at bottom and it acts as a settling chamber or elutriator.

The cotton then passes from the first separator onto the feed control, into the tower dryer, through a boll trap, and then to the sixcylinder cleaner which opens and cleans the boll cotton. The waste discharge from the six-cylinder cleaner is carried to the dust house by a moving air stream and consists of fine particles of leaf trash, dirt, sand, stems, and small sticks. From the cleaner the cotton is moved to the stick and bur machine which removes burs, sticks and stems, together with fine trash not removed by the cylinder cleaner. The discharge duct from the stick and bur machine joins with the air discharge duct from the gin stand. Wastes from these sources are carried to the dust house.

From the stick and bur machine the cotton passes to a second separator, then to a stub tower dryer, and then to a seven-cylinder cleaner. The discharge from the second separator is emitted directly to the atmosphere outside the building. These wastes, carried through the separator, consisted mainly of fine particles of leaf trash, dirt, sand and stems.

The waste discharge from the seven-cylinder cleaner is carried to cyclones. These wastes consist mainly of sand, trash, and dirt.

The seed cotton then passes from the seven-cylinder cleaner on a belt distributor to the extractor-feeder and then to the huller front gin stand. The trash from the gin stand (burs, sticks, stems, motes, and sand) is combined with the waste discharge from the stick and bur machine and blown to the dust house.

From the gin stand the cotton is transferred first to a separator which removes fine leaf particles, motes, dust, and sticks, which are discharged directly to the atmosphere outside the building. The cotton next travels to the lint cleaner, and then to the condenser which discharges sand and dirt to the dust house. From the condenser the cotton goes to the baler and out as a finished product.

8.5.1 Emissions

Data on atmospheric emissions from cotton ginning operations are limited in scope. Reference 8 presents data from a study conducted at the Cotton Ginning Laboratory, Agricultural Research Service, U.S.D.A., Stoneville, Mississippi. This operation was considered to be representative of ginning operations in general, and the cotton harvested by both machineand hand-picked methods and processed during testing was representative of the cotton from the test area. $\frac{8}{2}$ The ginning operation and subsequent incineration of the waste can release pesticide residues, bacteria, benzene-soluble organic matter, and arsenic compounds to the atmosphere. Paganini⁹/ reported data on particulate matter collected upwind and downwind from cotton gins.

The bacteria and fungi counts in samples taken upwind were 88 to 100 and 33 to $70/m^3$ of air, respectively, when collected on nutrient agar. The counts in samples taken downwind ranged from 172 to 1,752 and 19 to $129/m^3$ of air, respectively.

Smoke emitted from incineration of cotton gin waste was found to contain significant amounts of benzene-soluble organic matter and arsenic, and to reduce visibility to such an extent at times in some locations that driving was hazardous on the highway.

Emission rates from cotton ginning are summarized in Table 8-2. Particulate emissions currently total 45,000 tons/year.

8.5.2 Effluent Characteristics

Available data on the chemical and physical properties of effluents from cotton ginning operations are summarized in Table 8-3. The concentrations of arsenic, pesticides, and defoliant in effluents from various phases of the ginning operation generally exceed many times the concentration found in natural ambient air.

8.5.3 Control Practices and Equipment

The ginning operations employ small-diameter cyclones for removal of dust, trash, fibers, etc. The small-diameter cyclone that came into widespread use several years ago has proved effective. It creates more static pressure but its higher efficiency makes up for this increased cost of operation. $\frac{10}{}$

It is standard practice to place all but one of the cyclones in a battery beside the gin building. They all discharge into a screw conveyor that has a dust-tight cover. The conveyor in turn discharges trash through a conventional dropper into an air line that conveys it to a bur house or incinerator. The air from one of the gin's fans, preferably the fan handling the lint cleaner's trash, is used for this purpose, because this fibrous material has a tendency to choke a conveyor. In some areas the dust coming from the exhaust of the cyclones may be objectionable and further filtering may be necessary. This can probably best be accomplished using an in-line filter or other commercial type filter. $\frac{10}{2}$ A guide in selecting the proper cyclone arrangement and dimensions for normal gin plant installations is given in Reference 2. This guide also describes the sizing of lint fly catchers and in-line air filters. The in-line air filters have proven to be over 99% efficient in the collection of trash and fly (see Figure 8-3).11/

Another source of emissions is the incinerators at cotton gins which have been in use for many years for the purpose of burning burs, sticks, stems, leaf trash, and motes. $\frac{11}{2}$

The concentration of particulates which exit the cyclone collector on a seven-cylinder cleaner has been found to be as low as 0.005 grains/scf for a 34-in. diameter high-efficiency cyclone. $\frac{12}{}$

8.5.3.1 <u>Control Equipment</u>: The methods available to the ginner for removal of particulate matter and lint fly from this discharge air are limited by economic and practical reasons to the following, listed in order of increasing capital investment. $\frac{13}{2}$

8.5.3.1.1 Gravity or settling chamber: Air is introduced into a large enclosure to lose velocity and drop out particles prior to discharge of air. The condenser exhaust "dog house" is an example. Condenser exhaust air introduced into large chambers with screened sides has been observed to operate satisfactorily where 14 x 18 mesh screen wire was employed. It is not believed that settling chambers alone are feasible for use on air exhausts other than from the condensers because of the greater dust loads from other gin exhausts. $\frac{13}{2}$

In some instances, use of settling to remove larger particles prior to passage of air through a cyclone collector unit will reduce the load on the cyclone and increase its collection efficiency.

8.5.3.1.2 <u>Cyclones</u>: The cyclone collector is widely used in cotton gin emissions. Its first cost compares favorably with other types of collectors. It is simple, rugged, has a low operating cost, and requires little attention. The cyclone will operate very well under surprisingly wide limits. However, careful sizing must be done to avoid excessive pressure drop and at the same time provide for the most efficient collection of dust and lint.

The smaller the cyclone, the greater the efficiency; therefore, it is recommended that multiple, parallel units be used rather than one larger cyclone. Sizing of cyclones is described and illustrated in References 11 and 13.



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Figure 8-3 - In-Line Air Filter - Cotton Gin11/

8.5.3.1.3 <u>Scrubbers</u>: The use of settling chambers with adequate water sprays or tanks has been observed to operate very well in some instances. However, care must be taken that water disposal does not become a problem. $\frac{13}{}$

8.5.3.1.4 Lint fly catchers and filters: All of the lint fly units permit a build-up of lint on the screen and this provides additional filtration. Each of these units must be of sufficient size and properly installed and maintained to prevent back pressure build-up on the system they serve.

Cloth filters are efficient collection devices and various commercial units are available. The cost of proper installation of filter units is high because sufficient particle arrestment capacity must be provided to allow shutdown of portions of it at intervals for cleaning. $\frac{13}{2}$

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CHAPTER 9

IRON AND STEEL INDUSTRY

9.1 INTRODUCTION

The manufacture of iron and steel involves many different processes until semifinished products are available for sale or further use. Some of the processes produce large quantities of particulates and gaseous emissions, while other processes are relatively free of air pollution problems. The pyrometallurgical processes inherent in the iron and steel manufacturing processes emit a very fine-size particulate material.

The major sources of particulate air pollution are: sintering plants, coke-oven plants, blast-furnace operations, steel-making furnaces (especially those using large amounts of oxygen for steel making), and materials-handling operations.

The manufacturing process, particulate emission sources, emission rates of individual sources, chemical and physical properties of the effluents, control practices, and control equipment are discussed in the following sections.

9.2 IRON AND STEEL MANUFACTURING

A composite flow diagram for an integrated iron and steel plant is shown in Figure 9-1. The diversity of the operations and the myriad emission sources are apparent. A compilation of potential emission sources is presented in Table 9-1. The numbering sequence corresponds to that shown in Figure 9-1.

A detailed discussion of manufacturing processes has been presented in a recent NAPCA report and those seeking more information on the individual processes are referred to it. $\frac{1}{2}$ Emission rates from individual sources are discussed in the following sections.

9.3 EMISSION RATES FROM IRON AND STEEL MANUFACTURE

9.3.1 Sinter Machines

Sintering machines generally accept and process a wide variety of feeds and produce a considerable quantity of emissions of variable quantity and nature.^{1/2} Emissions from sinter plants vary widely in quantity

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Figure 9-1 - A Composite Flow Diagram for a Steel Plant

114

TABLE 9-1

POTENTIAL PARTICULATE POLLUTANT EMISSION SOURCES IN IRON AND STEEL MANUFACTURING

Source

Particulates

| 1. | Ore crushing | Ore, coal and limestone dust |
|------|--|--|
| 2. | Materials handling and stockpiles | Ore. coal and limestone dust |
| 3. | Pelletizing dryer | Ore and coal dust |
| 4. | Sinter machine (a) Windbox (b) Discharge end | Iron oxides, calcite, iron calcium silicates, and quartz |
| 5. | Sinter machine screen | • |
| 6. | Sinter cooler | |
| 7. | Coke ovens (a) Charging (b) Coking (no by-product recovery) | Coal, smoke, and coke |
| 8. | Coke quenching tower | |
| 9. | Coke by-product recovery | Hydrocarbon vapors and/or mists |
| 10. | Blast furnace (a) Charge (b) Heat | Iron oxides, coke, and limestone |
| | (c) Tap | Kish |
| Stee | 1-Making Furnaces | |
| 11. | Open hearth | Iron oxides, lime, kish, silica |
| 12. | Basic oxygen | |
| 13. | Electric-arc | |
| | (a) Channel Dentioulate emitted | |

- - (a) Charge Particulate emitted
- (b) Heat
- (c) Tap during these stages
- 14. Scarfing
- 15. Pickling
- from each furnace
 - Iron oxide
 - H₂SO₄, HCl fumes, Water-oil mist

and particle size and depend upon, among other things, raw mix composition, types of machines, and exhaust-fan characteristics.

Sinter machine emission sources can be divided into two categorie. (a) windbox emissions, and (b) discharge-end emissions. Windbox emission dusts are mainly generated early in the sintering process, and again later, when the flame front has reached the bottom of the bed. Emissions from the discharge end parallel those of the windbox on a basis of pounds emitted per ton of sinter. However, grain loadings are higher at the discharge end

9.3.2 Coke Ovens

Metallurgical coke is the major fuel and reducing agent used in the production of blast furnace hot metal, and will probably be the major fuel and reductant for many years in the future. Beehive coke is still made to a limited extent, but 99% of coke production utilizes the by-product coke oven.

During the manufacture of coke and during the processing of coke by-products, emissions are generated in several locations and operations: (1) coal handling; (2) oven charging; (3) oven operation, pushing and quench ing; (4) coke handling; and (5) by-product processing. Most of the particulates escape during the charging and discharging (i.e., pushing) operations. At the end of the coking cycle, the incandescent coke is transferred from the oven into a quenching car by a hydraulic ram. The quantity of smoke rising from the mass during the period required to transport the coke to the quenching station is dependent upon the degree of coking. Incompletely carbonized coke gives rise to considerable quantities of smoke; conversely, thoroughly carbonized coke gives rise to very little smoke.²/

9.3.3 Blast Furnace

The blast furnace is one of the largest chemical reactors used by industry. It acts as a counter-current reactor in which solid materials descend by gravity from the top and react with gases generated near the bottom.

Iron ore, fluxes, and coke are charged into the top of the furnace through a succession of two of three seals that serve to limit leakage of gas at this point. Freheated air (sometimes sugmented with oil, gas, oxygen or steam) is forced through ports (tuyeres) arranged radially near the bottc of the furnace and just above the hearth. The incoming air and admixed additives react between themselves and with the hot coke to generate a reducing gas rich in hydrogen and carbon monoxide, at a flame temperature of up to 3500°F. The hot reducing gases liberate some of their heat to melt the iron and slag, then continue upward to carry energy and chemical potential to the unreduced ore in the upper part of the furnace. Molten iron and slag drip down into the hearth and are tapped intermittently through special ports.2/

Two emissions come from the top of a blast furnace: top gas and the dust which it entrains. The top gas is a mixture mainly of steam, nitrogen, carbon monoxide, and carbon dioxide. On a dry basis, this gas may average 25 to 30 vol. % carbon monoxide. Emissions to the atmosphere occur from leakage around hoppers and seals. Top gas may leak from openings such as ports for rods used to determine the height of the charge materials inside the furnace. Dust entrained in the top gas is a result of the abrasion sustained by the burden materials during charging and during the initial stages of passage down the blast furnace. It is possible to minimize particulate emissions by choice of raw materials and sound operating practices, and thereby to reduce the load on the dust-cleaning system. $\frac{1}{2}$

9.3.4 Steel-Making Furnaces

9.3.4.1 Open-Hearth Furnaces: Particulate and gaseous emissions from the open-hearth process originate from (1) the physical action of the flame on the charged materials and the resulting pickup of fines, (2) the chemical reactions in the bath, (3) the agitation of the bath, and (4) the combustion of fiel. $\frac{1.3.4}{}$ The amount of dust generated during the open-hearth process varies according to the different stages of the process and according to operating practices. Oxygen lancing produces more particulate emissions than open-hearth practice without lancing.

A typical heat is composed of 60% hot metal and 40% scrap, and usually proceeds as follows: the bottom of the furnace is first built up with dolomite and the burners are fired. The furnace is then charged with limestone and steel scrap. The time required for this charging and meltdown of the scrap varies between 2 and 4 hr., depending upon the furnace size and the ratio of hot metal to scrap. The hot metal is added when the scrap is partially melted. Decomposition of the limestone begins when the temperature of the bath increases. The release of carbon dioxide gas from the limestone increases agitation in the bath. After the lime boil has been completed and the lime solution is in the slag, the rate of decarbonization increases. When gaseous oxygen is used for decarbonization, the flow of oxygen is started after the addition of hot metal.²/

Fume generation from the open hearth occurs during the charging, melting, and refining phase. Emission rates vary considerably during the process cycle, and quite likely vary from cycle to cycle depending on the quality of the scrap charged into the furnace. For the furnace utilizing oxygen-lancing (i.e., impinging stream of high-velocity oxygen), Reference 5 gives a dust loading of 0.78 grain/scf at 60,000 scfm gas flow at meltdown, 1.9 grains/scf at 64,000 scfm at hot metal addition, 2.70 grains/scf at 66,000 sofm at the lime boil, up to 5 grains/sof during oxygen lancing and 0.21 grain/sof at 64,000 sofm during refining.

9.3.4.2 <u>Basic Oxygen Furnaces</u>: Basic oxygen furnaces (BOF) are becoming the principal method of making steel in the U. S. In basic oxygen steel-making, the need for a large-surface bath (such as is required in open-hearth steel-making) is overcome by forcing a jet of high-purity oxyge below the surface of the metal. The jet also provides violent agitation, and therefore increases the area of the slag-metal interface. The BOF proc is exothermic to the extent that up to 30% (or more) of steel scrap can be melted, using as fuel only the carbon and other metalloids dissolved in the metal. No conventional fuel is added. In terms of emissions, the sulfur dioxide and unburned hydrocarbons associated with open hearths are nonexistent with BOF furnaces. 1/

In the initial stage of basic oxygen steel-making, the charging of carbon-saturated hot metal upon cold scrap results in a release of kish as the molten iron is rapidly cooled. Only a part of this kish is contained by the furnace vessel. The initiation of oxygen blowing is marked briefly by a heavy dark-brown smoke (caused by the direct burning of iron). This smoke persists until the metalloids begin to oxidize and refining begins.

As most of the metalloids become oxidized, the oxidation of carbo increases to consume the rest of the oxygen blown, and the volume of gas leaving the furnace mouth increases noticeably. An excess of air often is permitted to mix with the exhaust gases as they pass into the fume-exhaust system. The use of excess air is a safety precaution to prevent the existence of a high carbon monoxide content in the flue system, and eliminate a possible explosion hazard.

During the oxidation of carbon, the fuming appears to be limited to iron dust either from iron vaporized from the bath or as iron droplets ejected by the carbon monoxide rising from the molten bath. Factors that determine the amount of fumes generated during the blowing process include the type of oxygen lance used, the velocity of the oxygen, the carbon content of the iron, and the temperature of the iron. $\underline{1}/$

9.3.4.3 <u>Electric-Arc Furnaces</u>: Emissions generated during electri furnace steel-making originate from the physical nature of scrap used, scra cleanliness, the nature of the melting operation, and oxygen lancing. Fume and particulate are emitted from the furnace during the charging and refini operations. During the charging period, the top of the furnace is opened to charge cold metal. Exposure of the cold charge to high temperatures wit the furnace results in the generation of large quantities of fume. Fume emissions can be affected by the sequence of charge additions to the furnace The method of refining also has a pronounced effect on fume emission. An oxygen lance leads to higher fume release rates because of the breaking of the slag film and because of the high temperatures reached during the lancing stage.

The nature of the material charged also has a marked influence on emission rates. Thin steel scrap will oxidize easily, and result in heavy fuming and a high metal loss during melting in electric-arc furnaces. Dirty scrap is a major source of emissions. Electric furnaces melting dirty scrap can generate as much dust as an electric furnace with oxygen lancing. \underline{L}

9.3.5 Scarfing Operations

Before steel can be rolled, surface defects in the bloom, ingot, and billets must be removed. The scarfing operation removes these defects. Jets of oxygen are directed at the surface of the steel, which is maintained at high temperature, causing localized melting and subsequent oxidation of the steel.

9.3.6 Summary of Emission Rates From Iron and Steel Manufacture

Table 9-2 summarizes the emission rates from the various operations that comprise the manufacturing cycle for iron and steel. Particulate emissions currently total about 1.4×10^6 tons/year. Furnace operations, sinter machines, coke manufacture, and material handling operations are the dominant sources of particulate emissions. Emissions from the material handling operations were calculated using engineering estimates of average efficiency of control devices and degree of application of control.

9.4 CHARACTERISTICS OF EMISSIONS FROM IRON AND STEEL MANUFACTURE

Table 9-3 presents a summary of the chemical and physical properties of the effluents from the various processes involved in the manufacture of iron and steel. The nature of the emissions is highly variable. The pyrometallurgical steps present distinct control problems because of the generation of very fine particulate matter. Emissions from open-hearth, basicoxygen, and electric-arc furnaces may consist entirely of submicron metallic fumes and particulates.

The variation in resistivity of open-hearth furnace fumes shown in Figures 9-2 to 9-5 gives an indication of the data spread for this type of data. This variation is to be expected because of the different compositions of the heats, especially varying concentrations of limestone. Therefore, wherever the resistivity exceeds a value of about 2×10^{10} ohm-cm, in-situ measurements should be made.

Data on particle shapes, which could not be readily presented in tabular form are detailed in the following paragraphs.

TABLE 9-2

PARTICULATE EMISSIONS IRON AND STEEL INDUSTRY

| | Source | Quentity of Material | Emission Factor | Effici- ency of Control C _c | Applics- tion of Centrol C _t | Net Control C _c ·C _t | Emiss' (tons/y |
|------|--|---|-----------------------------------|---|--|--|-------------------|
| I. | Ore Crushing | E2,000,000 tons of iron ore | 2 lb/ton of ore | C .0 | c.0 | c.c | 82,00 |
| 11. | Materials Handling | 131,000,000 tons of steel | 10 1b/ton of steel | 0.90 | 0.35 | 0.32 | 446,00 |
| | A. Loading-Unloading, Freight Cars, Barges, Ore Boats | | • | | | | |
| | 1. Cre and ore fines | | - | - | - | - | - |
| | 2. Clay (bentonite) | | - | - | - | - | - |
| | 5. Limestone | | - | - | - | - | - |
| | 4. Coal | | - | - | - | - | - |
| | Scrap metal Conveyors | | - | | | - | |
| | 1. Transfer points | | - | - | - | - | - |
| | Discharge to bins stockpiles | | - | - | - | - | - |
| | C. Elevators | | | | | | |
| | 1. Boots | | - | - | - | - | - |
| | 2. Heads | | - | - | - | - | - |
| III. | Pellet Plant | 50,000,000 tons of pellets | | | | | 80,00 |
| | A. Grate Feeder | | - | - | - | - | - |
| | B. Dryer | | - | - ' | - | - | - |
| | C. Kiln | | - | - | - | - | - |
| IV. | Sinter Plant | 81,000,000 tens of sinter | | | | | |
| | A. Sintering Process | | 20 lb/ton sinter | 0.90 | 1.0 | C.90 | 51,00 |
| | B. Crushing, Screening, | | 22 lb/ton sinter | 0.90 | 1.0 | C.90 | 56,00 |
| | Cooling | | | | | | |
| ۷. | Coke Manufacture | | | | | | |
| | A. UVens Bashiwa | 775 200 forst of | 200 lb/top of coa! | 0.00 | 0.00 | 0.00 | 130.00 |
| · | I, DEENIVE | coke - 1,300,000 tons of coal | | | | | 200,00 |
| | a. Charging | | - | - | - | - | - |
| | b. Coking | | - | - | - | - | - |
| | c. Pushing | | 0.08 lt/ton of coal | - | - | - | - |
| | 2. By-Product | 63,700,000 tons of coke - 90,000,000 tons of coal | 2 lb/ton of coal | 0.00 | 0.00 | 0.00 | 90,00 |
| | a. Charging | | - | - | - | - | - |
| | b. Coking | | | - | - | - | - |
| | c. Pushing | | 0.08 lb/ten of coal | - | - | - | 4,00 |
| | B. Quenching Tower | | 0.38 lb/ton of coal ^{B/} | - | - | - | 17,00 |
| | C. Grinder | | - | - | - | - | - |
| | D. Screen | | - | - | - | - | - |
| | E. By-Product Recovery Plant | | - | - | - | - | - |

| | Source | Quantity of Material | Emission Factor | ency of Control | tion of Control | Net Control $C_c \cdot C_t$ | Emissions (tons/year) |
|-------|---------------------------------------|---|-------------------------------|--------------------|--------------------|-----------------------------------|--------------------------|
| VI. | Blast Furnaces | 88,800,00 tons of pig iron | | | | | |
| | A. Charge | • – | - | - | - | - | - |
| | B. Hest | | - . | - | - | - | - |
| | C. Tap | | , - | - | - | - | - |
| | | | 130 lb/ten of pig iron | 0.99 | 2.00 | 0.99 | 58,00G |
| VII. | Steel Furnaces | | | | | | |
| | A. Open Hearth | 65,800,000 tons of steel | | | | | |
| | No oxygen lancing | 3 | | | | | |
| | a. Charge | | - | - | - | - | - |
| | b. Heat | | - | - | - | - | - |
| | c. Tap | | - | - | - | - | - |
| | | | 0 lb/ton of steel | - | - | - | - |
| | Oxygen lancing | | | | | | |
| | a. Charge | | - | - | - | - | - |
| | c. Heat | | - | - | - | - | - |
| | c. Tar | | | - | - | - | - |
| | B. Basic Cxygen (BOF) | Average for open hearth 48,000,000 tons of | 17 lb/ton of steel <u>b</u> / | - C.97 | 0.41 | - 0.40 | 337,000 |
| | | stecl | | | | | |
| | - Charge | | • | - | - | - | - |
| | 2. Heat | | - | • | - | - | - |
| | 5. TBO | | - | - | - | - | - |
| | C. Electric Arc | 16,800,000 tons of steel | AC 10/ton of sceet | 5.55 | 1.00 | 0.99 | 10,000 |
| | 1. Charge | | - | - | • | - | - |
| | 2. Heat | | - | • | - | - | - |
| | 3. Cap | | - | - | - | - | - |
| | | | 10 lb/ton of steel | C.99 | Ç.79 | 0.78 | 18,000 |
| VIII. | Scarfing | 131,000,000 tons of steel | 3 lb/ton scarfed | 0.90 | 0.75 | 0.63 | 63,000 |
| IX. | Pickling | | - | • | - | - | - |
| | | | Total for Iron and Stee. | 1 | | | 1,442,000 |

TABLE 9-2 (Concluded)

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TABLE 9-3

EFFLUENT CHARACTERISTICS - IRON AND STEEL INDUSTRY*

A. Particulate (Part I)

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| | Source | Particle Size | Solids Loading | Chemical Composition | Perticle Density | Electrical Properties | Moisture <u>Content</u> | Toxicity. |
|------------|---|---|--|---|---------------------|--|----------------------------|-----------|
| Iron | and Steel | | | | | | | |
| <u>a</u> . | Sinter Plant (1) Windbox | 15-45 < 40 9-30 < 20 4-19 < 10 1-10 < 5 Also see Figure 9-2 | C.2-3.2 | Fe ₂ O ₃ : 45-5C SiO ₂ : 3-15 CaO: 7-25 MgO: 1-10 Al ₂ O ₃ : 2-8 C: 0.5-5 S: 0-2.5 Alkali: 0-2 | | See Figures 9-3, 9-4 and for detailed date | 9-5 | |
| | (2) Discharge end | 8C < 100, 10 < 1C (cne sample) | 1-5 | Fluorides | | See Table 9-4 for data | | |
| b. | Coke Oven (1) Quench tower | 95-97 > 47 | c.c5-0.1 | Coke balls, coal dust, pyrolytic carbon | | | | |
| | (2) Oven charging | | 1-15 | Coal dust | | | | |
| с. | Elast Furnace | Highly veriable 15-90 < 74 | 4-30 7-10 (avg.) | Fe: 36-50 Fe0: 12-47 S10 ₂ : 8-30 A1203: 2-15 MgC: 0.2-5 C: 3.3-15 Ce0: 3.8-29 Hen: C.5-1.0 P: 0.03-0.2 S: 0.2-0.4 | 3.4 | | | |
| d. | Open-Hearth Purnace (No oxygen lance) *(1) Charge to hot metal *(2) Hot metal to line up *(3) Lime up to tag *(4) Tap to charge **(5) Composite for heat | 50 < 5 Electron microscope 0.01-0.5 Mean count size: 0.03; Mass median: 0.65 | 0.55 0.61 0.18 0.1-3.5 (de- pendent upon stage of heat) avg. for heat, 0.4 | Fe ₂ O ₃ : 85-90 Small amounts of other metallic oxides re- flecting charge com- position SiO ₂ : 0.5-0.7 CaO: 0.85-1.0 MnO: 0.6 P ₂ O ₅ : 0.5-1.2 S: 0.4-1.0 Loss on ignition: 1.1 Fluorides | 5.0 | Eee Figures 9-6 - 9-10 for detailed data | | |

Data from one plant only.
* Data from several plants.
* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 9-3 (Continued)

A. Particulate (Part I) (Continued)

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| | Source | Particle Size | Sclids Londing | Chemical Composition | Particle Density | Electrical Properties | Moisture <u>Content</u> | Toxicity |
|----|---|--|--|---|---------------------|---|----------------------------|----------|
| d. | Open-Hearth Furnace (xxygen lance)(Conclu- ***(1) Charge to hot metal ***(2) Hot metal to line up ***(3) Lime up to tap ***(4) Tap to charge **(5) Composite for heat | uded) Variable, de- pendent on stage of heat a. Lime boil 45 < 2 75 < 5, 92 < 10 b. Composite 20 < 2 45 < 5 69 < 10 Number count: ~ 100 < 0.1 | 0.25-0.78 0.45-1.90 0.8-2.7 0.21-0.87 0.2-7.0 (dependent on stage of heat) Avg. for heat: 1.5 | Fe ₂ 0 ₃ : 80-90 Fe0: 0.3-3.2 Si 2_2 : 0.4-2.0 Al ₂ 0 ₃ : 0.2-0.7 Ca0: 0.6-1.9 Ma0: 0.3-1.0 F2 ₀ 5: 0.5-1.5 Mg0: 0.4-1.1 S: 0.4-3.0 | 5.0-5.2 | See Figures 9-6 - 9-10 for detailed data | | |
| с. | Besic Oxygen Furnace (1) Composite for heat (2) Transfer of hot metal from bottle car to charging ladle (KISH) | <pre>85-95 < 1 Electron micrograph: count median diameter C.Cl2 Mess median diameter, 0.095 Geometric devia tion, 2.3 35 > 149 54 > 74 84 > 10 97 > 1</pre> | 2-10 | <pre>Typical composition Fe205: 9C FeC: 1.5 Mn: 0.4-1.5 SiC₂: 1.3-2.0 Al₂C₃: 0.2 CaC: 3-5 MgO: 0.6-1.1 F₂O₅, C, SiO₂ Fe₂O₅, CaC, MgO, S</pre> | 3.44 | See Figures 9-9, 9-10 and 9-11 for detailed data | | |
| f. | Electric-Arc Furnace (1) No oxygen lence (composite for heat) | Highly variable, but generally 6C < 5 BAHCO analysis 6E < 5, 54 < 10 95 < 20, 99 < 40 | , 0.1-2.2 | Variable, dependent on nature of charge Fe ₂ C ₃ : 19-44 Fe ₀ : 4-10 Cr ₂ O ₃ : 0-12 SiO ₂ : 2-9 Al ₂ O ₃ : 1-13 Ce ₀ : 5-22 MgO: 2-15 MgO: 2-15 ZnO: 0-44 CuO: 0-1 NiO: 0-3 FbO: 0-4 C: 2-4 Alkelies: 1-11 S: 0-1 P: 0-1 | 3.8-3.9 | Apparent re- sistivity 6 x 10 ⁵ - 6.6 x 10 ⁻³ ohm-om (de- pendent or chemical com- position) Also see Figure 9-9 | | |

*** Data from three plants.

TABLE 9-3 (Continued)

A. Particulate (Part 1) (Concluded)

| | Source | Particle Siz | e <u>Sclids Loadi</u> | ing <u>Chemical</u> | Composition | Particle Density | Electrical Properties | Moisture <u>Content</u> | Texicity |
|-----------------|---|--|---|-----------------------------|-----------------------------------|--------------------------------------|---|----------------------------|-----------------------|
| f. E (| Clectric-Arc Furnac 2) Oxygen lance (composite for heat) | e (Concluded) | 1-10 | Similar lance co | to no C ₂ mposition | 3.9-4.0 | | | |
| g. M (| tiscellaneous 1) Scarfing machi | ne | 0.4-4.4 Commonly use values 0.4-0 | Mostly F ad 0,8 | eS03 | | See Figure 9-9 | | |
| A. <u>Psr</u> | ticulate (Part II) | | | | | | | | |
| | Source | Solubility | F Wettability <u>Cha</u> | ivgroscopic mecteristics | Flemmability of Explosive Limi | er <u>ts Handli</u> | ing Characteri | istics | Optical Properties |
| Iron en a. S | <u>d Steel</u> Sinter pl <u>e</u> nt | CaO - s. H ₂ O CaO, SiO ₂ , Pe ₂ O ₃ , Al ₂ O ₃ - s. 1C≸ HCl | | | | Hardne Abrasi | ess: 3-5 moh: ve | 5, | |
| Ъ. Е | last furnece | CaO - s. H ₂ CaC, SiC ₂ , Al ₂ C ₃ - s. 10% HCl | 0 | | | Abresi Will & | ve, fluid col arch and bridg | nesive, Ge | |
| c. O | pen-hearth | Fe ₂ 03 - s. 10≸ HCl | Difficult to wet | | | Abrasi repose cohesi and ar | ive, high angl (90 degree ive and will f ch | le of s); vridge | |
| d. 3 f | Basic-Cxygen Jurnace | Fe ₂ 03 - s. 10≸ HCl | Difficult to Wet | | | Atrasi repose cohesi and ar | ve, high angl (~90 degree ve and will b ch | le of s), pridge | |
| e. E f | lieotrio-arc Mirnace | | Difficult to wet | | | Abrasi high a will b | ive, fluid-con angle of repos bridge and arc | nesive, De, Sb | |

B. Carrier Gas

| | Source | Flow Rate | Temperature | Moisture Content | Chemical Composition | Toxicity | Corrosivity | <u>Odor</u> | Flammability or Explosive Limits |
|------------|--|---------------------------|-------------|---------------------|---|---|-------------|-------------|--|
| Eron e. | and Steel Sinter plant (1) Windbox | (m) 30-450 (b) 149-230 | 100-400 | 2-10 | O ₂ : 10-20 CO ₂ : 4-10 CO: 0-6 SO ₂ : 0-0.4 N ₂ : 64-86 Fluorides | SO ₂ - 5 irritant CO - 100 | | | |

TABLE 3-3 (Continued)

B. Carrier Ges (Continued)

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| | So | urce | Flow Rate | Temperature | Moisture Content | Chemical Composition | Toxicity | Corresivity | <u>Odor</u> | Flemmability cr Explosive Limits |
|----|------------------|---------------------------------|---|--|--------------------------|---|---|---|-------------|--|
| 8. | Sinter (2) 1 | r plant (Conci Discharge end | luded) (a) C.C3-0 | .2 100-300 | | | | | | |
| ъ. | Coke ((1) | Oven Quench tower | Of the ord 900 M ft ³ j guench | er 140-150 per | | Steam, air | | | | |
| | (2) (| Oven charging | Of the ord 2.1 M ft ³) charge | er per | | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | • | | | |
| c. | Blast | Furnace | (a) 40-140 (b) 60-138 | 390 at threat 3000 in furnace | 9.6 Dew point, 95-122 | CO: 21-42 ewg. 26 CO ₂ : 7-19 wwg. 16 H ₀ : 1.7-5.7 wwg. 3.1 CH ₄ : C.2-3 N ₂ : SC-60 Iraces: S, H ₂ S, SO ₂ , O ₂ | C0 - 10C S0 ₂ - 5 irritant | | | Explosive due to CO and Hy content |
| d. | Open-H (No ox | earth Furnace ygen lance) | | | | | | | | |
| | *(1) | Charge to | (в) 63.5 | | 17.2 | | | | | |
| | * (2) | Hot metal | (m) 75.2 | | 18.5 | | | | | |
| | *(3) | Lime up to | (a) 70.7 | | 17.2 | | | | | |
| | *(4) | Tap to | (a) 47,6 | | 13.3 | | | | | |
| | **(5) | Composite for heat | (a) 25-10C | 460-1800 (depending on utiliza- tion of waste heat boiler) | 7-15 | CO ₂ : 8-9 O ₂ : 8-9 K ₂ : balance SO ₂ : 2-5 ppm SO ₃ : 100-200 ppm NC _x : 500-800 ppm Fluorides may by emitted due to fluxing age or fluoride co tent of ore (0-300 ppm) | SO ₂ - 5, irritant HF - 3 ent | Potentially corrosive fue to SO ₂ , SO ₃ | | |

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TABLE 9-3 (Concluded)

B. <u>Carrier Gas</u> (Concluded)

| | Source | Flow fate | Temperature | Moisture Content or Condensable Vapors | Chemical Composition | Toxicity | Corrosivity | Odor | Flemma or Ext Lim |
|----|--|--------------------------|--|---|---|---|---|------|---|
| 1. | Cpen-Hearth Furnace (Concluded) (Cxygen lance) +*(1) Composite for heat | (a) 45-200 | 400-2000 (depending on utilize- tion of waste heat boiler) | Varies dur- ing cycle 13-19 avg. 15 | Similar to no O ₂ lance composition | SO ₂ - 5, irritant HF - 3 | Potentially corrosive due to SO ₂ , SO ₃ | | |
| е. | Basic Oxygen Furnac | e | | | | | | | |
| | Composite for heat | (a) 35-250 | 56C-3000 (depending on utiliza- tion of waste heat boiler) | | Before com- bustion with appirated air: a. BOF CO ₂ : 5-1 CO: 74-9 N ₂ : 3-8 b. Kalde Pro CO ₂ : 72. CO: 22.7 N_2 : 4.4 After combus- tion with aspirsted air: a. BOF CO ₂ : C.7 13. CO: 0-0. N_2 : 74.5 76.9 C ₂ : bala | 6 1 жезя 9 5 3 - 5 3 - | | | Highly mable ; to comi tion wi aspirat air |
| f. | Electric-Arc Furnace (in- cludes both unlanced and lanced furnaces) Miscellaneous (1) Scarfing | (s) 10-100 (e) 20-150 | <pre>215-3006 (Dependent on use of cooling techniques)</pre> | C.G45 lb/lb dry ges (1 sample) | Meinly CO ₂ , C O ₂ , and N ₂ Composition v iss with oper ting practice For O ₂ lance composition varies with t Typicel variation: CO: 8-65 CO ₂ : 5-15 N ₂ : 5-85 | С, аг- аг- аг- іте. | | | Flemmet due to contert |
| | machine | | | | | | | | |

** Data from several plants.



Figure 9-2 - Particle Size Distribuiion by Weight of Sintering Machine Dust 36/

127








Figure 9-5 - Electrical Resistivity of Sintering Machine Dust 36/



* Figure shows percent water vapor by volume.

Figure 9-6 - Resistivity of Open Hearth Furnace Fume Under Varying Conditions of Temperature and Moisture in Gasl/



* Figure shows percent water vapor by volume

Figure 9-7 - Apparent Resistivity of Fume from Open-Hearth Furnace1/



* Figure shows percent water vapor by volume Figure 9-8 - Apparent Resistivity of Fume from Open Hearth Furnace1/







* Figure shows percent water vapor by volume.

Figure 9-10 - Electrical Resistivity of Red Oxide Fume From Various Oxygen-Blown Steelmaking Processes $\frac{1}{2}$



Figure 9-11 - Resistivity vs. Gas Temperature for BOF Furnace Dust<u>36</u>/ (Laboratory Measurements)

IRON SINTER DUST RESISTIVITY* (ohm-cm)

| %H20 | <u>150°F</u> | 200°F | 250°F |
|------|----------------------|------------------------|------------------------|
| 1.4 | 2 x 10 ¹⁰ | 3 x 10 ¹⁰ | 1.6×10^{12} |
| 3.0 | l x 10 ¹¹ | 6.5 x 10 ¹¹ | 1.6 x 10 ¹² |
| 9.0 | 9 x 10 ¹⁰ | | 1.6 x 10 ¹² |

* Discharge end.

9.4.1 Particle Shape

9.4.1.1 Sinter Plant: Sinter dust may contain particles of iron exides, calcite, iron-calcium silicates, and quartz. Iron exide can be opaque, black, rounded particles of magnetite (Fe304) with granular faces, and/or dense, rounded, elongated, and nearly spherical agglomerates of hematite (Fe203). Calcite occurs as smooth, rounded particles, and quartz as a transparent, rounded particle. The iron-calcium silicates are transparent, vitreous, colorless to yellow to green. Particles are irregularly rounded with smooth surfaces.1.6/

9.4.1.2 Coke Ovens: Emissions from coke plants can be identified $\frac{1,7}{}$ as follows:

9.4.1.2.1 <u>Coal dust</u>: Bituminous, or soft coal, is translucent in thin areas: it is reddish-brown by transmitted light, and brownishblack with dull to moderately high reflectivity in reflected light. The surfaces are slightly rough with occasional indications of the original fibrous structure. These irregular chips have sharp edges, and in places show conchoidal surface fractures. $\frac{6}{2}$

9.4.1.2.2 <u>Coke balls</u>: Oval in shape with an unusual networklike internal structure. It has been suggested that coke balls are produced during the thermal-drying stages of coal processing. Similar conditions occur during charging or by-product coke ovens, where some coal fines are carried through the hot zone and out adjacent, open charging holes. 2/ 9.4.1.2.3 Char: Partially devolatilized coal particles exhibit optical properties between those of coal and coke. The partial devolatilization of coal particles suggests that they have not been subjected to temperatures high enough or for periods long enough to complete the coking process. 7/

9.4.1.2.4 <u>Pyrolytic carbon</u>: A tarry residue comes from the volatile organic portion of coal. Two forms of pyrolytic carbon have been identified. The first is an aggregate of minute oval grains; each grain is relatively uniform in size, extremely smooth in appearance, and exhibits extreme anisotropy in polarized light. The second normally occurs as a crenulated band of varying width and length, is smooth in appearance, and is strongly anisotropic in polarized light. The size of these materials is extremely variable.?/

9.4.1.2.5 <u>By-product coke</u>: The optical characteristics of particles of by-product coke are controlled by the rank (reflectance) of the coal which is carbonized. Because coals of different rank are usually blended to make an optimum mix, particles of coke produced from these mixes have complex and highly variable optical properties. Particulates of coke made from high-volatile and medium-volatile coals may be granular in appearance, have thick coke walls, and have few internal pores. Particulates from coke made with low-volatile coals have distinctive ribbon-like textures, thin coke walls, and comparatively large internal pores. $\frac{7}{2}$

9.4.1.3 <u>Blast Furnace</u>: Particulate emissions generated in the making of iron in the blast furnace and in its immediate auxiliaries have the following characteristics:1/

9.4.1.3.1 Iron-ore dust: Particles are rounded to elongated in shape and can be as small as 2 μ . Larger particles are opaque and redorange in top light. Individual small grains are transparent and blood-red. $\frac{6}{2}$

9.4.1.3.2 Coke dust: Particles are opaque, irregularly shaped, quite porous and rough with some straight, sharp edges. They are gray-black in reflected light.⁶/

9.4.1.3.3 Limestone dust: Calcite. It is colorless, with light-transmitting characteristics varying from transparent to translucent. Particles generally occur as rhombohedra because of their perfect rhombohedral cleavage. Fragments may also occur as prisms.⁶/

9.4.1.3.4 Flue dust: Blast furnace flue dust typically contains 15% metallic iron, 40% red iron oxide, 40% magnetic iron oxide, and 5% limestone, $\frac{6}{}$ but many variations exist:

a. Iron--fragments are opaque, black, and sharp, magnetic with finely granular surfaces $\frac{.6}{}$

b. Red iron oxide--particles are transparent, rounded grains, usually less than 2 μ in maximum dimension.⁶/

c. Magnetic iron oxide--particles are opaque, black, rough fragments, partially or completely covered with red iron oxide. $\frac{6}{}$

d. Limestone dust--particles are transparent, colorless rhombohedra, and rounded; many may also be covered with red iron oxide <u>6</u>/

9.4.1.3.5 <u>Kish</u>: Carbon in the form of flaky graphite that is rejected by the molten iron as it cools during flow from the blast furnace to ladles. Other types of particles may be entrained with this kish. The graphite particles are opaque, black, sharply angular flakes with smooth surfaces. Some are in layered agglomerates, occasionally showing rounded 120-degree angles, and even forming rounded hexagonal tablets. Other particles accompanying the kish may consist of opaque, black, rather coarse fragments of magnetic iron oxide, and transparent, deep-red, rounded particles of hematite. Traces of quartz and calcite may also be found with the kish $\frac{6}{}$ Graphite typically makes up about 90% of the emission, with the magnetic oxide at 5% and hematite at 5%.

9.4.1.4 Open-hearth Furnace: Open-hearth furnaces generate four major types of particulate emissions.1/

9.4.1.4.1 <u>Open-hearth dust</u>: Charging period. Two components appear in the dust generated during charging of the furnace. One is a magnetic iron oxide of black, opaque spheres, and elongated, rough particles with sharp jagged edges, all generally coated with red iron oxide. The second component comprises transparent, rounded particles of red iron oxide, usually less than 2 μ in dimension. They occur free or in simple agglomerates. $\frac{6}{2}$

9.4.1.4.2 <u>Open-hearth dust</u>: Hot metal to lime-up. Three components make up the dust from this period of open-hearth operation. (a) Loose agglomerates of tiny transparent grains are usually less than $l \mu$ in dimension. It is a hydrated iron oxide such as HFeO₂. Individual grains and agglomerates are yellow under top light. (b) Tiny, rounded, transparent, red grains of iron oxide are usually less than $l \mu$ in dimension. (c) Opaque, black spheres and rounded particles of magnetic iron oxide. Some particles are covered with hydrated iron oxide and/or the red iron oxide .6/

9.4.1.4.3 Open-hearth dust: Tap to charge. This is the same as Item 1 with the addition of black, opaque, frothy, rounded particles of coke.6/

9.4.1.4.4 Particulates in combustion product: About 85% of the material is transparent, deep red, rounded grains of iron oxide, usually less than 1 μ in dimension. The remaining 15% is black, opaque spheres 3 to 5 μ in dimension, of magnetic iron oxide. The smaller grains are orange in top light and tend to form simple agglomerates or loose lumps.

All lime dust does not occur as a visually apparent particulate; it is present in open-hearth dust in very small quantities as shown by chemical analysis. Sulfur in the form of sulphates also occurs in openhearth dust, but information in visual characteristics is not available in the published literature.

9.4.1.5 <u>Basic Oxygen Furnace</u>: The major particulate emissions from basic oxygen furnaces are:

9.4.1.5.1 <u>Kish</u>: Carbon in the form of graphite is rejected by the molten iron as it cools during charging into a BOF steel-making vessel. The graphite particles are opaque, black, sharply angular flakes with smooth surfaces. Some are in layered agglomerates, occasionally showing rounded 120-degree angles, and even forming rounded hexagonal tablets. Other particles may consist of opaque, black, rather coarse fragments of magnetic iron oxide and transparent, deep red, rounded particles of hematite. Traces of quartz and calcite may also be found with kish.⁶/

9.4.1.5.2 <u>Silica fume</u>: Approximately 50 to almost 100% silica material often contains small quantities of iron, manganese, magnesium and carbon. Color of the collected material is grey to off-white.

9.4.1.5.3 <u>Basic oxygen process dust</u>: Tiny (1μ in dimension), rounded, transparent particles of red iron oxide tend to agglomerate. Shiny black spheres of magnetite are covered with red iron oxide.

9.4.1.6 <u>Electric-Arc Furnace</u>: Emissions from electric-arc furnaces include:

9.4.1.6.1 Electric-furnace dust: Opaque, rounded grains are peach to reddish in color in top light. Small agglomerates are present, but are not common. $\frac{6}{2}$

The chemical composition of electric-furnace dusts will be influenced by the composition of the steel being melted. Because of this, optical characteristics of the dust may also vary because of the different alloying-element oxides that may be present. Because electric furnaces are used for melting a wide range of alloy and stainless steels, the chemical composition of any particulate dust will reflect the composition of the alloy melted. \underline{L}

9.4.1.6.2 Dust from scrap preheaters: Information on the physical and optical characteristics of dust generated during the preheating of scrap is not available. However, it can be assumed that the composition of the dust will be influenced mostly by the cleanliness of the scrap, its content of volatile matter, and presence of surface coatings on some of the steel.1/

9.5 CONTROL TECHNIQUES FOR THE IRON AND STEEL INDUSTRY

9.5.1 Control Practices - General

The operation and types of furnaces associated with the iron and steel industry vary widely. Therefore, the criteria for the type of control equipment are determined by the specific operation. A tabulation of the types of equipment used in the various processes is given in Table 9-5. \pm / The installation of fume control systems in the iron and steel-making processes requires considerable instrumentation. This required control instrumentation is discussed and graphically depicted in Reference 9.

The cost of the different types of control equipment for these applications has been reported in a NAPCA document "A Cost Analysis of Air Pollution Controls in Integrated Iron and Steel Industry." Section V of that report presents the cost/effectiveness investigation and the cost models which were developed. $\frac{9}{2}$

The applied control systems are more thoroughly discussed in a companion document, "A Systems Analysis Study of the Integrated Iron and Steel Industry."1/ Excerpts of Section VI of that report are included herein, and the estimated capital and operating costs are summarized in Figures 9-12 - 9-20.

9.5.2 Control Practices - Specific

9.5.2.1 Sinter Plants: Major sources of dust in sintering plants are the combustion gases drawn through the bed, discharge end gas, and the exhaust gases from sinter grinding, screening and cooling operations. $\frac{10}{}$ Because dust generated in the sintering operation can be returned to the process, most plants are at least equipped with cyclones.

REPRESENTATIVE EMISSION-CONTROL APPLICATIONS IN THE INTEGRATED IRON AND STEEL INDUSTRY1/

| Iron-or Steel-Making | Type of Emission-Control Equipment | | | | | | |
|----------------------|------------------------------------|-----------|---------------|---------|--|--|--|
| Segment | Mechanical | Scrubbers | Precipitators | Fabrics | | | |
| Sinter plant | 17 | 2 | 9 | 3 | | | |
| Blast furnaceª/ | 130/ | 51 | 108 | 0 | | | |
| Open-hearth furnace | 0 | 6 | 93 | 0 | | | |
| Basic oxygen furnace | 0 | 15 | 23 | 0 | | | |
| Electric furnace | 0 | 5 | 1 | 29 | | | |
| Scarfing | 4 | 4 | 3 | 2 | | | |

a/ Final control equipment.
b/ Dust collectors followed by other equipment are not considered.

139

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Figure 9-13 - Estimated Annual Operating Costs for Air-Pollution-Control Equipment for Steel-Making Process 1/ (Depreciation and Capital Charges are not Included)



for Air-Pollution-Control Equipment for Steel-Making Processes 1/



Figure 9-15 - Estimated Installed Capital Costs of Air-Pollution-Control Equipment Installed on Electric-Arc Steel-Making Furnaces. Control equipment designed to handle emissions from any one furnace at one time. 1/



Figure 9-16 - Estimated Installed Capital Costs of Air-Pollution-Control Equipment Installed on Open-Hearth Furnaces. Control equipment designed to handle emissions from furnaces operating at the same time. \underline{l}'



Figure 9-17 - Estimated Installed Capital Costs of Air-Pollution-Control Equipment Used in Sinter and Pellet Plants.1/



Figure 9-18 - Estimated Annual Operating Costs for Air-Pollution-Control Equipment Used in Sinter and Pellet Plants (Depreciation and Capital Charges are Not Included)¹/



Figure 9-19 - Estimated Capital and Annual Operating Costs for Air-Pollution-Control Equipment Used on Scarfing Machines (Depreciation and Capital Charges are Not Included in the Operating Costs)-/



Figure 9-20 - Range of Estimated Operating Costs for Air-Pollution-Control Equipment/Net Ton of Raw Steel--Open-Hearth Furnaces, BOFS, and Electric Furnaces (Two-Furnace Operations)1/

Dry-type cleaners are best suited for this cleaning because the sulfur content of the gas streams can lead to corrosion problems in wet systems. Cyclones, electrostatic precipitators, Venturi scrubbers, and baghouses have been used in various combinations at the various points of emission. However, there are some problems that limit the application of these devices.

. Wet scrubbers, which have high maintenance cost because of lime buildup, add to water-treatment problems. Baghouses suffer from the abrasiveness of the dust, as do the fans in the sintering machines. With sinter that contains flux (such as limestone), the efficiency of electrostatic precipitators decreases as basicity of the sinter increases $\frac{1}{2}$

Dust created at the junction points of conveyors has been suppressed by water sprays containing a wetting agent $\frac{11}{2}$

9.5.2.1.1 <u>Cyclones</u>: Because of the large particle size, cyclones applied to sintering plants usually operate at over 90% efficiency by weight. However, cyclone exit loadings range from 0.2 - 0.6 grain/ft³.10/

9.5.2.1.2 Electrostatic precipitators and baghouses: Highefficiency baghouses and electrostatic precipitators offer promise of much better collection than the cyclones normally used. However, few have been applied to sintering machines 10/

Electrostatic precipitators have been installed in series with cyclones. One such installation is reported to operate at an efficiency of 95%, and the final discharge contains only 0.05 grain/scf.^{2/} Another installation handled 457,000 cfm with an inlet loading of 2.5 grains/scf and yielded an output loading of 0.038 grain/scf, an efficiency of 98.5%. However, the materials charged to the sintering machine have changed from straight ore fines to ore, flue dusts, and lime. The characteristics of the ore used have also changed. These changes in materials have resulted in an increased output loading of 0.25 grain/scf, a decrease in collection efficiency to 90%.1/ The use of self-fluxing sinter has also impaired the operation of electrostatic precipitators in this service at other plants.

There are only three known applications of baghouses at sinter plants. $\frac{1}{}$ Data are given in Table 9-6. $\frac{1,12}{}$

9.5.2.1.3 <u>Wet scrubbers</u>: Only two known sinter plants have wet-scrubber installations. Operating problems occur due to erosion and imbalance of fan blades. Dust carried over to the exhaust fans is moist and has a tendency to accumulate on the blades.

9.5.2.2 <u>Coke Production and Coke Ovens</u>: Gaseous and particulate matter relased in the by-product coking operation, except that which escapes from ovens to the atmosphere, are conveyed in ducts to a coal chemical

DESIGN AND OPERATING DATA FOR SINTER-PLANT / FABRIC FILTERS ON SINTER STRAND DISCHARGE

| Design or Operating Variable | U. S. Steel Corp., Gary, Indiana | Bethlehem Steel Corp., Bethlehem, Pa. |
|---|-------------------------------------|--|
| Volume of Air, cubic feet per minute: | 172,000 at 255 F | 240,000 at 350 F |
| Suction, inches of water: | 12 | n.a. |
| Pressure Drop Across Bags, inches of water | 4 | n.a. |
| Hoppers in Unit, number | 10 | 16 |
| Bags per Hopper, number | 88 | 72 |
| Total Bags, number | 880 | 1,152 |
| Bag Size: Diameter, inches Length, feet | 11.5 32.2 | 12 28 |
| Bag Type | Fiberglass | Fiberglass |
| Bag Life, months | 17 . | 36 |
| Bag Permeability, ofm per ft ² of cloth | 12 - 20 | n. a . |
| Air-to-Cloth Ratio (Normal), cîm per ft ² of cloth | 2.17 | 2.29 |
| Air-to-Cloth Ratio (One Compartment Cleaning), ofm per ft ² of cloth | 2. 4 1 | 2.44 |
| Air Temperature, F | 175 to 300 | 200 to 500 |
| Theoretical Design Efficiency, percent | 99+ | 99+ |

n.a. - Not available.

processing plant for recovery of chemicals. The coke-oven gas remaining after these operations has a gross heating value of about 525 Btu/ft^3 and is used as fuel throughout the steel plant.

Emissions occurring from handling operations, primarily charging and pushing, and leakage from oven doors, etc., present dust containment problems that are difficult to control. However, a technique to control emissions during charging is being developed at the Pittsburgh Works of Jones and Laughlin Steel Corporation, under the sponsorship of the National Air Pollution Control Administration and the American Iron and Steel Institute, to eliminate this emission by minimizing the openings through which smoke can escape and, more importantly, by creating a slight vacuum inside the oven during charging so that air flows into the openings instead of smoke coming out. Engineering studies are also under way to develop designs for control of coke-oven emissions during pushing.30/

The quenching of hot coke in quench towers produces a rising cloud of steam in the chimney which lifts coke dust into the atmosphere. Most of this dust appears to fall out in the vicinity of the quench tower. Baffles installed in a quench tower can reduce the emission of particulates into the atmosphere by 75% or from 6 lb. down to 1-1/2 lb. of dust per load of coke. This can amount to a capture of 900 lb. of particulates per day from one tower. $\frac{1}{2}$

9.5.2.3 <u>Blast Furnace</u>: Under normal conditions the untreated gases from a blast furnace contain from 7 to 30 grains of dust per sof of gas. Most of the particles are larger than 50 μ . Blast-furnace gas-cleaning systems normally reduce particulate loading to less than 0.01 grain/sof to prevent fouling of the stoves in which the gas is burned. These systems are composed of settling chambers, cyclones, low-efficiency wet scrubbers, and high-efficiency wet scrubbers or electrostatic precipitators connected in series <u>10</u>/ One of the main reasons for cleaning blast-furnace gas is to render it sufficiently clean for use as fuel. Recovered dust is returned to the iron-making process.

Blast-furnace gas is cleaned in three stages; the first two, at least, are used almost universally throughout the industry. The majority of furnaces have secondary cleaning facilities as well. The three stages and the equipment used in each, along with average outlet dust loading from these stages are:

- Preliminary Cleaning settling chamber or dry-type cyclone (3-6 grains/sef)
- Primary Cleaning gas washer or wet scrubbers (0.05-0.07 grain/scf)
- 3. Secondary Cleaning electrostatic precipitator or high-energy scrubbers (0.004-0.08 grain/scf).

9.5.2.3.1 <u>Electrostatic precipitators</u>: The use of electrostatic precipitators for cleaning blast-furnace gas has come about because of the requirements for cleaner gas for the hot-blast stoves. The operation of these units has been relatively trouble free because the blast furnace is an almost continuous producer of gas and because of a high percentage of the particulate emissions removed by the wet scrubbing systems that have previously been used to clean up the gases. The wet scrubbers also serve to condition the gases, for both temperature and resistivity, prior to their entry into the electrostatic precipitator.

9.5.2.3.2 <u>Wet scrubbers</u>: High performance of a Venturi scrubber can be achieved only if the blast furnace is operating at a high enough top pressure to provide the required pressure drop. Lack of sufficient top pressure has usually required use of an electrostatic precipitator as the final gas-cleaning unit.

The effect of water rate at a constant throat velocity on the outlet dust loading of a Venturi scrubber handling blast-furnace gas is shown in Figure 9-21.¹/ Other operating characteristics are shown in Figures 9-22 and 9-23.¹/

Great Lakes Steel Corporation (Detroit) has three blast furnaces equipped with high-energy scrubbers. These units have made it possible to clean the gas at a low cost, although there have been troublesome problems in design and operation of equipment. Some of the gas-cleaning results are given in Table 9-7.13/

TABLE 9-7

BLAST-FURNACE GAS-CLEANING RESULTS¹³/

| | | Dust Loading, Grains/Ft ³ | | | | | |
|----------------|---------|--------------------------------------|---------------|--|--|--|--|
| | Before | After | After | | | | |
| Date | Orifice | Orifice | Precipitators | | | | |
| March 30, 1966 | 6.0881 | 0.0208 | 0.0010 | | | | |
| May 11, 1966 | 13,9233 | 0.0600 | 0.0104 | | | | |
| May 19, 1966 | 13.0181 | 0.0160 | 0,0141 | | | | |
| May 25, 1966 | 7,2084 | 0.0293 | 0.0017 | | | | |
| June 1, 1966 | 10.1117 | 0.0219 | 0.0048 | | | | |
| June 8, 1966 | 11.6293 | 0.0258 | 0.0047 | | | | |
| June 22, 1966 | 12.2045 | 0.0581 | 0.0040 | | | | |
| June 29, 1966 | 10.5555 | 0.0299 | 0.0206 | | | | |
| July 7, 1966 | 9.7877 | 0.0214 | 0.0099 | | | | |
| July 13, 1966 | 11.0075 | 0.0293 | 0.0140 | | | | |



Figure 9-21 - Effect of Water Rate on Output Dust Loading for a Venturi Scrubber Handling Blast-Furnace Gas $\underline{l}/$



Figure 9-22 - Effectiveness of Gas Cleaning by a Fixed-Orifice Scrubber and a Variable-Orifice Scrubber When Gas-Flow Rate is Varied-



Figure 9-23 - Operating Characteristics of a Blast-Furnace Venturi Scrubber¹/

9.5.2.4 <u>Open-Hearth Furnace</u>: The small size of the particles emitted from open-hearth furnaces requires high-efficiency collection equipment such as Venturi scrubbers and electrostatic precipitators. Because of the cost involved and the growing obsolescence of open-hearth furnaces, industry has been reluctant to invest money in the required control equipment. Often these furnaces have been replaced by controlled basic oxygen furnaces and electric furnaces.

However, electrostatic precipitators, Venturi scrubbers and baghouses are being used on open-hearth systems. $\frac{8.16}{}$ Exit gas loading would have to be reduced to at least 0.03 grain/scf to be sure of a clear stack. $\frac{14}{}$

The use of slag wool filters was investigated about 1958 by the Harvard School of Public Health. However, efficiencies were only of the order of 50% and the project was prior to the advent of oxygen lancing. $\frac{15}{}$

9.5.2.4.1 Electrostatic precipitators: Two major problems that have faced the steel companies and equipment manufacturers in the installation of electrostatic precipitators for open hearths have been (1) design of the ducts used to carry the gases from the open hearths to the precipitators, and (2) the design of the gas distribution systems at the entrance to the precipitators. The use of transparent gas flow-distribution models is considered to be almost a necessity in the practical design of ducting.

The major problem with respect to actual efficiency of electrostatic precipitators on open hearths is the open-hearth process itself. The problem stems from the variation in the properties of emissions from the open-hearth furnace during a heat. During the period of a heat, the moisture content of the gases may drop from a normal value of 18% to 2%, with a resultant increase in resistivity and drop in precipitator efficiency. The situation may be corrected by steam injection.

The relationship between the collection efficiency and size of a precipitator is shown in Figure 9-24. This figure shows that removing the dust from 315,000 cfm of open-hearth waste gas required 58,300 ft² of collecting surface for an efficiency of 95%. An increase in the collecting surface area to 96,500 ft² resulted in an increase in efficiency to 99.3%.

References 4 and 18 discuss using electrostatic precipitators to collect the fume from open-hearth furnaces. Another electrostatic precipitator system was put in service in 1965 by Weirton Steel Division, National Steel Corporation. This system is used for the control of fumes from 550-ton and 600-ton capacity oxygen-lanced furnaces. A flow-distribution model was used to facilitate designing a high efficiency unit.



Figure 9-24 - Relationship of Electrostatic Precipitator Collecting Surface to Collection Efficiency for Open-Hearth Emissions (315,000 acfm)1/

Table 9-8 gives the gas flow and dust loadings for different phases of a heat and Table 9-9 shows the results of the performance test conducted during the part of the heat when the dust loadings were at the maximum. $\frac{17}{2}$

TABLE 9-8

OPEN-HEARTH STACK GAS DATA17/

| | Scrap Charge | Hot <u>Metal</u> | Limeboil | Refine |
|--------------------------------|-----------------|---------------------|----------|--------|
| Dust concentration, grains/scf | 0.78 | 1.9 | 2.70 | 0.21 |
| Waste gas flow, scf/min | 60,000 | 64,000 | 66,000 | 64,000 |
| Gas temperature, °F | 580 | 600 | 620 | 580 |

TABLE 9-9

| | PERFORMANCE | TESTS | OF EL | ECTROS | TATIC | PRECIP | TTATOR | ON | OPEN-EEAR | TH (| GASES ¹⁷ | / |
|---------|------------------------------|-------------------|----------|---------------|-------|-----------------------|--------|-------------|----------------------|--------|---------------------|-----------|
| Te N | 5 st Va 0. <u>Cu</u> . | tack olume | <u>1</u> | lemp. (°F) | 2 | Sample Volume, | ם | isch Gra | arge Load ins/scf | ļ, | Estima Efficie | te ncy |
| 1 | 24 | £7,000 | | 500 | | 82 | | | 0.007 | | 99.8 | 3 |
| 2 | 22 | 23,000 | | 4 60 | | 85 | | | 0.019 | | 99.4 | : |
| 3 | 24 | 1000,81 | | 440 | | 41 | | | 0.010 | | 99.7 | |
| 4 | 24 | 48,000 | | 44 0 | | 113 | | | 0.016 | | 99.4 | : |

9.5.2.4.2 <u>Wet scrubbers</u>: Outlet grain loadings of 0.01 to 0.05 grain/scf have been reported for wet-scrubber installations. The relationship between outlet grain loading and pressure drop is illustrated in Figure 9-25, although it is not necessarily representative of present-day practice using higher oxygen-blowing rates.

A description of the application of Venturi scrubbers to control open-hearth stack emissions is given in Reference 19. Reference 3 describes the application of a Venturi scrubber on a 200-ton open hearth. Tables 9-10 and 9-113/ give the dust loadings and pressure drops during the oxygen and nonoxygen periods. It is pointed out that the investment and operating costs of a Venturi scrubber system would compete very favorably with those of a precipitator-waste-heat boiler system for cleaning the gas from openhearth shops that have an anticipated operating life of no more than a few years.





SCRUBBER-PRESSURE DROP VS. CLEANING EFFICIENCY AND OUTLET DUST LOADING (NONOXYGEN PERIODS)3/*

| Pressure | Dust Loading | Cleaning | |
|-------------------------------------|-------------------|--------------------|-------------------|
| Drop, Inches Of H ₂ O | Scrubber Inlet | Scrubber Outlet | Efficiency (%) |
| 26 | 0.35 | 0.06 | 86 |
| 30 | to | 0.03 | 92 |
| 35 | | 0.01 | 96 |
| 40 | 0.45 | 0,008 | 98 |

TABLE 9-11

SCRUBBER-PRESSURE DROP VS. CLEANING EFFICIENCY AND OUTLET DUST LOADING (OXYGEN PERIODS)3/*

| Pressure | Dust Loading | Cleaning | |
|-------------------------------------|-------------------|--------------------|-------------------|
| Drop, Inches of H ₂ O | Scrubber Inlet | Scrubber Outlet | Efficiency (%) |
| 26 | 0.82 | 0.10 | 89 |
| 30 | to | 0.05 | 94 |
| 35 | | 0.02 | 97 |
| 40 | 0.87 | 0.01 | 99 |

* Gas flow rate was approximately 40,000 scfm.

Republic Steel Corporation of Buffalo, New York, installed a Venturi scrubber handling 60,000 scfm of waste gases from a 300-ton oxygenlanced open hearth in 1964. This installation is discussed in Reference 20. The system was designed to reduce the dust content to 0.05 grain/scf of dry gas provided that the inlet loading did not exceed 5 grains/scf of dry gas. The waste gases from this open hearth contained sufficient sulfur from the fuels that the scrubbing slurry had a pH of 3 or less, thus requiring that all contacted materials be adequately protected against corrosion. The major problems experienced were buildup on fan blades, fan noise and failure of redwood mist eliminator elements. $\frac{20}{}$

9.5.2.4.3 <u>Baghouses</u>: One glass-fabric baghouse has been applied to the collection of fume from an oxygen-lanced open-hearth furnace by Bethlehem Steel Corporation in Sparrows Point, Maryland. This unit is described in a 1966 article.<u>21</u>/ The authors state that the capital cost estimates favored the baghouses over an electrostatic precipitator and the subsequent operating experience has shown the maintenance and operating cost to be approximately half that required on an electrostatic precipitator. This baghouse serves a 380-ton/heat furnace having a waste heat boiler and economizer which cool the gas to below 500°F.<u>21</u>/

One baghouse installation was made on an open-hearth system after several pilot studies. However, the actual system installed experienced problems of high pressure drop which had not been resolved when this openhearth shop was shut down. $\underline{12}/$

9.5.2.5 <u>Basic Oxygen Furnace</u>: The basic oxygen furnace creates more emissions than the open-hearth furnace, and the particles are smaller. All basic oxygen furnaces in the U. S. are equipped with high-efficiency electrostatic precipitators or Venturi scrubbers. Final effluent from these control devices will contain 0.03 to 0.12 grain/scf. Inlet loadings may vary from 2.0 to 5.0 grains/scf. Table 9-12 presents a list of basic oxygen furnaces and their control equipment.

The major operation causing dust and fume generation is oxygen blowing. The volume of waste gases produced is proportional to the blowing rate. Gau arrived at a design volume rating of 25 scfm of waste gases/cfm of oxygen blowing. $\frac{22}{}$ It is common practice to operate BOFs in pairs so that one is operating while the other is relined. Therefore, the two furnaces are usually ducted to one control device. The hood over the BOFs gives rise to problems as the substantial variation in temperatures can cause the structure to warp and crack.

The dust problem in BOFs can be minimized if the entire gas and dust-handling process is considered as one system. Specially designed equipment which supplies a controlled amount of excess air to the hood can reduce the size of requisite waste gas-cooling and dust-collecting equipment. The effect of "controlled combustion" is shown in Table 9-13.

BASIC OXYGEN FURNACE INSTALLATIONS AND ASSOCIATED AIR-POLLUTION CONTROL EQUIPMENT $\underline{\mathbb{L}}'$

| | | | | Annual Car | macity, | | | |
|---------------------------------|---------------------|---------------------|----------|------------|------------|---------------|--------------|-----------------|
| | | Net Tons (Net Tons) | | | | Electrostatic | | |
| | | Number | Per Heat | March 1969 | Future | Startup Date | Precipitator | High-Energy Wet |
| Alan Wood Steel Co. | Conshohocken, Pa. | 2 | 140 | 1,250,000 | | 1968 | x | |
| Allegheny-Ludlum Steel Corp. | Natrona, Pa. | 2 | 80 | 500,000 | | 1966 | | x |
| Armco Steel Corp. | Ashland, Ky. | 2 | 160 | 1,400,000 | | 1963 | X | |
| - | Middletown, Ohio | 2 | 200 | | 2,000,000 | 1969 | | X |
| Bethlehem Steel Corp. | Bethlehem, Pa. | 2 | 250 | 2,500,000 | | 1968 | x | |
| - | Burns Harbor, Ind. | 2 | 250 | | 1,800,000 | 1970 | | X |
| | Lackawanna, N. Y. | 3 | 290 | 4,700,000 | | 1964-66 | | X |
| · | Sparrows Point, Md. | 2 | 200 | 2,500,000 | | 1966 | | X |
| CF & I Steel Corp. | Pueblo, Colo. | 2 | 120 | 1,100,000 | | 1961 | х | |
| Crucible Steel Corp. | Midland, Pa. | 2 | 90 | 1,250,000 | | 1968 | | X |
| Ford Motor Co. | Dearborn, Mich. | 5 | 250 | 2,500,000 | | 1964 | Х | |
| Granite City Steel Co. | Granite City, Ill. | 2 | 225 | 2,200,000 | | 1967 | X | |
| Inland Steel Co. | East Chicago, Ind. | 2 | 255 | 3,000,000 | | 1966 | | X |
| | | 2 | 210 | | 2,000,000 | 1973 | | X |
| Interlake Steel Corp. | Chicago, Ill. | 2 | 75 | 730,000 | | 1959 | X | |
| Jones & Laughlin Steel Corp. | Aliquippa, Pa. | 2 | 80 | 1,000,000 | | 1957 | X | |
| | | 3 | 200 | 3,000,000 | | 1968 | Х | |
| | Cleveland, Ohio | 2 | 225 | 2,250,000 | | 19 61 | X | |
| Kaiser Steel Corp. | Fontana, Calif. | 3 | 110 | 1,440,000 | | 1958 | X | |
| McLouth Steel Corp. | Trenton, Mich. | 2 | 110 | | | 1958 | х | |
| - | | 1 | 110 | 2,800,000 | | 1960 | X | |
| | | 2 | 110 | | | 1969 | X | |
| National Steel Corp. | | | | | | | | |
| Great Lakes Steel Div. | Ecourse, Mich. | 2 | 300 | 3,500,000 | | 1 9 62 | Х | |
| | | 2 | 200 | | 2,000,000 | 1970 | X | |
| Weirton Steel Div. | Weirton, W. Va. | 2 | 325 | 3,400,000 | | 1967 | | X |
| Republic Steel Corp. | Buffalo, N. Y. | 2 | 100 | | 1,000,000 | 1970 | Х | |
| | Cleveland, Ohio | 2 | 240 | 2,400,000 | | 1966 | X | |
| | Gadsden, Ala. | 2 | 190 | 1,500,000 | | 1965 | X | |
| | Warren, Ohio | 2 | 180 | 1,600,000 | | 1965 | x | |
| United States Steel Corp. | Braddock, Pa. | 2 | 220 | | 2,250,000 | 1972 | | X |
| • | Duquesne, Pa. | 2 | 215 | 2,400,000 | | 1963 | | X |
| | Gary, Ind. | 3 | 200 | 3,700,000 | | 1965 | | Х |
| | Lorain, Ohio | 2 | 220 | | 2,250,000 | 1970 | | x |
| | South Chicago, Ill. | 3 | 150 | | 3,000,000 | 1969 | | X |
| Wheeling-Pittsburgh Steel Corp. | Monessen, Pa. | 2 | 200 | 1,500,000 | | 1964 | x | |
| U U I | Steubenville, Ohio | 2 | 250 | 2,000,000 | | 1965 | | x |
| Wisconsin Steel Div. | , | | | | | | | |
| International Harvester Co. | South Chicago, Ill. | 2 | 140 | 1,200,000 | | 1964 | x | |
| Youngstown Sheet & Tube Co. | East Chicago, Ill. | 2 | 265 | | 2,400,000 | 1969 | <u>x</u> | |
| | | TOT | TAL | 57,320,000 | 18,700,000 | | 23 | 15 |

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COMPARISON OF EQUIPMENT REQUIREMENTS, ENERGY AND GAS FLOW FOR BOF23/

| | <u>No. 1</u> | <u>No. 2</u> |
|--|--|---|
| System Description | 100% Excess Air, Injection of Water and Water-Cooled Flue | 25% Excess Air, Controlled Combustion and Waste-Heat Boiler |
| Quantity of gas to be cleaned | 920,000 actual cfm . | 176,000 actual cfm |
| Note | High proportion of leakage air and vapor in the waste gas | Controlled combustion. No vapor in the waste gas, after cooling |
| Size of filter | 8 electric precipitators (1 for spare) | 3 electric precipitators (l for spare) |
| Energy gain or loss to the system | Approx. 35-kw-hr/ton of steel Loss | Approx. 100-kw-hr/ton of steel Gain |
| Energy comsumption for the exhaust fans with use of scrubbers (45-in. H ₂ O pressure drop) | 9,500 hp. | 1,710 hp. |

The gas emanating from the mouth of the furnace is essentially CO and is burned in the hood with induced air. It is desirable to burn all of the CO to CO₂ in the hood; therefore, the hood should be treated as a combustion chamber. A Japanese process has been introduced which does not burn the CO in the mouth of the furnace thereby taking advantage of lower temperature and less volume of gas. The gases are wet-scrubbed and the cleaned gas can be burned at the stack or the CO can be used as fuel. The cost of this system is estimated at \$1.0 to \$1.5 million for a typical 150-ton BOF.32/

The factors to be considered in the selection of a wet or dry cleaning system and the problems associated with each system are clearly presented in Reference 24. Another source of emissions associated with the BOF is kish that is emitted during transfer of hot metal from bottle car to charging ladle. Emissions generated have been reported as 0.16 lb/ton of hot metal with grain loadings of 0.42 grain/scf. A baghouse handling 100,000 acfm has been installed for control of these emissions and is reported to operate at 99.9% efficiency.33/ Experimental studies of fabric filters in this application indicated that air-to-cloth ratio of 4.5 to 1 should not be exceeded. A full canopy hood located just above the ladle, sized for approximately 500 ft/min velocity through all open areas, will usually control the fume.34/

9.5.2.5.1 <u>Electrostatic precipitators</u>: Problems associated with applications of electrostatic precipitators to basic oxygen furnaces are basically those of variability in gas flow, in the moisture content, and in temperature of the entering gases, as well as maintenance. Also, collection is lower during the initial phase of oxygen lancing before the temperature and water sprays produce a properly conditioned gas stream for efficient collection.

The hoods over the BOF are a necessary part of the collection system, and can result in operating problems. The gap between the BOF and the hood is usually dictated by the anticipated operating conditions and the buildup on the mouth of the furnace ("skull"). Excess buildup can restrict the flow of air required for combustion of the carbon monoxide, with the result that a significant amount of carbon monoxide may reach the electrostatic precipitator with possible disastrous results.

The hot gases leaving the BOF are cooled by heat exchange and water sprays to a preferred temperature of 450° to 500° F. The moisture content of the gas going to the precipitators is quite important; it should be kept between 20% and 30% to insure adequate conductivity of the dust layer.

9.5.2.5.2 <u>Wet scrubbers</u>: Problems associated with the use of wet scrubbers include inadequate water treatment facilities or lack of sufficient water and the abrasive and corrosive nature of the dust-laden water. The dirty water from Venturi scrubbers is cleaned by a combination of liquid cyclones, clarifiers and vacuum filters. The recovered dust may be sintered if the composition is suitable; otherwise it is hauled to storage.

References 25 and 26 discuss the use of wet scrubbers on BOF furnaces. With a wet scrubber system it is not essential to burn all the CO in the hood since a wet system can tolerate a considerable amount of CO without danger of explosion. 9.5.2.5.3 <u>Fabric filters</u>: No installations of fabric filter devices exist in the U.S. However, fabric filters have been applied in Europe. This system uses refractory surfaces in an accumulator to absorb heat from the gases and depends on the cyclic nature of the BOF for its operation. The refractory accumulator absorbs the heat from the gases during the blowing cycle, cooling the gases to approximately 250°F before the baghouse. As soon as the blowing cycle is over, the accumulator is cooled by back-blowing atmospheric air through the accumulator.27/

9.5.2.6 Electric Furnace: Electric furnaces are becoming more popular for many metal melting operations. Particulate emissions from electric furnaces are difficult to collect because of their small size and because of a strong tendency to adhere to fabric surfaces, a high angle of repose, and high resistivity. Nevertheless, except for difficulties inherent in the charging operation, over 95% effective collection can be achieved with appropriate hooding and high-efficiency collection equipment. $\frac{10}{}$

The characteristically small particle size of electric-arc steel furnace fume precludes the use of dry centrifugal collectors, settling chambers, etc. High-efficiency scrubbing systems, electrostatic precipitators and baghouses are used to control fumes from electric-arc steel furnaces.

High-energy scrubbers installed on one oxygen-lanced electric furnace producing a dust concentration of 3.2 to 6.4 grains/sef reduced the dust output to the range of 0.256 to 0.0512 grain/sef. Baghouses reduced it to the range of 0.004 to 0.0064 grain/sef. Electrostatic precipitators, not performing as well, reduced the dust loadings to a range of only 0.256 to 0.512 grain/sef. $\underline{l}/$

The high temperature of the fumes leaving the electric furnace may require the use of tempering air, evaporative coolers or radiation chambers prior to the collection equipment.

Effective dust and fume control during melting and tapping can be achieved. However, a technologically acceptable method has not been found for capturing the heavily polluted air escaping during the charging period. Complete shop evacuation can be used for control of all fumes, but large volumes of air must be handled.

9.5.2.6.1 <u>Electrostatic precipitators</u>: The only known installation of an electrostatic precipitator on an electric furnace plant is at Jones and Laughlin Steel Corporation in Cleveland. The precipitators are considered to be operating satisfactorily. Precipitators installed in 1955 at Bethlehem Steel Corporation in Los Angeles were replaced by baghouses in 1967.
9.5.2.6.2 <u>Wet scrubbers</u>: High-energy scrubbers for electric steel-making furnaces are known to be used in only two plants.

9.5.2.6.3 <u>Baghouses</u>: Fabric filters have been successfully applied to the control of emissions from electric furnaces ranging up to 100 to 150 net-tons capacity, and for multiple-furnace shops as well as one-furnace shops. The application and operating problems for a baghouse installed on a 150-ton electric furnace are discussed in a recent article by W. W. Bintzer and D. R. Kleinton of Lukens Steel Company.<u>28</u>/

Wherever fluorspar is employed, the fluorides in its off-gas attack glass-filter media. Hence, fiberglass in any form is not recommended on furnaces employing fluorspar as a fluxing agent. However, other synthetic fabrics work well.

The approximate air volumes for various furnace sizes are shown in Table 9-14. Typical side-draft and roof-tap-load systems are illustrated in Figure 9-26.29/

TABLE 9-14

APPROXIMATE BUDGET SIZING CHART²⁹/ (Air Volume at Standard Conditions (scfm) for Electric-Arc Furnaces)

. . .

| Roof Ring Diameter | | | | |
|-----------------------|-----------------|----------|------------|----------|
| (ft.) | KVA | Capacity | Side Draft | Roof Tap |
| 9 | 4,500 | 8 tons | 18,000 | 12,000 |
| 11 | 7,000 | 15 tons | 30,000 | 22,000 |
| 13 | 10,000 | 25 tons | 65,000 | 50,000 |
| 15 | 18,000 | 50 tons | 80,000 | 68,000 |
| 17 | 25,000 | 70 tons | 110,000 | 85,000 |
| 19 | 4 0,000 | 100 tons | 155,000 | 115,000 |
| 22 | 6 0,00 0 | 150 tons | 190,000 | 165,000 |





Figure 9-26 - Typical Side-Draft and Roof-Tap-Hood Systems for Electric-Arc Furnaces29/

166

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CHAPTER 10

CEMENT MANUFACTURE

10.1 INTRODUCTION

Cement, a nonmetallic mineral product, is used as an intermediate product for many materials including concrete, mortar, concrete block and concrete pipe. Raw materials for cement production include lime and silica as the principal constituents, with alumina and ferric oxide as fluxing components. Limestone, cement rock, chalk, marl, shell residues, and blast furnace slag are sources of lime. Five types of cement are produced, the classification determined by limitations on compositions of raw materials and production methods.

Cement is a granular material and dust control is a problem in the industry. Dust emissions result from quarrying and crushing, grinding, kiln, and finish grinding and packaging operations. The manufacturing process, particulate emission sources, emission rates of individual sources, chemical and physical properties of effluents, control practices, and control equipment are discussed in the following sections.

10.2 CEMENT MANUFACTURING PROCESS

Portland cement is made by either the wet or dry process. Figure 10-1 presents a schematic of the two processes. There are four major steps in the production of portland cement: quarrying and crushing, grinding and blending, clinker production, and finish grinding and packaging. Most deposits of cement rock, limestone, clay, and shale are worked in open quarries. The rock is transported from the quarry to crushing plants. The types of primary crushers used depend on the hardness, lamination, and size of rock produced at the quarry, and include gyratory crushers, jaw crushers, roll crushers and heavy hammer mills or impact mills. From the primary crushers the rock is screened and conveyed to the secondary crusher, where crushing is completed. Typical crushers are hammer mills that reduce the rock to a maximum of 3/4 in. $\frac{1}{}$

In the wet process, the wet, ground material is pumped in the form of a slurry containing about 40% water into a series of large mixing tanks and from these it is pumped into the kiln. In the dry process, the dry, ground, raw material is carried by a conveyor to the storage bins, and from the bins it is fed into the kiln.

171

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Figure 10-1 - Sources of Dust Emissions Cement Plants

172

The raw materials, either in the wet or dry form, enter the kiln at the top end and contact the combustion gases which pass through the kiln counter-current to the material. As the kiln revolves, the raw materials fall down toward the clinkering zone, having been first dried by the hot gases, and then having the carbon dioxide driven off from the calcareous materials. The partially fused product or cement clinker passes from the lower end of the kiln to the clinker cooler where some of its heat preheats air going to the kiln. The clinker, with the addition of a little gypsum or water to regulate the setting time, is then ground in ball and tube mills to the requisite fineness for a finished product.

10.3 EMISSION RATES FROM CEMENT MANUFACTURING PLANTS

The major source of particulate emissions in cement plants is the calcining kiln. Dust is generated in kiln operations by the grinding and tumbling action within the kiln, by the liberation of gases during calcination which tends to expel particles into the gas stream, and by the condensation of material that is volatilized during passage through the kiln. Volatilization and condensation generally produce smaller particles than the mechanical processes.

The principal secondary sources in the cement industry are dryers and crushers. Dust emissions from dryers result from abrasion of the material being processed and carry over from the kiln. The magnitude of the dust problem from crushing operations depends on the type and moisture content of the raw material, and the characteristics and type of crusher.

10.3.1 Cement Kilns

Variations in kiln operation and design can contribute to the nature and quantity of emissions. The types of kilns used in the dry and wet processes are discussed in the following sections.

10.3.1.1 Dry-Process Kiln Systems: Dry-process kiln systems consist of (1) short rotary kiln with or without a waste-heat boiler, (2) rotary kiln with suspension preheater, (3) long rotary kiln with or without a built-in preheater, (4) "Lepol" kilns with double gas flow (semidry process), (5) pit kiln, and (6) traveling sintering grate kiln. Rotary kilns are used in the United States, and almost all new plants utilize long kilns with chain or other preheating systems. 10.3.1.1.1 <u>Rotary kiln</u>: The rotary kiln used in most plants is a steel cylinder with a refractory lining. The kiln feed is introduced into the upper end of the revolving sloped kiln. During the passage through the kiln, the raw materials are dried, calcined, and heated to a point of incipient fusion. The combustion gases pass through the kiln counterflow to the material, and leave the kiln, along with carbon dioxide driven off during calcination, at temperatures of 300-1800°F, depending on kiln length and the process used.

10.3.1.1.2 Rotary kiln with ascending gas heat exchanger: In dry-process rotary kilns with suspension-gas heat exchanger the dry raw material powder is fed into the first and highest of four vertically arranged stages of a cyclone located ahead of the kiln. While passing through the four stages of the cyclone, the classifying action of the cyclone suspends the fines of the raw material in the waste gases and the dust beyond the heat exchanger is $90\% < 10 \mu$. Collection of this dust is difficult.

10.3.1.1.3 "Lepol" furnace with double gas flow: In the "Lepol" kiln with double gas flow, the clinker formed in a drum or on a plate from raw material powder and water is dried initially on a traveling grate by the waste gases of the rotary kiln, then heated and partially calcined and subsequently transformed into clinker in the rotary kiln.²/

The waste gases of the rotary kiln are first drawn upward into the "hot chamber" through the layer of clinker on the grate, preliminary dust removal being effected in an intermediate dust removal installation (cyclone). The waste gases are then transported by means of a blower into a drying chamber where these gases are again drawn through the moist layer of clinker. During this process, the residual dust is almost completely retained in the still moist layer of clinker. The gases are discharged at a temperature of about 200°F through a stack of a second blower.

High dust-emission levels from these units may have the following causes:

a. Damaged grate units so that the gases are not filtered in passing through the grate.

b. Too rapid heating of the granulate. Feed material which has been heated too quickly, or is too dense, has a tendency to burst. In order to obtain granulate as resistant to heat as possible, the raw-material powder and water distribution on the granulating plate should be uniform. Temperatures in the drying and in the hot chambers must be continuously controlled, and frequent inspection of the separation well between "hot" and drying chamber is also required. c. Maladjusted suction fans. Fans must be adjusted so that vacuum in the hot chamber is always higher than the vacuum in the second chamber. All gases will then undergo intermediate dust separation in the moist layer of granulate of the drying chamber.

10.3.1.2 <u>Wet-Process Kiln Systems</u>: Two basic types of wetprocess kilns are in use in the U.S.: (a) short kilns with waste-heat boilers, and (b) long kilns with internal chain preheaters.

10.3.1.2.1 Rotary kiln with built-in units: In kilns with chain baffles in the preheating area, the chains serve to distribute the raw paste over a large surface. The effect of the chains increases with their number. Their position and length in the rotary kilns are arranged so that the clinker material still contains about 10% moisture upon leaving the last chain. This percentage is necessary so as not to overheat the chains.

In preheated kilns, chambers ahead of the chain area are arranged crosswise and rotate with the kiln. Through a suitable arrangement of the inlet and outlet apertures of the chambers, the paste flowing along the bottom of the kiln enters the chambers and comes in close contact with waste gases flowing through the chambers.

The dust emission from wet-process rotary kilns is highly dependent on variations in kiln operation. If the waste-gas temperature becomes too high, which may be the case when there are variations of the calorific value of the fuel or through increase of the kiln output, the raw paste may lose its entire water content in the chain area. Any granulate formed is reduced to dust by the last of the chains, and this dust is then carried out of the kiln by the waste gases.

10.3.1.2.2 Rotary kilns with paste dryers: In wet-process rotary kilns with paste dryer (concentrator, calcinator), the raw material paste enters the slowly rotating grate drum through ducts. The drum contains baffles and is arranged ahead of the kiln. The hot waste gases of the rotary kiln enter the grate drum from below, heat the baffles and thereby dry the raw material paste into granulate. Additional drying, as well as calcination and sintering into clinker, takes place in the rotary kiln.

Heat economizers (e.g., scoops) in the kiln and particularly at the inlet increase the production of dust. The kiln-inlet chute should extend very close to the lining of the kiln so that the high-velocity waste gases will not entrain the fines and return them to the paste dryer, which will increase the dust content of the gas. $\frac{2}{}$

10.3.2 Effect of Feed Composition on Dust Emission

Different types of feed composition also affect emission rates. One of the most important causes of dust emissions is the way in which gases are liberated and expelled from the raw feed during calcination. Some raw materials remain relatively calm while the liberated gases escape; others appear to expand and explode, throwing the material into the gas stream. This may explain why some wet-process plants have a higher dust loss than some dry-process plants. $\frac{1}{2}$

10.3.3 Secondary Sources in Cement Manufacture

Particulate emissions also originate from dryers, coolers, grinding, and packing operations. Meager data exist on emissions from these sources.

10.3.4 Summary of Emission Rates

The emission factors for individual sources and total particulate emissions are summarized in Table 10-1. A statistical analysis of emissionfactor data for wet- and dry-process kilns indicated that the differences between the average emission factors for each process are not statistically significant. A single emission factor was therefore used for kilns. The emission factor, 166 lb/ton, is the geometric mean of 31 items of data.

Emission-factor data are meager for the secondary sources (i.e., dryers, mills, elevators). Reference 3 indicates that in dry-process plants emissions from secondary sources are about 40% of kiln emissions, while in wet-process plants they are about 15% of kiln emissions. On this basis, emission factors of 67 and 25 lb/ton were selected for secondary sources in dry- and wet-process plants. Total emissions from these secondary sources were calculated with the assumption that the average operating efficiency of control equipment and the percentage of production capacity controlled were the same as for kilns. Information collected during a survey of the cement industry indicated that bag filters are used extensively on these sources. Therefore, the assumption of the same degree of net control as for kilns is not believed to be unreasonable.

Total particulate emissions, as shown in Table 10-1, currently total 934,000 tons/year.

TABLE 10-1

PARTICULATE EMISSIONS CEMENT INDUSTRY

| Source | Production | Emission Factor (e _f) | Efficiency of Control (C _C) | Application of Control (C _t) | $\frac{\text{Net Control}}{(C_{c} \cdot C_{t})}$ | Emissions (tons/year) |
|--------------------------------------|------------|---|---|--|--|--------------------------|
| Kilns | 74,600,000 | 167 | 0.94 | 0.94 | 0.88 | 745,000 |
| Grinders, Dryers, elevators, etc. | | | | | | |
| Wet Process | 43,600,000 | 25 | 0.94 | 0.94 | 0.88 | 65,000 |
| Dry Process | 31,000,000 | 67 | 0.94 | 0.94 | 0.88 | 124,000 |

177

Total for Cement 934,000

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10.4 CHARACTERISTICS OF CEMENT PLANT EMISSIONS

The chemical and physical properties of cement plant effluents are summarized in Table 10-2. Mechanical, volatilization, and condensation processes produce the particulate emissions. Volatilization and condensation generally produce smaller particles than the mechanical processes. The mass median size of particulate emissions from kilns is 8.5μ and the geometric deviation is 4.1.

10.5 CONTROL PRACTICES AND EQUIPMENT FOR CEMENT PLANTS

10.5.1 Control Practices

Dust can be adequately arrested in the cement industry by proper selection of dust control equipment. Dust emissions as low as 0.03 to 0.05 grain/scf have been obtained in newly designed well-controlled plants. \underline{l}' Table 10-3 gives ranges of dust emissions for various combinations of control devices. \underline{l}' An emission level of 0.1 grain/scf is probably the value needed to preclude nuisance complaints from nearby residents. $\underline{3}'$

The hot kiln gases are the main source of emission and they present a major problem because gas volumes are large; they contain acid gases such as H_2S and SO_2 , varying amounts of H_2O , and a temperature range usually above 500 or $600^{\circ}F.4/$ A kiln producing 20 tons/hr of cement clinker will produce about 240,000 lb/hr of exit gases, or about 92,000 acfm.5/

10.5.2 Control Equipment

10.5.2.1 <u>Multicyclones</u>: Although a number of types of dust collectors are used in the cement industry, only the high-efficiency collectors such as the electrostatic precipitator and fabric filter, sometimes used in series with inertial collectors, effectively collect fine dust. The multicyclones alone are not an acceptable means of reducing dust emission from the kiln to the atmosphere.

Multicyclones, when preceding other control equipment, can be expected to scalp off about 70 wt. % or all of the coarser particles.

10.5.2.2 Electrostatic Precipitators: In a wet-process plant the performance of an electrostatic precipitator is greatly enhanced by the extra water vapor present in the exhaust gases from the slurry. Dry-process kilns do not have this water in the feed and often it is necessary to add it as an aid to precipitator operation. $\frac{6}{2}$

TABLE 10-2

EFFLUENT CHARACTERISTICS - CEMENT MANUFACTURE*

A. <u>Farticulate</u> (Part I)

| | Source | Farticle Size | Solids Losding | Chemical Compositio | Particle n Density | Electrical Resistivity | Moisture Content Toxicity |
|-------------|---|---|---|--|--------------------------------|---|------------------------------|
| Cemer | nt Plant | | | | | | |
| ā. | Kiln | Wagner Turbidimeter 15.5 < 5, 43 < 10 64 < 20, 89 < 40 BAHCO Analysis: 25-32 < 5 Average 3C < 5 40-52 < 10 Average 47.6 < 10 55-73 < 20 Average 66.7 < 20 67-89 < 40 Average 80.5 < 40 (Also see Figure 10-2 mass median - 8.5 $\sigma = 4.1$ | Dry Process 1-17 (stack conditions) Average 6.4 Wet Process 1-14 (stack conditions) Average 5.7) | CaO: 39-50; SiC ₂ : 9.8-19; Fe ₂ O ₃ : 2-11; A1 ₂ O ₃ : 2-8; K Na ₂ O: 0.5-1.1; MgO: 1.3-2.5 | 2.6-3.2 ₂ 0:2-8; | See Figures 10-3, 10-4, 10-5 and 10-6 for detailed data | N.T. |
| Ъ. | Dryer (1) Standard drum (2) Quick dryer (3) Unspecified type | 40-70 < 13 ⁺ 50-70 < 10 ⁺ | 13-40 ⁺ 13-100 ⁺ 5-40 (stack conditions) | | | | |
| ¢. | Cement Cooler (clinker dust) | BAHCO Analysis 3-6.5 < 5 Average 4.7 < 5 4.8-12 < 10 Average 7.9 < 10 10.4-18.1 < 15 Average 12.4 < 15 | | | 3.6-3.9 | | |
| A. <u>I</u> | Particulate (Part | II) | Mattableiten | Hygroscopic FL | armability or | Handling | Optical |
| | Source | SOLUDILITY | weccapility | Characteristics Ex | plosive Limits | Unaracteristic | s rroperties |
| Cemer a. | nt Plant Kiln | CaO - s. H ₂ O CaO, SiC ₂ , Fe ₂ O3, Al ₂ O3, TiC ₂ - s. 10% HC1 | | Will absorb H ₂ 0 | | Angle of repos 39 degrees (Portland Ceme: | e nt) |

+ = German data.

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* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 10-2 (Concluded)

Flammability

B. Carrier Gas

| Sour | 128 | <u>F1</u> | ow Rate | Temperature | Moisture Content | Chemical Composition | Toxic- ity | Corro- sivity | Odor | or Explosive Limits |
|---------------------|-----------------------|-----------------------------|---|--|--|--|---------------|---|------|------------------------|
| Coment Pl | lant | | | | | | | | | |
| a. Kil r | a | Dry a. b. We a. | y Process 34-300 (stack conditions) 94-614 (stack conditions) t Process 72-445 (stack conditions) 166-570 (stack conditions) | Dry Process 150-845 Wet Process 290-650 | Dry Process 1-2 Wet Process 20-40 | CO_2 , steam, O_2 , N_2 , small amounts SO_2 , NO_x , CO , and polysulfides <u>Typical Analysis</u> CC_2 : 17-25 O_2 : 1-4 CC: 0-2 N_2 : 75-80 | N.T. | Gases con- tain C-40% steam and will cor- rode dead spots in piping | | |
| b. Dryd | er | | | | | | | | | |
| (1) | Standard drum | ε. Ъ. | 26-64 ⁺ (stack conditions) | 158-302* | Dew point: 104-158 ⁺ | | | | | |
| (2) | Quick dryer | a. b. | 16-48 ⁺ (stack conditions) | 158-302* | | | | | | |
| (3) | Unspeci- fied type | а. Э с. | 10-60 (stack conditions) | | 5-12 | | | | | |

+ = German data.

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Figure 10-2 - Typical Particle Size Range of Cement Kiln Dust10/

181



Figure 10-3 - Resistivity of Cement Kiln Dust Under Varying Conditions of Temperature and Moisture in Gas<u>11</u>/





Curve 2 originated from a rotary cement kiln of the older type, operated by a dry process. Curve 3 pertains to a rotary cement kiln with heat exchanger.

Curve 4 cement dust rotary kiln with concentrator.

Curve 5 cement dust rotary kiln with sludge injection.

^{*} Figure shows percent water vapor by volume.



Figure 10-5 - Typical Laboratory and Field Resistivities of Cement Kiln Dusts10/





TABLE 10-3

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RANGES OF DUST EMISSIONS FROM CONTROL SYSTEMS SERVING DRY- AND WET-TYPE CEMENT KILNS1/

| | Range of Dust Emissions | | | | |
|------------------------|--|--|--|--|--|
| | from Coll | ector | | | |
| Type of Dust Collector | grain/scfa/ | lb/ton of Cement | | | |
| Multicyclones | 1.55 - 3.06 | 26.2 - 68.6 | | | |
| Electrical | | | | | |
| precipitators | 0.04 - 0.15 | 1.7 - 5.7 | | | |
| Multicyclone and | | | | | |
| electrical pre- | | | | | |
| cipitators | 0.03 - 1.3 | 0.6 - 29.4 | | | |
| Multicyclone and | | | | | |
| cloth filter | 0.039 | 0.7 | | | |
| Electrical pre- | | | | | |
| cipitators | 0.03 - 0.73 | 0.52 - 9.9 | | | |
| Multicyclone and | | | | | |
| electrical pre- | · | | | | |
| cipitators | 0.04 - 0.06 | 4.3 - 24.2 | | | |
| Cloth filter | 0.015 | 0.35 | | | |
| | <pre>Type of Dust Collector Multicyclones Electrical precipitators Multicyclone and electrical pre- cipitators Multicyclone and cloth filter Electrical pre- cipitators Multicyclone and electrical pre- cipitators Cloth filter</pre> | Range of Dus from CollType of Dust Collectorfrom Coll grain/scf2/Multicyclones1.55 - 3.06Electrical precipitators0.04 - 0.15Multicyclone and electrical pre- cipitators0.03 - 1.3Multicyclone and cloth filter0.039Electrical pre- cipitators0.03 - 0.73Multicyclone and electrical pre- cipitators0.04 - 0.05Cloth filter0.04 - 0.05 | | | |

a/ Grains/scf - Grains/standard cubic foot of gas corrected to 60°F and 1 atm. pressure. The operation of electrostatic precipitators has not been entirely satisfactory in the past because of decreasing efficiency over extended periods due to the effects of the cement dust on the high voltage components. $\frac{4}{}$ Also, when kilns have been shut down and then restarted, it may be necessary to by-pass the electrostatic precipitator for periods up to 24 hr. because of the danger of explosion from the presence of combustible gas or coal dust.

The total installation cost of an electrostatic precipitator is shown to be as high as 400% of the purchase cost in the HEW publication AP-51.7/ It is reported that this figure should be somewhat higher based on costs frequently experienced in the cement industry.8/ Recent cost data for electrostatic precipitators used in the cement industry indicate that the installed cost for precipitators having efficiencies of 99.0 - 99.9% ranges from \$1.00 to \$3.50/acfm with an average of \$1.80/acfm.10/

10.5.2.3 <u>Fabric Filters</u>: Fiberglass baghouse filters have had much success in controlling kiln emissions. Bag life averages 2 years or more.⁴/ A big plus in baghouse installations is the fact that duct designs are simple and uncomplicated, requiring little study for the flow of gases when compared with the frequently complicated model studies necessary for good gas-flow patterns in the electrostatic-type dust collector.⁴/

Moisture condensation in glass-fabric filters can present problems. However, dew point temperatures are normally avoided by proper application of insulation to ducting, etc., and by proper operation to avoid condensation.

The simplicity of design and operation of the fiberglass filter system, which lowers the cost, is balanced to some extent by increased fan power needed to overcome pressure drop across the baghouse. Many baghouses operate with a pressure drop of 3 to 7 in. of water. Sample data for fiberglass baghouses are given in Reference 9.

The total installation cost of fabric filters is shown to be as much as 400% of the purchase cost in HEW Publication AP-51. $\frac{7}{}$ This figure is claimed to be in line with cement industry experience. $\frac{8}{}$

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CHAPTER 11

FOREST PRODUCTS INDUSTRY

11.1 INTRODUCTION

The forest products industry as considered here encompasses forestry, sawmill, plywood, particleboard, hardboard, and pulp mill operations. Emissions from this industry are highly variable, and range from dust resulting from logging operations to particulates emitted from lime kilns in pulp mills. Particulate emission sources include wood-waste incinerators, plywood dryers, sawmill planers, sanders, recovery furnaces, and power boilers. Figure 11-1 presents a composite flow diagram for the forest products industry.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment associated with this industry are discussed in the following sections.

11.2 FORESTRY OPERATIONS

Forestry operations center around timber cutting. Trees are harvested by logging crews and transported to sawmills, plywood plants, etc., for subsequent processing. Logs are transported by truck, floated down a river, or towed by tugs in the form of "log booms or rafts."

11.2.1 Emission Sources and Rates

Apart from the dust generation resulting from logging operations, a major source of air pollution in forestry operations is the burning of wood residues. Common methods of disposal include open burning and incineration in a "wigwam" burner. The diversity of reasons for burning and the large land areas involved lead to significant pollution from these practices.

Determination of the emission potential of slash burning is difficult because accurate estimates for total acreage or fuel loading for range burning are not available. Particulate emissions from slash burning have been estimated by two agencies of the U. S. Department of Agriculture.¹/ The Forest Service reported an estimate of 17 million tons of particulate matter produced by "Prescribed Fires" in the United States in 1967. Six million tons of this total are attributed to slash burning. Slash burning, primarily practiced in the western United States, is employed to reduce the flammability of heavy concentrations of slash left after timber cutting.



Figure 11-1 - Composite Flow Diagram - Forest Products Industry

190

Prescribed burning in the eastern United States is used primarily to remove accumulated litter on the forest floor and the ll million tons emitted are not included in the slash-burning category. The Forest Service also estimates that the "fuel consumed in the west" is 21×10^6 tons per year.

The Soil and Water Conservation Research Division estimates that 25 million tons of logging debris are burned each year and that 6.5×10^6 tons of particulates are produced by prescribed burning in the forests.²/

As shown in Table 11-1, emissions from slash burning are taken to be 6 million tons in accordance with the estimate of the Agriculture Department. Emissions from vehicle traffic on logging roads were not estimated.

11.2.2 Effluent Characteristics

Data on effluent characteristics from slash burning are meager. Research is being conducted on the subject at Oregon State University, Washington State University, and the University of Washington.

Field tests on slash burning conducted by the University of Washington investigators have resulted in the following observations: $\frac{3}{2}$

1. Ground-level particulate increased to nearly 10 times the background immediately downwind from a broadcast burn. The particulate in the smoke plume in the fire vicinity reduced visibility to 0.5 km., but at a distance of 19 km. from the fire the visibility had increased to the level found over Seattle.

2. Similarly, high CO and CO_2 concentrations found at the fire site decreased rapidly to ambient conditions in horizontal and vertical directions.

3. Hydrocarbon analyses of the gas samples revealed low concentrations of 25 components, the most significant of which appeared to be the low molecular weight hydrocarbons and alcohols including ethylene, ethane, propene, propane, methanol, and ethanol. Several unsaturated components were found, but the quantities were relatively low.

The results of the study of broadcast fires, plus those on pile and laboratory fires, suggest that broadcast fires can be modeled in the laboratory with respect to burning characteristics, gaseous and particulate emissions from different fuel density, packing, quality, and method of ignition. Furthermore, that study indicates that the air pollution aspects of slash burning can be minimized by establishing a high energy fire with a strong convection column under conditions favorable for rapid atmospheric dispersion.

TABLE 11-1

| | | PARTIC FOREST P | ULATE EMISSIONS RODUCTS INDUSTRY | | | | |
|----------|---|--|--|--|--|---|---|
| | Source | Quantity of Material | Emission Factor | Efficiency of Control C_ | Application of Control Ct | Net Control <u>Cc^{.C}t</u> | Emission (tons/yr) |
| 1. | Slash Burning | 23,000,000 tons/yr | | | | | 6,000,000 |
| 11. | Wigwam Burners | 27,500,000 tons/yr | 10 lb/ton | | | | 132,009 |
| ш. | Chemical Pulp Mills | | | | | | |
| 26T 2 | A. Kraft Process Recovery furnace Lime kiln Dissolving tanks B. Sulfite Process Recovery Furnace N.S.S.C. Process Recovery furnace Fluid bed reactor D. Bark Boilers | 24,300,000 tons pulp 1/3 of 2,500,000 tons pulp 1/3 of 3,500,000 tons pulp 15% of 3,500,000 tons pulp 32,000,000 tons pulp | 150 lb/ton 45 lb/ton 5 lb/ton 268 lb/ton 24 lb/ton 533 lb/ton | 0.92 0.95 0.90 0.92 0.92 0.70 Total fr | 0.99 0.99 0.33 0.99 0.99 1.00 om Chemical Pulp | 0.91 0.94 0.30 0.91 0.91 0.70 Mills | 164,000 33,000 42,000 10,000 1,000 42,000 82,000 374,000 |
| | Hardboard | 1,500,000,000 sq. ft. plywood/yr | | | | | |
| | A. BoilersB. CyclonesC. Veneer Dryers | 2.6 45 250 | b lb/ton burned dry tons MM sq. ft., plywood lb/MM sq. ft., plywood | | | | 3,000 67,000 <u>4,000</u> 74,000 |
| | | | | Total fo | r Forest Product | s Industry | 6,580,0 00 |

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Available data on the chemical and physical characteristics of effluents from forestry operations are summarized in Table 11-2.

11.2.3 Control Practices and Equipment

The various forestry operations that emit particulate matter, which include slash burning and incineration, do not lend themselves to the use of control equipment. Although some considerations of burning methods and meteorological conditions would undoubtedly influence these emissions, these factors do not fall in the category of control equipment.

11.3 SAWMILL OPERATIONS (LUMBER PRODUCTION)

The sawmill or lumber industry includes production of lumber, shingles and shakes, posts and pilings, and some lumber remanufacture and planing mills. Operations include debarking, sawing, and planing.

11.3.1 Emission Sources and Rates

The basic lumber production processes create few pollutants. Sawing and planing equipment generate wood wastes--sawdust, shavings--in particulate form. Planers usually have effective containment of this waste; but saws are seldom designed to contain and control fine particles, and wood dust emissions occur.

Collecting, transferring, and processing wood wastes for by-product markets or incineration cause significant particulate emissions because of the huge volume of the material.

Kiln drying of lumber probably does not create hydrocarbon emission, although this process has not been adequately studied.

Incineration of sawmill wood and bark wastes is the main air contaminant source. The "wigwam"-type burner is one common device used for this purpose. Reference 4 reports on a study of "wigwam" burners in the Pacific Northwest. Average temperature of the gases leaving the burner was 485°F, which is considerably below the 600-900°F temperature range recommended for smoke-free operation. Improving the combustion efficiency would reduce emissions from these burners.

Emissions from "wigwam" burners associated with sawmills are included in the 1.32×10^5 tons/year shown for these burners in Table 11-1.

TABLE 11-2

CHARACTEREDITICS OF EFFICIENTS FROM

A. Particulate (Part I) Chemical Composition Particle Density Electrical Resistivity Moisture Content Toxicity Source Particle Size Solids Loading Forest Products Industry 1. Forestry operations 950-1,510* a. Slash burn-Alkanes, alkenes, al-(dependent on locohols, ketones, ing cation, wind diessential oils, rection and stage fly ash of fire) 2. Savaills a. Planers Fine sawdust b. Wigwam burner Microscope: 0.004-0.61 Average: 24 < 2 0.17 (corrected to 12\$ 00,) Plywood plant a. Incineration (see wigwam burner) Hydrocarbons b. Vencer dryer c. Sander Drum sander; Balico Sawdust, sander dust analysis, 5.2 <5, 18 <10, 35.5 <20,</pre> 93.1. <40 Optical microscope: Mean count size, 22 d. Pressing Phenolic resin machine 4. Particleboard plant a. Incincration (see wigwam burner) b. Dryer c. Pressing anchine Formaldchyde-urea resin d. Sander (see plywood)

Micrograms/cubic meter.

See Coding Key, Table 5-1, Chapter 5, p. 45, for units for individual effluent properties.

A. Particulate (Part 1) (Concluded)

| Source | Particle Size | Solids Loading | Chemical Composition | Density | Resistivity | Content | Toxicity |
|--|---|----------------------------------|---|---------|--|-------------------------|----------|
| Forest Products Industry 5. Pulp Wills | | | | | | | |
| (1) Hecovery furnace | 50-85 < C | 3-8 (dry) Mean loading 3.8 | Na ₂ SO ₄ : 14-90 Average - 80 Na ₂ CO ₃ : 2.6-73 Average - 11.2 | | See Figures 11-2 and 11-3 for detailed data | 0.2-1.2 Average 0.45 | N.T. |
| | Electron microscope count 16.0 < 0.5 53.2 < 1 30 > 1 Cascade impactor 50 < 0.95-1.1 | | NaCl: 0.6-14 Average - 2.3 Nn2S: 3.3-5.4 Average - 4.4 Carbon, Fly ash | | | | |
| (2) Lime kiln | 95 < 25 | 3-20 | СвО. СаСО3, Na2CO3, Na2SO4, MgCO3, Fe2O3, Al2O3, SlO2 | | | | N.T. |
| (3) Smelt dissolving tank | 9 0 < 5 | 0.17-1.3 | Na ₂ CO3, Na ₂ S, Na ₂ SO4 | | | | N.T. |
| (4) Boilers | Pabeo Analysta | | | | | | |
| (a) Dark-Lifeu | Large $74 < 40$ | 1.5-2.4 (ury) | | | | | |
| <pre>(b) oil-fired (c) coal-fired</pre> | | 0.04-0.4 (dry) 3.1-3.5 (dry) | | | | | |
| b. Sulfite, (1) Recovery furnace (megnesium bisulfite) | | 4.94 | | | | | |
| (2) Boilers (a) bark-fired (b) oil-fired (c) coal-fired | | 1.32 0.04 3.1-3.5 | | | | | |
| 2. N.S.S.C. | | | | | | | |
| (1) Recovery furnace | | 4 -0 | | | | | |
| (2) Smelt dissolving tank | | 1.3 | | | | | |
| (3) Boilers | | 2.07.2.4 | | | | | |
| (b) oil-fired | | 2.05-2.4 0.04 | | | | | |
| · · | | | | | | | |

* High NaCl content due to seawater immersion of logs.

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A. Particulate (Part II)

| Source | Solubility | Wettability | Hygroscopic Characteristics | Flammability or Explosive Limits | Handling <u>Characteristics</u> | Optical Properties | <u>Odor</u> |
|--------------------------------------|--|---------------------------------|--------------------------------|-------------------------------------|------------------------------------|---|-------------|
| Porest Products Industry | | | | | | | |
| 1. Porestry operations | | | | | | | |
| a. Slash burning b. Wigwam burner | | | | | | | |
| 2. Savaills | | | | | | | |
| 5. Plywood plant | | | | | | | |
| 4. Particleboard plant | | | | | | | |
| 5. Pulp sills | | | | | | | |
| a. Eraft and soda | | | | | | | |
| (1) Recovery furnace | Na ₂ SO ₄ - s. H ₂ C Na ₂ CO ₅ - s. H ₂ C NaCl - s. H ₂ O, s.s. al. |), glc.), s.s. al. glyc. | Нудтовсоріс | | Agglomerates, corrosive | Sodium salts- white;char, fly ash - black | |
| (2) Lime kiln | Να ₂ CO ₃ - 3. Η ₂ Ο CaCO3 - 5. Η ₂ Ο ΜgCO3 - 5. Η ₂ Ο Να ₂ SO ₄ - 3. Η ₂ Ο s.s. al. |), s.s.nl.), glyc. | | | | | |
| (3) Smelt dissolv- ing tank | Na2CO3 - s. H2C Na2S - s. H2O a |), s.s. al. s.s. al. | | | | | |

B. Carrier Gas

| Source | Flow Rate | <u>Temperature</u> | Moisture Content | Chemical Composition | Toxicity | Corrosivity | <u>Odor</u> | Flammability or Explosive Limits |
|---|---|----------------------------|----------------------|--|----------|-------------|-------------|-------------------------------------|
| Forest Products Industry 1. Forestry operation | | | | | | | | |
| a. Slash burn- ing | | 900-1550 | | 002, 00, CH4, C3 A8 C2H4, C2H6, C3H6 | | | | |
| 2. Sammills | | | | N2, 02 | | | | |
| a. Planers | | | | | | | | |
| b. Wigwam burner | Avg. veloc- ity at burner top, 600 ft/min | 166-866 Avg. 485 | | 02, N2, CO, CO2, and various gaseous products of wood pyrolysis | 1 | | | |
| 3. Plywood plants | | | | | | | | |
| a. Incineration (see wigwam burner) | | | | | | | | |
| b. Dryer | | 296-334 | Dew Point 108-133 | Hydrocarbons, sir | | | | |
| c. Sander | a) 40-60• | | | Air | | | | |
| d. Pressing machine | | | | Phenolic resin (gas and vapor) air | | • | | |
| Particleboard plant | | | | | | | | |
| a. Incineration (see wigwam burner) | | | | | | | | |
| b. Dryer | | | | | | | | |
| c. Pressing machine | | | | Formaidehyde-urea resin, air (gas and veccr) | | | | |
| d. Sander (see plywood) | | | | *** | | | | |
| | | | | | | | | |

* Actual cubic feet/min.

197

B. Carrier Gas (Continued)

| S | ource | Flow Rate | Temperature | Moisture Content | Chemical Composition | Toxicity | Corrosivity | <u>Odor</u> | Flammability or Explosive Limits |
|----|--|--|---------------------|---|---|---------------------------------|---|----------------------|--|
| 5. | Pulp mills a. Kraft & Soda (1) Recovery furnace | (w.) 20-568 (b) 278-568 Avg. 432** | 270-650 avg. 350 | 20-40 Dew Point 135-180 | Typical Orsat analysis $CO_2 = 12.5$ CO = 0.1 $O_2 = 7.6$ $N_2 = 79.8$ Minor components $H_2S = 150-935$ ppm 1M = 60-1,400 ppm (1-15 ppm new plants) 1DS = 0-125 ppm $SO_2 = 1-350$ ppm | \$0 ₂ - 5 | Corrosive due to sulfur compounds | Mal- odor- ous | H ₂ S: upper limit in air, 45.5%; lower limit in air, 4.3% CH ₃ SCH ₃ ; upper limit in air, 9.19%; lower limit in air, 2.23% CH ₅ SH: upper limit in air, 21.6%; lower limit in air, 3.9% |
| | (2) Linne kiln | (a) 7-50 (b) 31-53** Avg. 44 | 400-900 | 400-600 *** Avg. 556 | CO ₂ - 16.5-22 CO - 0-0.7 O ₂ - 0.3-5.1 N ₂ - 77.1-78.4 Minor components H ₂ S: 0.08-0.25*** SO ₂ : 0-2.5*** MMM, DS: 0-0.6*** | SO ₂ -5 irritant | Corrosive due to sulfur compounds | Hal- odor∽ ous | |
| | (3) Smelt dissolving tank | (b) 45 ** | 170-200 | 670 *** | SO ₂ : 0-0.05*** H ₂ S: 0.01-0.04*** MM, DS: 0.01-0.09*** Ng balance | SO ₂ - 5 irritant | Corrosive due to sulfur compounds | Mal- odor- Sus | |
| | <pre>(4) Boilers (a) bark-fired</pre> | (b) 96-125 Avg. 112** | | 654-868*** Avg. 774 | CO ₂ , O ₂ , N ₂ , SO ₂ | SO ₂ - 5 irritant | " | | |
| | (b) oil-fired | (b) 99-366** Avg. 218 | | 336-1,240*** Avg. 739 | CO ₂ , O ₂ , N ₂ , SO ₂ | SO ₂ - 5 irritant | " | | |
| | (c) coal-fired | (b) 91.4-340** Avg. 204 | | 2 45-908 ** Avg. 539 | CO ₂ , 02, N2, SO2 | SO ₂ - 5 irritant | " | | |

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Standard ft³/air-dried ton.
 Pound/air-dried ton.
 MM - Methyl Mercaptan. DS - Dimethyl Sulfide.

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TABLE 11-2 (Concluded)

B. Carrier Gas (Concluded)

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| Source | Flow Rate | Temperature | <u>Moisture Content</u> | Chem. Composition | Toxicity | Corrosivity | <u>Odor</u> | Flammability or Explosive Limits |
|---|---|-------------|---|---|---------------------------------|--|----------------------|--|
| b. Sulfite (1) Recovery furnace (magnesium bisulfite) | b) 463** | 509 | 3,000*** | СО2, №, О2, SO2, H2S, MM, DS | SO ₂ - 5 irritant | Corrosive due to sul- fur com- pounds | Mal- odor- ous | See above |
| (?) Boiler (a) bark-fired | b) 105-122 ^{**} Average 113 | | 780-910 ^{***} Average 833 | ^{CO} 2, №2, ^O 2, SO2 | n | | | |
| (b) oil-fired | b) 148-470 ^{**} Average 295 | | 505-1,430 ^{***} Average 1,000 | 11 | | | | |
| (c) coml-fired | b) 137-388 ^{*#} Average 258 | | 367-1,040 ^{***} Average 730 | n | 'n | " | | |
| c. N.S.S.C. (1) Recovery furnace | b) 107-189 ^{**} Average 148 | 325-1100 | 1,100-1,400 ^{%**} Average 1,250 | ^{СО} 2, №2, О2, SO2, Н ₂ S | 19 | " | | |
| (?) Smelt dis- solving tank | b) 45** | 500 | 670*** | 14 ₂ 5, 50 ₂ , MM, DS | " | | " | |
| (3) Boilers(a) bark-fired | b) 59-68 ^{##} Average 63.5 | | 454 | co2, N2, O2, SO2 | " | " | | |
| (b) oil-fired | b) 306-318 Average 310 | | 1,040-1,080 ⁰⁰⁰ Average 1,060 | | | | | |
| (c) coal-fired | b) 284-317 Average 303 | | 757-802*** Average 778 | | | | | |

•• Methyl Mercaptan. ••• Dimethyl sulfide.

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Figure 11-2 - Electrical Resistivity of Salt Cake<u>18</u>/



Figure 11-3 - Electrical Resistivity of Sodium Sulfate as a Function of Moisture in Gas at 300°F (Laboratory Measurements)<u>18</u>/

11.3.2 Effluent Characteristics

Limited data were found for the effluent characteristics of emission sources in sawmills. Available data are summarized in Table 11-2.

11.3.3 Control Practices and Equipment

Comments on control practices for sawmills are included with those for plywood plants in Section 11.4.3.

11.4 PLYWOCE, PARTICLEBOARD, AND HARDBOARD PLANTS

Part of the wood wastes from sawnills is utilized in the manufacture of plywood, particleboard, and hardboard. Figure 11-1 presents typical process flow diagrams for plywood veneer and layout plants and a particleboard plant.

In the plywood manufacturing cycle, the logs first go through debarking, peeling, and clipping to produce a veneer material. Following drying, the veneer proceeds through layup and glue spreading, pressing, trimming, and final sanding.

In a particleboard plant, the waste wood is screened, ground, and dried in the initial processing steps. After the drying step, the material is mixed with resin to form panels. The panels are then pressed, trimmed and sanded to produce the finished product.

11.4.1 Emission Sources and Rates

Particulate pollutants in comparatively small amounts are produced in these processes. In plywood veneer plants, the disposal of wood waste creates the major emission problem. In plywood layout and finishing plants some emission sources also involve wood wastes. Incineration and boiler plants are the principal means of disposal and "wigwam" burners are used quite extensively.

Emission sources in a plywood layout and finishing plant, in addition to incinerators and power boilers, include veneer dryers, panel pressing operations, and sanders. Green veneer panels (50% moisture) are dried to less than 10% moisture in long enclosed heated chambers called ventilated veneer dryers. Two dryers are rarely ever alike. They emit a visible blue plume which is saturated with water vapor and loaded heavily with hydrocarbons.
Plywood pressing operations are another source of emissions. Phenolic resin loss to the atmosphere during pressing of panels may contribute to local air pollution problems. Overall emissions from this type of resin appear to be very minor although detailed data are not available.

Plywood sanding operations produce a large volume of sanderdust. Plywood is either produced as unsanded sheathing or it is sanded on either one side or two sides. Volume of sanderdust generated has been reported to vary from 33.3 to 99.5 tons/million sq ft of sanded plywood panels. $\frac{5}{}$

Emission sources at a particlebcard plant include: (1) transfer operations, (2) drying operations, (3) pressing operations, (4) sanding operations, and (5) incineration.

The only waste material at particleboard-hardboard plants is sanderdust, as other wastes are recycled to the manufacturing process. Emissions from incineration of this material would be similar to those described for sawmills.

Particleboard plants purchase plywood trim, planer shavings, and sawdust, which includes small quantities of sanderdust, as raw materials. As the loaded trucks dump into receiving hoppers, considerable quantities of the fine particulate are carried into the atmosphere.

Particleboard and hardboard plants process "green" raw material through rotary kiln-like dryers. No data were found for emissions from these dryers.

Emissions of formaldehyde-urea resin during pressing operations have produced air pollution problems near particleboard and hardboard plants. The formaldehyde odor of the finished product is the main problem. The bulk of formaldehyde emission occurs during the high temperature $(350^{\circ}F)$ press which cures and sets the resin. It has been reported that at a press temperature of 350°F, and with a 1.8:1 molecular weight ratio of formaldehyde urea resin, 3% of the total solids will be leached as free formaldehyde. One percent would be emitted at a 1.2:1 mole ratio. The resin binder itself consists of approximately 10% of the total weight of particleboard and 6% in hardboard produced by the dry method.

Emissions from sanding operations would be similar to those discussed under plywood manufacture. After being sized in the trim saws, particleboard is sanded on two sides and the hardboard on one. The quantity of sanderdust generated depends on sanded depth and density of the board and has been reported to vary from 42.5 to 156 tons/million so ft sanded. $\frac{5}{2}$ Emission rates from these plants are summarized in Table 11-1. Limited data are available as these plants have not been thoroughly studied as air pollution sources.

11.4.2 Effluent Characteristics

Data on effluent characteristics from plywood, particleboard, and hardboard plants are limited. Table 11-2 summarizes information currently available. Dust from a drum sander is about 20 wt. % less than 10 $_{\rm H}$.

11.4.3 Control Practices and Equipment

Emissions from these operations and from sawmills result primarily from steps producing sawdust or from incineration. Cyclones have wide application in the collection of sawdust but very little information is available on their design or operating efficiency. Baghouses can probably be used for the collection of this sawdust in many instances, but the pressure drop involved would be higher than for cyclones. Afterburners could be used on sources which emitted combustible vapors or mists.

11.5 PULP INDUSTRY

Characteristic air-pollution problems of the pulp industry are associated with the release of malodorous sulfur compounds and particulate matter. Pulp is made by either the sulfate (kraft), sulfite, semichemical, soda, or by a mechanical process. Most of the pulp produced in the United States is made by the kraft process. The sulfite process accounts for less than 10% of the pulp production.

11.5.1 Kraft Process

The chemical pulping process known as kraft pulping, employs a cooking liquor whose main ingredients are sodium sulfide and sodium hydroxide in solution. High-pressure digestion of wood chips dissolves the liquor in wood, and frees its cellulose fiber for use as pulp. A typical batch digester will reach temperatures of 350° F and pressures of 110 lb/ sq in., and take 3 hr. for a cook. The full cooking pressure is used to blow the digester contents into the blow pit, ending the cooking cycle.

More recently, new mills have been utilizing continuous digestion because of improved control over the cooking cycle and hence a better quality of pulp. Wood chips, liquor and steam are supplied continuously at one end of the digestor, while the finished pulp and spent liquor are removed at the other end. Continuous digesters are also used to produce a low-grade pulp from sawdust. As shown in Figure 11-1, diluted pulp from the blow pits is separated from the spent liquor by filtration and washing. The spent cooking liquor at this point is black from the lignin, waste fibers, and dissolved sulfide salts--and hence called "black liquor." Vitally important to the economics of the kraft process is the recovery and recycle of inorganic chemicals in the black liquor. To accomplish chemical recovery, black liquor is concentrated by evaporation and burned in recovery furnaces. Most of the organic and inorganic sulfur is reduced in the lower oxygen-poor region of the furnace to form an ash or smelt of molten chemicals, primarily sodium sulfide and carbonate. The upper zone of the recovery furnace, ideally an oxygen-rich zone, serves to oxidize the residual sulfur organics carried up from the reducing zone below.

Recovery furnaces also produce valuable process steam from the heat of the burning black liquor. Hot gases from the combustion zone relinquish most of their heat energy in passing over boiler tubes and heat economizers. Steam may be used elsewhere in the pulp-making process or sent to turbines for electrical power generation. Additional utilization of the furnace heat is accomplished by the use of a direct contact evaporator. Such an evaporator utilizes the heat of the flue gases to further evaporate black liquor just prior to its firing in the recovery furnace. Direct contact evaporation has one serious drawback, however, from an air-pollution standpoint--the stripping of hydrogen sulfide which occurs when acidic flue gases contact the black liquor. Following the direct contact evaporator, furnace gases pass through collectors (such as electrostatic precipitators and scrubbers) to remove particulate matter consisting of sodium salts and carbon particles. Exhaust gases containing the remaining particulates, plus the malodorous sulfur compounds, then pass to the atmosphere.

The sodium sulfide and sodium carbonate smelt, formed at furnacegrate level, falls into the smelt tank where it dissolves in water, forming the "green liquor." The sodium carbonate is converted to sodium hydroxide by the addition of lime. The reaction performed in the causticizer or shaker is shown below. (1) Calcium carbonate precipitates as a lime mud, and after washing is sent to the lime kiln where it is calcined to calcium oxide. (2) This fresh lime is then slaked (3) and available for further causticizing. After conversion of sodium carbonate to the hydroxide, the "green" liquor becomes "white" liquor and is ready for recycle as cocking liquor.

> (1) $Ca(OH_2) + Na_2CO_3 \longrightarrow 2NaOH + CaCO_3$ (2) $CaCO_3 \longrightarrow CaO + CO_2$ (3) $CaO + H_2O \longrightarrow Ca(OH)_2$

11.5.1.1 Emission Sources and Rates: The kraft pulp mill emits a wide range of air pollutants, with the malodorous sulfur gases being the most objectionable because of their low threshold of detection in the ambient air. Other categories of kraft mill emissions include particulates, mists, and less odorous gases which are emitted from numerous process points. Table 11-3 shows the atmospheric emission sources and the general category of atmospheric emission which each source contributes.⁶/ Table 11-4 identifies the emission category by chemical composition. $^{6/}$

TABLE 11-3

ATMOSPHERIC EMISSION SOURCES IN A KRAFT MILL6/

| Source | Emission Categories |
|--|--|
| Digester relief and blow gases | Malcdorous gases and water vapor |
| Knotter and brown stock washers, washer seal tanks | Malodorous gases, mists and organic vapors |
| Black liquer storage | Malodorous gases |
| Black liquor oxidation tower | Malodorous gases and organic vapors |
| M. E. evaporators | Malodorous gases |
| Recovery furnace | Particulates, malodorous gases, other gases (including sulfur dioxide) |
| Smelt dissolver tank | Mists and odorous gases |
| Lime kiln | All categories |
| Causticizer | Mists |
| Bleach plant | Mists and other gases |
| Power boilers (including oil-fired and bark-fuel boilers) | Particulates and other gases |
| Paper incinerators | Particulates and other gases |
| Materials handling | Particulates |

TABLE 11-4

ATMOSPHERIC EMISSIONS FROM KRAFT PULP MILLS2/

| General Category | Composition |
|--|---|
| Particulates | sodium carbonate, sodium sulfate (salt cake), calcium oxide (lime), sodium oxide, carbon (char), fly ash |
| Mists | sodium carbonate, sodium sulfate, black liquor, caustic and hypochlorite + sul- furous gases |
| Malodorous (sulfurous gases) | hydrogen sulfide, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, ethyl mercaptan, isopropyl mercaptan, n-propyl mercaptan, ethyl sulfide, and others |
| Other gases (less odors and including organic vapors) | Carbon monoxide, sulfur dioxide, chlorine and chlorine dioxide, carbon dioxide, methanol (wood alcohol), ethanol (rubbing alcohol), alpha-pinene, acetone |

The largest source of potential particulate emission is the recovery furnace; other sources of particulate emission include the lime kilns, smelt tanks, and bark- and/or coal-fired power boilers. The recovery furnace can also account for half of the total potential sulfur emissions, although other sources such as the digesters and multi-effect evaporators should not be ignored as maledorous emission sources.

Water vapor

In the recovery furnace, heat is obtained from the combustion of the organic constituents of the black liquor, and the inorganic constituents are recovered as a molten smelt. The concentrated black liquor at 60 to 65% solids content is sprayed into the furnace where the water content is flashed off.

When the black liquor is burned in the furnace, an appreciable quantity of particulate is liberated. Chemical content of the solids entrained in the recovery furnace flue gases is a function of furnace operating conditions and feed liquor composition. Usually Na₂SO₄, Na₂CO₃, and NuCl constitute 75 to 90% of the particulate weight. The remainder is composed of NaHCO₃, unburned organic material, and water-soluble fly ash. The relative mass fractions of Na₂SO₄, Na₂CO₃, and NaCl in the fune can vary greatly from mill to mill. For example, NaCl is present in measurable quantities when logs have been stored in salt water before chipping; inland mills have less NaQl passing through the recovery system.

The smelt recovered from combustion of black liquor in the recovery furnace is dissolved in water and weak wash in the dissolving tank. As a result of violent reaction and flashing, a considerable quantity of moisture containing dissolved sodium compounds is discharged from the dissolving tank to the atmosphere.

Boilers which are wholly or partially fired with bark are another source of particulate emissions. Fly ash is the dominant particulate emitted from this source.

Emission levels for the kraft pulping process are summarized in Table 11-1. Farticulate emissions from kraft mills currently total about 239,000 tons/year.

11.5.1.2 Effluent Characteristics: The chemical and physical properties of effluents from kraft pulping processes are detailed in Table 11-2. Particulates emitted from the recovery furnace range from 50 to 85 wt. %less than 2 μ . Lime kiln particulates are 95 wt. % less than 25 μ , while those from the smelt tanks are 90 wt. % less than 5 μ .

11.5.1.3 <u>Control Practices and Equipment</u>: Electrostatic precipitators are normally used to recover particles emitted from the recovery furnaces. Electrostatic precipitators may remove 85 to 97% of the particulate matter while Venturi scrubbers may remove 60 to 95%.7/

The recovery of particulate matter from the flue gases leaving the recovery furnace, lime kilns, and dissolving tanks is described in Reference 8. Uncontrolled emissions from the smelt tank may be as high as 20 lb/ton of pulp. Use of a simple water spray may reduce this to 5 lb/ton, while a mesh demister may further reduce this to 1 or 2 lb/ton.7.9/ The control equipment used to decrease smelt tank emissions are mesh pads, packed towers, orifice scrubbers, or cyclonic scrubbers. The pressure drop for an orifice scrubber is approximately 8 in. of water. The pressure drop across a mesh pad is usually less than 1 in. of water, but sprays located above the pads may be required periodically to remove collected chemicals. $\frac{11}{}$ The recovery of particulate matter from the flue gases leaving the recovery furnace (and from the lime kilns and dissolving tanks) is described in Reference 8. To reduce fallout in the mill vicinity and/or comply with stack emission standards, some mills practice secondary wet scrubbing as an adjunct to the use of primary recovery devices on the recovery furnace flue gases. Six types of secondary scrubbers for particulate matter removal in flue gases are in use in the U.S. industry at the present time. $\underline{12}$ / These are usually low-pressure-drop devices of less than 2 in. of water. They may be constructed of fiberglass or lined with acid resistant brick or concrete. The wide variation in water usage rate for these secondary scrubbing installations is shown in Tatle 11-5. $\underline{12}$ / It has been reported that the initial installation cost of various secondary scrubbing systems ranges from \$35,000 to \$55,000/100 tons pulping capacity. $\underline{13}$ /

TABLE 11-5

| | gpm/1,000 cfm | |
|------------------------------|---------------|--------------------|
| | Water Use | Shower |
| Type | Rate | Rate |
| Vertical impingement screen | 0.4-2.3 | 1.0-2.3 |
| Multiple Venturi impingement | 4.6-11.3 | 10.8 <i>-</i> 22.6 |
| Chevron baffle plate | 0.3 | 8.7 |
| Pease-Anthony cyclonic | 0.5-4.1 | 1.2-7.6 |
| Vertical baffle plate | 0.6 | 1.2 |

WATER USAGE FOR SECONDARY SCRUBBING INSTALLATIONS12/

The installation of scrubber units downstream of an electrostatic precipitator is discussed in Reference 14. Table 11-6 shows average performance data for this type of unit and Figure 11-4 gives the particle size efficiency curve. Tests showed conclusively that dust collection efficiency <u>decreased</u> when the flue gas entered the washer saturated with water vapor (at the dew point temperature). It is surmised that when flue gas enters the washer at a temperature considerably above the dew point, large quantities of steam or fog are produced at the first bank of spray nozzles, where the gas is cooled to the dew point. Solid particles carried in the gas act as condensation nuclei for the saturated steam, thereby resulting in the high collection efficiency for the 5 to 30 μ range particles as shown in Figure 11-4.



Figure 11-4 - Particle-Size Efficiency Curve TE Washer-Black Liquor Recovery Furnace*14/

* Pressure drop less than 1 in. w.g.

TABLE 11-6

AVERAGE PERFORMANCE DATA FOR FULL-SCALE TE WASHER*14/

| Gas flow, ft ³ /min | 57,000 |
|--|--------|
| Dust loading, grains/std ft ³ | |
| Inlet | 0.21 |
| Outlet | 0.027 |
| Efficiency, % | 88 |
| Soda ash recovered, 1b/min | 1.7 |
| Liquid effluent from scrubber, grm | 25.3 |
| Concentration, g/liter as $NaHCO_3$ | 7.73 |
| Gas temperature, °F | |
| Inlet: | |
| dry-bulb | 272 |
| wet-bulb | 169 |
| Outlet: | |
| dry-bulb | 166 |
| wet-bulb | 162 |

* Pressure drop less than 1 in. w.g.

Venturi scrubbers are used on stack gases from recovery furnaces to serve as direct-contact evaporators by using black liquor as the scrubbing medium. The particulate collection efficiency of one such unit is reported to be 74.2%.5/ The pressure across this unit was not given. It was stated that steam-atomizing nozzles were installed in an effort to improve collection efficiency.

Wet scrubbers are also used on lime kiln stack gases. Test data for one unit are given in Table 11-7. $\frac{16}{}$

Pilot plant studies have been conducted making use of electrostatic pre-agglomeration of black liquor boiler fume followed by a flooded disk or Venturi scrubber. $\frac{17}{}$

Large diameter cyclones of 48 in. to 60 in. are commonly used for collection of the emissions from bark boilers. Recovery efficiencies are in the range of 98% with a pressure drop of 3 to 4 in. w.g. $\frac{10}{2}$

TABLE 11-7

TEST DATA, LIME KILN VENTURI SCRUBBER16/

| Inlet gas temperatures, Exit gas temperatures, Scrubbing slurry temper Inlet gas volume, cfm a Inlet gas volume cfm a Outlet gas volume, cfm Outlet gas volume, cfm | °F - sat' atures, °1 t STP - 33 t duct ec: at STP - 3 at duct co | d F 2°F, 29.9 nditions 32°F, 29.9 onditions | in. Hg 9 in. Hg | 309- 156- 155- 17,4 27,8 20,4 26,2 | 344 168 166 00-24,71 00-40,00 00-25,80 00-32,80 | 00 00 00 00 |
|---|---|--|--------------------|--|---|----------------------|
| | | | Run No | . | | |
| | 1 | 4 | 5 | 6 | 7 | 8 |
| Pressure dron ecross venturi | | | | | | |
| and cyclone, in w.g. | 11.25 | 6.75 | 10.75 | 6.75 | 5.5 | 5.5 |
| Scrubbing liquid used | Filtrate | Filtrate | Slurry | Slurry | Slurry | Slurry |
| Scrubbing liquid gpm | 510 | 290 | 4 1C | 160 | 200 | 100 |
| Scrubbing liquid, 🖗 solids | 3.3 | | 46.7 | 18 | | |
| Inlet dust load, tons/day | | | | | | |
| Acid insoluble | 0.08 | 0.16 | 0.06 | | | |
| CaCOz | 4.14 | 14.70 | 19.62 | | | |
| NaoSO4 | 0.30 | 0.03 | 0.06 | | | |
| NaoCO3 | 2.34 | 2.41 | 1.64 | | - - | |
| Total | 6.86 | 17.30 | 21.38 | | | |
| Outlet dust load, tons/day | | | | | | |
| Acid insoluble | 0.01 | 0.05 | C.02 | 0.01 | 0.09 | C.03 |
| CaCO ₇ | 0.03 | 0.10 | 0.15 | 0.15 | 0.08 | 0.37 |
| NaoSO4 | 0.04 | 0.01 | 0.02 | 0.02 | 0.02 | C.01 |
| NacCoz | 0.86 | 0.48 | 0.45 | 0.75 | 0.30 | 0.31 |
| Total | 0.94 | 0.64 | 0.64 | 0.93 | 0.49 | 0.72 |
| Dust loading, grains/ft ³ * | | | | | | |
| Inlet | 2.94 | 6.86 | 11.94 | | | |
| Outlet | 0.45 | 0.24 | 0.30 | 0.40 | 0.18 | 0.27 |
| Dust removal efficiencv % | | | | | | |
| For CaCOz | 99.3 | 99.4 | 99.5 | | | |
| For NapSO4 | 86.5 | 63.3 | 59.6 | | | |
| For Na _o CO _z | 63.0 | 80.0 | 72.5 | | | |
| Overall | 86 | 96 | 97 | | | |

* Wet gas at STP 32°F, 29.9 in. Hg.

It has been reported that the large cyclones are preferred to the smaller diameter multicyclone systems. Part of the reason for this is the low density of the bark char which is easily re-entrained and does not flow well out of the collection hoppers. $\frac{10}{}$

11.5.1.3.1 Control costs in kraft pulp mills: The cost of control equipment for the wood pulping industry is a major part of a NAPCA study conducted by Environmental Engineering, Inc., and the J. E. Sirrine Company. $\underline{11}$ / Detailed cost studies for many different control systems and combinations were developed for this study. A portion of this cost information has been extracted from the above report and is included in the following section. The reader is directed to the original report for more detailed information and for a complete set of ccst studies.

11.5.1.3.2 Descriptions of capital cost items:

<u>Purchased equipment</u>: Cost of the emission control device and all accessories and auxiliaries required for its full operation.

Equipment erection: The erection of purchased equipment only. The erection cost of building and foundations, piping and wiring is included elsewhere.

Equipment foundations and building: The installed cost of all equipment foundations, building and building foundations, floors, roof, stairs, and walkways, that are required for support, access, and enclosure of the control device.

<u>Process and instrument piping</u>: Cost of all pipe and pipe supports, erected, and including insulation and protective coating where required.

Power wiring and lighting: The installed cost of all power wiring and lighting is included. Wherever required, any substation, transformers, or switchgear costs are included under "Purchased Equipment."

Indirect capital cost: The summation of the above capital cost composes the total direct capital cost to which is added indirect cost as a percentage of direct cost. The following is a breakdown of this indirect cost:

| 15% | ContingencyUnforeseen conditions and items |
|------------|--|
| | not practical to estimate |
| 7 % | EngineeringPreparation of specifications and |
| | working drawings, selection, and evaluation of equipment |
| 1% | General Construction OverheadIncludes tempo- rary facilities, contractual supervision, timekeeping, etc. |
| 3% | Start-up CostLoss of production not included |
| 2% | Spare Parts |
| 2% | Sales Tax |
| 30% | TOTAL |

11.5.1.3.3 Description of annual cost items:

<u>General</u>: Any estimated annual cost may vary considerably from mill to mill. The following values may be considered typical and should provide reasonable comparisons of emission-control-device annual cost:

<u>Direct operating cost</u>: Direct operating cost consists of charges for:

(1) Operating labor, including overhead. A national average hourly rate of \$4.25 has been assumed. To this rate, an additional 29% is added for vacations, sick pay, holidays, payroll taxes, insurance, and fringe benefits. (Total \$5.50/hr)

(2) Power, electric, and/or steam. An electric cost of \$0.01 per KWH, and a steam cost of \$0.65/1,000 lb of steam has been used.

(3) Water. A water cost of \$0.13/1,000 gal has been used.

(4) Maintenance, including maintenance labor, replacement parts, and maintenance materials.

<u>Taxes and insurance</u>: Local property taxes vary widely over the country. Generally, this is applied as a millage on the assessed valuation. Assuming the property is assessed at 50% and 30 mills tax is applied, then the property tax would be 1-1/2% of the construction cost.

1.5% of Capital Cost

An average insurance cost has been used for the entire pulp and paper mill.

0.5% of Capital Cost

Total Taxes and Insurance 2.0% of Capital Cost

Administrative costs: This is an average cost applied to the overall plant and includes all salaried personnel (officers and supervisors), fringe benefits for salaried personnel, legal and other professional services, public relations, contributions, and office supplies and expenses. This does not include any marketing costs.

5.0% of Capital Cost

Depreciation and interest (capital recovery): Depreciation

plus interest charges were calculated from the following formula which is one of several commonly used for this purpose. An interest rate of 10% was assumed.

> Equal ennuel payment = $\frac{i(1 + i)^n \times 100\%}{(1 + i)^n - 1}$ i = interest rate

> > n = life in years

SUMMARY OF CAPITAL CHARGE ITEMS (As \$ of Capital Cost)

Estimated Life of Equipment in Years

| Item | 8 | <u>10</u> | 16 |
|---|----------|-----------|----------|
| Taxes and Insurance Administration | 2% 5% | 2% 5% | 2% 5% |
| Depreciation and Interest (Capital Recovery) | 18.7% | 16.3% | 12.8% |
| TOTAL | 25.7% | 23.3% | 19.8% |

Net annual costs have been computed on basis of equipment life as follows:

| Electrostatic Precipitators | - | 10 years |
|-----------------------------|---|----------|
| Venturi Scrubbers | - | 8 years |
| Packed Towers | - | 10 years |
| Cyclones | - | 16 years |

UTILITY COST

| | Fixed | Operating Costs Fuel, Labor, Maint., | Total (Rounded to |
|--|---------|---|----------------------|
| Item | Charges | Etc | <u>Nearest Cent)</u> |
| Steam \$/1,000 lb. Based on 1,000 BTU/lb | \$C.116 | \$ 0.535 | \$ 0.65 |
| Electricity \$/KWH | 0.0023 | C.0077 | 0.01 |
| Water \$/1,000 gal. | 0.104 | C.046 | 0.15 |
| Kraft Waste Treatment \$/1,000 gal. (primary and secondary | 0 13 | 0.03 | |
| treatment) | 0.13 | 0.03 | 0.16 |

These are values that may be considered typical in a general sense. All of these values vary considerably from mill to mill--any proper evaluation of control cost should be specifically calculated for the individual mill. However, the above costs should provide reasonable comparisons of emissioncontrol method for this study.

| | 1 | | |
|------------------------|--|-----------------|---------------|
| | CHEMICAL COSTS | | |
| | Per Ton Except as Noted | | |
| Salt Cake | \$34.00 East | | |
| | 24.50 West | Average: | \$30.00 |
| Lime (CaC) | 15.00 | Average: | 15.00 |
| Sulfur | 39.00 to | | |
| | 42.00/long ton | Average: | 40.00 |
| Soda Ash | 31.00 to | | |
| | 32.00 | Average: | 3 1.00 |
| Caustic Soda | 57.00/tor of NaOH in a 50% solution | | |
| Magnesium Hydroxide | 37.68/ton 100% solid tank car lots, FOB | s , Michigan | |
| Chlorine (Papermakers) | 3.35/100 lb. | , U | |

Case descriptions: The following cases have been considered for application of control methods to recovery systems. (See Reference 11 for complete study.)

<u>Case 1.</u> Replacement of an existing 90% AOE* precipitator with a higher efficiency precipitator.

<u>Case 2</u>. Installation of additional control equipment in series with an existing 90% AOE precipitator.

<u>Case 3</u>. Installation of a cyclonic scrubber in series with an existing 95% precipitator located on the roof.

Case 4. Application of additional control methods to an existing recovery system with an 80% AOE black liquor Venturi.

Case 5. Installation of a black-liquer oxidation system to an existing recovery system.

Case 6. Capital costs of new recovery systems.

11.5.1.3.4 Recovery furnace system:

Application: This case is based on the replacement of an existing 90% AOE precipitator with a higher efficiency precipitator. Most of the existing older recovery precipitator installations are arranged with the precipitator on the ground. Usually there is no additional space on the ground in the vicinity of the recovery unit; therefore, an additional precipitator would have to be installed above the existing precipitator. Further, the existing precipitator could not be removed and replaced with a new one since this would require a lengthy mill shutdown resulting in a high dollar cost due to the loss of production.

<u>Costs</u>: The capital costs are based on a double chamber, common wall, tile construction precipitator. Auxiliaries included are: agitators, dampers, circulation pumps, instruments and controls for proper operation of the above, and revised ductwork to connect the addition of replacement precipitator in the system. The cost also reflects the structure required to support this addition, and the demolition cost for removal of the existing precipitator. Capital costs and net annual costs are presented in Figures 11-5 through 11-7.

Effectiveness: Particulate removal. Methods are considered for replacing a 90% AOE precipitator on an existing recovery boiler. These methods and their particulate efficiencies are as follows:

^{*} Average operating efficiency.



Figure 11-5 - Control Method Costs for 99.9% Efficiency Electrostatic Precipitator Replacing an Existing Precipitator - Recovery Boiler (99.5% A.C.E.)



Figure 11-6 - Control Method Costs for 99.5% Efficiency Electrostatic Precipitator Replacing an Existing Precipitator - Recovery Boiler (99.0% A.O.E.)



Figure 11-7 - Control Method Costs for 99.0% Efficiency Electrostatic Precipitator Replacing an Existing Precipitator - Recovery Beiler (98.5% A.O.E.)

| Control Method | Guaranteed Efficiency | Annual Operating Efficiency |
|----------------|-----------------------|--------------------------------|
| Precipitator | 99.9 | 99.5 |
| Precipitator | 99.5 | 99.0 |
| Precipitator | 99.0 | 98.5 |

11.5.1.3.5 Smelt-dissolving tanks:

Application: The molten inorganic chemicals leave the furnace through smelt spouts to an agitated dissolving tank which contains weak wash liquor obtained from washing lime sludge in the succeeding causticizing operation. After being cooled and dissolved in the weak wash, the smelt solution is referred to as green liquor. Shatter nozzles are used to inject steam and/or recirculated green liquor into the solid smelt stream from the furnace to disperse the molten chemicals and ensure its safe dissolution.

Large quantities of water vapor are released by the green liquor which cools the molten smelt and by the steam from the shatter jets. Particles of smelt and droplets of green liquor become entrained in these vapors and are exhausted through the smelt-dissolving-tank vent.

The gas vented from the smelt-dissolving tank has a temperature of approximately 200°F and contains traces of organic sulfur compounds and particulate matter with a concentration of 1 to 1.5 grains/SCFD. The particulate matter is mostly sodium sulfide and sodium carbonate.

The majority of mills provide control equipment to minimize the emission of these chemicals and droplets to the atmosphere. Control equipment which is currently in use is as follows:

(1) <u>Mesh pads</u>. Mesh pads are used extensively to collect chemicals in dissolving-tank vents. Sprays located above the mesh pads operate periodically to remove the collected chemicals which are returned to the smelt-dissolving tank. A fan is not normally required due to the low pressure drop.

(2) <u>Packed towers</u>. Packed towers have been reported at two mills where they operate successfully. One concern with packed towers is the possibility of plugging; however, periodic use of condensate as scrubbing liquid is reported to remove any solids buildup. (3) Orifice scrubber. This scrubber has been installed at several mills and is reported to be successful where the scrubber is adequately sized. Due to the pressure drop (approximately 8 in. H_2 0) of this scrubber, inadequate sizing or improper operation may have a significant effect on emissions (for example, higher than design flows may require bypassing the scrubber).

Costs:

<u>Cyclonic scrubber</u>. This control method is based on the installation of a single cyclonic scrubber on an elevated floor within the confines of an existing recovery boiler building and adjacent to the existing vent stack. Since the capital cost and operating cost of the cyclonic scrubber is very similar to a packed tower, costs have not been calculated for the cyclonic scrubber. The reader is referred to the costs on the packed tower.

Packed tower. This control method is based on the installation of a single packed tower on an elevated floor within the confines of an existing recovery boiler building and adjacent to the existing vent stack. In addition, the following auxiliaries are included: an axial flow fan and motor located in the outlet of the tower, a circulation pump and motor, instruments and controls for proper operation of the above, piping for make-up circulation and tower effluent to dissolving tank, and revised ductwork including a by-pass to connect the tower to the existing vent stack (Figure 11-8).

Orifice scrubber. This control method is based on the installation of a single low-energy scrubber on an elevated floor within the confines of an existing recovery boiler building and adjacent to the existing vent stack. In addition, the following auxiliaries are included: an axial flow fan and motor located in the outlet of the tower, a circulation pump and motor, instruments and controls for proper operation of the above, piping for make-up circulation and scrubber effluent to dissolving tank, and revised ductwork including a by-pass to connect the scrubber to the existing vent stack (Figure 11-9).

<u>Mesh pad</u>. This control method is based on the installation of a mesh pad assembly in an existing recovery boiler vent stack.

Allowances have been included for the following: alterations to existing vent stack, normal piping for spray wash, and instruments and controls for proper operation. Cost curves are presented in Figure 11-10.



Figure 11-8 - Control Method Costs for Packed Tower Added to Smelt-Dissolving Tank Vent



Figure 11-9 - Control Method Costs for Orifice Scrubber Added to Smelt-Dissolving Tank Vent



Figure 11-10 - Control Method Costs of Mesh Pad Added to Smelt-Dissclving Tank Vent

Effectiveness:

Particulate removal. Efficiencies for the methods considered are as follows:

| Control Method | Annual Operating Efficiency |
|-------------------|--------------------------------|
| Cyclonic Scrubber | 80 |
| Packed Tower | 90 |
| Orifice Scrubber | 97 |
| Mesh Pad | 75 |

<u>Reduced sulfur and sulfur dioxide removal</u>. Depending on the scrubbing liquid used, both the packed tower and orifice scrubber would have potential for removing sulfur compounds.

<u>Operation</u>. Of the methods considered, the orifice scrubber should be the least subject to plugging.

<u>Summary</u>. The orifice scrubber and the packed tower are the most effective control methods for either particulate or gaseous pollutant removal. The orifice scrubber is less susceptible to pluggage and has the highest particulate collection efficiency.

11.5.1.3.6 Lime kiln:

Application: This control method is based upon the addition of a high-energy Venturi scrubber to replace existing 80% AOE cyclonic-type dust collectors. The system is to be arranged such that change over to a new system may be made with a minimum of lost production.

As a matter of convenience and water conservation, most kraft mills use contaminated condensate as a scrubbing liquid in the kiln scrubber. The condensate system is backed up with a fresh water supply. During time of chemical unbalance or lack of supply of condensate, fresh water is substituted as a scrubbing medium.

Any mercaptans which are emitted from the kiln stack come from the contaminated condensate used as a scrubbing liquid and make-up wash water in this system. Substitution of fresh water in these systems would eliminate emission of mercaptans from the kiln stack.

This substitution of fresh water as a scrubbing medium appears simple and relatively inexpensive. However, it must be emphasized that the lime kiln and causticizing areas are the prime users of contaminated condensate generated in other areas of the mill. If fresh water is used in place of contaminated condensate, the load to the waste-treatment system will be increased by the amount of water substituted.

The emissions from incineration of noncondensible sulfurbearing compounds in the line kiln are not being considered in this particular control method.

<u>Costs:</u> The capital costs are based upon purchase of equipment and installation of the new scrubbing system while the existing system is in operation. Items included are as follows:

- (1) New induced draft fan with drive
- (2) New scrubber, mist eliminator and stack
- (3) New pumps with drives
- (4) Modification to existing hot gas ductwork

Also included in the costs are new foundations and structures required to support the equipment and demolition cost for removal of the existing scrubbing system, once the new system is placed in operation. Cost curves are presented in Figures 11-11 and 11-12.

Effectiveness: This study considers a single method of replacing a low efficiency cyclonic-type dust collector with a high-energy Venturi scrubber. The new method is to have a 99.0 or 99.9% lime solids collection efficiency. AOE and design efficiencies are considered to be the same.

(1) The new system will replace an existing and operating inefficient system.

(2) The efficiency of solids collection of high-energy scrubber is a direct factor of the pressure drop taken across the throat of the scrubber. Because of this item the capital cost between a 99.0% and 99.9% efficiency would be very similar. Equipment sizing would be essentially duplicate in either case and the only variable would be a higher horsepower motor for driving the induced draft fan. Variables in operating cost are shown on the cost curves.

(3) High-efficiency scrubbers are important to the pulping industry for recovery of soda. Volatile soda compounds in the kiln exhaust gases are more difficult to recover than solids but are also more valuable. Equipment manufacturers presently estimate that a scrubber with 99.9% lime



Figure 11-11 - Control Method Costs for Fresh Water Venturi Added to Lime Kilr - 99.0% Lime Solids Collection



Figure 11-12 - Control Method Costs for Fresh Water Venturi Added to Lime Kiln - 99.9% Lime Solids Collection

solids collection efficiency will recover 90 to 95+% of the soda fume in the kiln exhaust gases. Ninety-nine percent lime solids collection should be equivalent to approximately 70% collection of soda fume.

11.5.1.3.7 Power boilers:

<u>Application</u>: This case is based on the addition of an electrostatic precipitator following an existing dust collector for a coalfired power boiler. Two precipitator sizes are considered.

<u>Costs</u>: Curves for capital costs and net annual operating costs are presented in Figures 11-13 and 11-14.

The equipment costs are based on a double chamber, steel shell precipitator. All labor and material for a complete installation are included in the capital cost and the net annual operating cost. The precipitator size is based on firing coal containing 2% sulfur.

Effectiveness:

<u>Particulate removal</u>. Guaranteed particulate efficiencies for the two precipitators considered are 99.0% and 90.0%. The resulting total annual operating efficiencies are:

| Precipitator Guaranteed Efficiency | Precipitator <u>AOE</u> | Dust Collector AOE | Total AOE |
|---------------------------------------|----------------------------|-----------------------|--------------|
| | | | |
| 90.0% | 89.0% | 80.0% | 98.0% |

Reduced sulfur and sulfur dioxide removal. Precipitators are ineffective for removing sulfur compounds.

<u>Operation</u>. The operating characteristics of the precipitators should be identical.

11.5.2 Sulfite Process

Little attention has been paid to the air pollution aspects of sulfite pulping. The pollution problem is not nearly as severe as in the kraft process. Some terpene-like odors, SO_2 leaks, and particulates from recovery furnace and steam power plants are the principal effluents.



Figure 11-13 - Control Method Costs for 99.0% Efficiency Electrostatic Precipitator Added to an Existing 90% Efficiency Dust Collector Coal-Fired Power Boiler (99.0% AOE)



Figure 11-14 - Control Method Costs for 90.0% Efficiency Electrostatic Precipitator Added to an Existing 90% Efficiency Dust Collector Coal-Fired Power Boiler (98.0% AOE)

Little consideration is currently being given to calcium or sodium as a future base in U. S. sulfite mills. Burning of calcium spent sulfite liquor yields combustion products in a form precluding reuse of the base chemical or sulfur value. Incineration of sodium liquor produces a mixture of sodium compounds requiring processing in satellite operations to reconstitute the base chemical for pulping. Armonia and magnesium liquor can be burned in a relatively simple system yielding the sulfur combustion product in the form of sulfur dioxide for recovery. Only the magnesia-base affords direct recovery of the base chemical.

Figure 11-15 illustrates a flow diagram for an ammonia-base pulping and recovery plant while Figure 11-16 presents the essential aspects of the magnesia-base liquor recovery process.

Meager data on emissions from sulfite mills exist in the literature. Table 11-8 summarizes some data from a pilot unit for ammonia-base liquor burning. Other emission data for sulfite mills are presented in Tables 11-1 and 11-2.

TABLE 11-5

AMMONIA-BASE LIQUOR BURNING (Filot Unit)

Dust loading: 1 - 2 lb/1,000 lb. of gas Particle density: 1.5 - 2.0 g/cm³ Particle size (average): 100 μ Furnace exit gas temperature: 1,750 - 2,240°F SO₂ at stack volume: 10 - 350 ppm

11.5.3 Semi-Chemical Pulping

Emissions from semi-chemical pulping plants are less intense than those from conventional pulping processes because of milder conditions. Emissions vary depending on process employed; e.g., neutral sulfite, or kraft. In the latter case, the air pollution problems will parallel those described under kraft pulping, but will be of a lower order of magnitude.

Very little data on emissions from semi-chemical pulping have been reported. Available information is summarized in Tables 11-1 and 11-2.



Figure 11-15 - Sulfite Pulping Process, Ammonia-Base Recovery



Figure 11-16 - Sulfite Pulping Process, Magnesia-Base Recovery

235

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CHAPTER 12

LIME MANUFACTURE

12.1 INTRODUCTION

Line is one of the most widely used chemicals. It is used for medicinal purposes, insecticides, plant and animal food, gas absorption, precipitation, dehydration, and causticizing. It is also employed as a reagent in the sulfite process for papermaking, manufacturing of high-grade steel and cement, manufacturing of soap, rubber, varnish, refractories, and sand-lime brick. $\frac{1}{2}$

The major air contaminant from lime manufacture is dust: limestone dust from handling, crushing, and screening operations; quicklime dust from kiln discharge, handling, shipping, and milling operations; hydrate lime dust from hydrator operations, milling, and packing.²/

The manufacturing process, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

12.2 LIME MANUFACTURING PROCESS

A simplified flowsheet for lime manufacture is presented in Figure 12-1. Following crushing and screening, the limestone is fed to kilns for calcination or burning. Lime burning is conducted in vertical, rotary, grate, fluosolid, and calcimatic kilns. Rotary kilns are used by a majority of plants.

Although the major tonnage of lime is sold as quicklime, there is still a substantial production of hydrated lime. (This hydrated lime does not include production by the many consumers of quicklime who slake their own lime into a putty, slurry, or milk-of-lime preparatory to their use.) This product is made by the lime manufacturer in the form of a fluffy, micron-sized, dry, white powder, and its use obviates the necessity of slaking by the consumer. A flow diagram of a commercial dry hydration plant is shown in Figure 12-2.

This process consists of adding water slowly to a crushed or ground quicklime in a premixing chamber or a vessel known as a hydrator which mixes and agitates the lime and water. The amount of water to be added is critical. If too much water is added, it will be impossible (or require costly drying) to produce the desired dry form; if too little is added, incomplete hydration will cause degraded quality, namely, chemical instability and structural unsoundness.

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Figure 12-1 - Simplified Flowsheet for Lime and Limestone $Products^{2/2}$

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Figure 12-2 - Flow Diagram of a Modern Hydrated Lime Plant from Ground Quick Lime^{2/} Feed Silos Through to Bulk Hydrate Storage Silos and Bagging Department.

12.3 EMISSION SOURCES AND RATES

The major potential source of particulates in lime manufacture is the calcining kiln. Emissions vary with kiln type and the composition of limestone burned.

Vertical kilns do not produce as much dust as do rotary kilns because of the larger size of the limestone charged, the low gas velocities, and the smaller amount of attrition. Nevertheless vertical kilns are apt to be considered dusty by modern air pollution standards.

Rotary kilns constitute the largest single source of particulate matter in the lime industry. Abrasion of limestone in the kiln produces dust. The stone becomes more friable as it approaches the decomposition temperature, and dusting increases. Simultaneously with dusting from attrition, the high-velocity gases from direct-fire-fuel combustion blow the dust from the kiln. This is a vexing dust to control and collect. It is hot, dry, difficult to wet, and prone to be electrostatically charged. It is of mixed composition, varying all the way from raw limestone to final calcined product. It will also be mixed with fly ash, tars, and unburned carbon if pulverized coal is used as the fuel.

Dust blown from a kiln varies greatly with gas velocity. The literature reports doubling of the dust blown out when a kiln production rate was increased from 100 to 135% of design capacity, while dropping production rate to 75% of capacity decreased the dust loading only by $8\%.3^{-1}$

Data on dust emissions from new kiln processes are largely lacking. Grate-type kilns are stated to produce less dust than rotary kilns.²/ Fluosolid kilns emit copious quantities of dust in the exhaust gases and require very efficient dust control equipment. Plants using the Calcimatic Process appear to be remarkably free of dust since the stone is stationary during calcination on a revolving hearth. The major sources of dust in this process are the exhaust from the stone preheater, the lime cooler, and the discharge lime conveyor.

The hydration of line presents a potential dust problem. Steam and moisture laden air sweep fine dust from the hydrating operation into the exhaust stack. High calcium hydrators operate at ambient pressure with "lazy" exhaust gas velocity. Pressure dolomitic hydrators discharge steam, air, and product through small orifices to maintain the pressure created by the reaction, and thus impart a high velocity to the exit gases.

Secondary sources of particulate emissions include crushers, coolers, dryers, transfer points, and hydrate bagging operations.

12.3.1 Summary of Emission Rates

Table 12-1 presents a summary of particulate emissions from lime manufacture. Total emissions are about 573,000 tons/year. The emission factors for the lime kilns include emissions from coolers. Emission factors and net control for primary crushing operations are assumed to be the same as those quantities used for these operations in the crushed stone industry (Chapter 7). Emissions from fugitive sources such as stockpiles, traffic and wind action on road dust, leaky bins, and truck spillage have not been determined.

12.4 CHARACTERISTICS OF EFFLUENTS FROM LIME MANJFACTURE

The chemical and physical properties of effluents from lime plants are summarized in Table 12-2. About 30% of the dust from rotary kilns is less than 10 μ . The mean size is 30 μ and the geometric deviation is 7.5. Rotary kiln dust is difficult to wet and prone to be electrostatically charged. Particle shape data are summarized below:

- Limestone Dust Mineral name: calcite. Colorless, with lighttransmitting characteristics varying from transparent to translucent. Particles generally occur as rhombohedra because of their perfect rhombohedral cleavage. Fragments may also occur as prisms.
- (2) Dolomite Dust Mineral name: dolomite. In the pure state, dolomites are colorless and the fine particles are generally transparent to translucent.
- (3) Lime Dust Lime is usually white in color of varying shades but some may have a light cream, buff, or gray cast depending on the nature of the impurities in the lime.

12.5 CONTROL PRACTICES AND EQUIPMENT FOR LIME MANUFACTURE

Many plants in isolated areas carry out meterials preparation operations with no control equipment or only the crudest kind of collection system.² Other plants collect the dust from exhaust systems with simple cyclones, water spray chambers, or baghouses.

The gases leaving a rotary kiln are usually first passed through a settling chamber to settle out the coarse particles. In some cases, dry cyclones may also be used for this primary collection. From 65-85% of the particulate matter may be collected here. $\frac{3}{}$ The major dust control problem is the dust passing the primary collector.

TABLE 12-1

PARTICULATE EMISSIONS LIME MANUFACTURE

| | Source | Quantity of Material | Emission Factor | Efficiency of Control (C _C) | Application of Control (C _t) | Net Control (C _c ·C _t) | Emissions (tens/year |
|--|--|---|---|--|---|---|--------------------------|
| I. Kilns and Coolers A. Rotary Kilns and Coolers B. Vertical Kilns C. Fluid-Bed Kilns | | 18,000,000 tons lime (excl 16,200,000 tons 1,800,000 tons | . pulp & paper) 180 lb/ton lime 7 lb/ton lime | 0.93 0.97 | 0.87 0.40 | 0.81 0.39 | 294,000 4,000 |
| II. M A B C C | inor Sources Stone Crushing and Screening Primary Crusher Secondary Crusher Secondary Crusher 3. Pulverizing, Quicklime Milling, Hydrated Lime Hydrator Materials Handling Conveyors | 28,000,000 tons of rock crushed for lime | 22 lb/ton of rock crushed 2.0 lb/ton of rock crushed 24 lb/ton of rock crushed | 0.80 0.95 0.95 | 0.25 0.80 0.80 | 0.20 0.76 0.76 | 264,000 |
| :4 | a. Transfer Points b. Discharge to Bins, Stockpiles 2. Elevators a. Boots b. Heads 3. Shipment of Product a. Bagging Machines b. Bulk Loading (1) trucks (2) freight cars Assumed for hydrator plus materials handling | | 5 1b/ton of lime urg(used | 0.95 | 0.80 | 0.76 | 11 000 |
| | materiars nandring | | lime produced | 0.95 | 0.80 Total for Lime Man | 0.76 ufacture | <u>11,000</u> 575,000 |

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TABLE 12-2

EFFLUENT CHARACTERISTICS - LINE MAN FACTURE

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|---|--|-----------------------|---|------------------|--|----------|--|
| <u>Sour v</u> | Particle Size | Solids <u>Conding</u> | Chemical Composition | Particle Density | Electrical Resistivity | Content | Tokicity |
| Lume Industry | | | | | | | |
| 1. Limestone M. Crusher fan exhaust (1 fest) | | 1.1-1.5 | Limestone | | | | |
| D. Reymond mill vent (1 test) | BAHCO analysis; 63 <5, 94.2 <10 96 5 <20 | | Lizestone | 2.5 | | | |
| Harrer mill (1 teat) | 0A-20 analysis: 47 <5, 60 <10 24 <20 00 <40 | | Lizestone | 8.9 | | | |
| u. Screen house (i test) | BAH70 analysis: 70 <5, 85 <10 95.5 <20, | | Limestone | 2.7 | | | |
| o, Stone iryer | 00:0 4.0 bAR(C analysis: (L Lests) 20.5-00 <5, 30.5-07 <10, 38.6- 03 <00, 45.5- 95 <40 <u>Microscope: Typical</u> range: (L-50 <5), 91.93 <40, 95.99 | 6.3-11 Avg.: 0.5 | Limestone | | | | |
| | <13. Avg.: 12 <5. | | | | | | |
| i kiln pre- neater exhaust | <pre>SANCO analysis: 9-20 <0, Avg.: 16 < 5; 15-40 <10, Avg.: 14 <10; 20- 46 <15, Avg.: 29 <10; <15; 30-65 <30,</pre> | | See rotary kiln | 2.5-2.7 | | | |
| | AVE: 41 <%. | 0.3-1.0 | Sec rotary kiln | | | | |
| s. hotany kulo | SALCE analysis: 10-70 ev, Avg.: 20 eS; 15-75 eLC; Avg.: 28 eLC; 21- 07 eVD; Avg.: 19 eS:128-10 eAC; Avg.: 16 e 40 Microsoft eAC; 20 eAC Factor 46-70 eS; 74-14 eLU; 85:15 | 2-25, Avg.: 15 | CaC), 23-61; CaC: ULAC; MagCG, 1.4; MaCG; 1.4-58,7; Feguy,AlgCy: 2.9 Fly ast 1: KiP is comifired | £.÷.₹.J. | der Plgum Lu-f för vesstrift as a fantiskrift totperature | | N.T., lime to in- rimbing to year respiratory year branes and moust skir |
| | 97 <10, 94 <20. | | | | | | |
| t, <u>lime</u> guler | BAHDI enalysis: ltir <5, 1 <15, 40 <10, 44 <40 | | | 3.0 | | | |
| . Szl.instik Virtave | 24920 inslpaid 1217 ≪8, 2917 ≪10, 5019 ≪20, 77 ≪41 | | | ¥. * | | | |
| in Colomate | | | | | | | |
| b. Di te stjer L. Kila | EARON analysic: 1:-10 <b, avg.<br="">1: 40, 70-29 <10, Avg. 20 < 10; 35-41 < 20, Avg. 39 < 20 42-53 < 40, Avg. 1 12 < 40.</b,> | €.1-30.4 2 | (One sample) CaC(g) A4; CaS: 7.2; NgC: 26.2; CaS(g) C.3. Acid :maclubles: C.45; R202: 0.33 (heavy matal ex- ides) | f.ñ. | | | |
| '. dvirated line | | | | | | | |
| 2. Aydrator (1 test) | 6AHCO anal,sis: 62 <5, 75 <10, 93 <201 90 <40 | | | C.5 | | | |
| <pre>D. Palvember entaust (1 test)</pre> | BARTO analysis: 52 <5, 83 <10, 96.5 <20, 99.8 | | | ¥.4 | | | |
| n. Wegging tin Vent (1 test) | BAHCC analysis: 71 <5, 67.3 <10, 96 <20, 98.8 <40 | | | 2.1 | | | |

- See using Key, Tible 5-1, Chapter 5, page 45, for units for individual effluent properties.

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| lime Infustry | | | | | | | |
|). Limestone a. Rotary kin | Callog - 9.H2O, acid; Cal - d. H2O: MgO - 3. al. H2O, s. acid: CaSO ₄ - 4, st. H2O, a. acid | Difficult to wet | | | | | |

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Figure 12-3 - Dependence of Specific Electrical Dust Resistance on Gas Temperature for Lime Shaft Kiln Dust 7/

Plants in some areas have installed high-efficiency cyclonic secondary collectors on their kiln operations. Table 12-3 lists data on a number of installations with secondary collectors. However, to meet emission requirements plants are increasingly turning to wet scrubbers and glass bag collectors. Electrostatic precipitators have also been found satisfactory. However, economics in the lime industry are such that precipitators are generally not installed as long as scrubbers and bag collectors give acceptable performance. Table 12-4 presents the estimated cost of three basic types of control equipment for a rotary kiln. $\frac{6}{}$ The control equipment costs are listed for two different efficiencies. These costs compare closely with general cost data given in Appendix A, except that the fabricfilter operating cost of \$14,000 is about double the typical value computed from Appendix A.

When making cost estimates of a collector system, the precooling or preconditioning section that may be required must be included. This can be very significant for baghouses and electrostatic precipitators.

Lime-hydrating processes can also be an important source of dust emissions. The loss of hydrated-lime dust represents loss of valuable product since the dust is high purity. It is easily wetted and can be scrubbed from the stack gases with a water scrubber. The recovered water slurry can be fed back to the hydrator as make-up water. Venturi-type scrubbers or other commercial wet scrubbers are used for this service. Effluent loadings of 0.01-0.07 grain/cu ft are reported. $\frac{3}{2}$, $\frac{4}{7}$ Table 12-5 presents data and costs reported for control equipment associated with various hydrate operations. $\frac{6}{7}$ Dryers also present a difficult dust control operation in a lime or limestone plant. Table 12-6 contains data and costs for control equipment associated with this operation. $\frac{6}{7}$

12.5.1 Cyclone Collectors

High-efficiency cyclones are suitable as primary collectors and precleaners for removal of the +10 μ size dust. One installation reports handling 80,000 acfm of kiln gas at 450-500°F and 30-35% moisture content in 72 9-in. size cast iron cyclones with a pressure drop of 2-1/4 in. of water and 70% collection efficiency. $\frac{3}{2}$

12.5.2 Bag Filters

A number of installations are reported making use of glass fiber bag collectors handling gas flows as high as 150,000 acfm at temperatures in the range of 350-550°F, with average particle sizes of 25 μ after precleaning with dust settlers. For the larger gas volumes the baghouse is compartmented so that only one section at a time is cleaned. A 12-compartment baghouse for a 500 ton/day kiln has been reported. The cleaning cycle (shaking is not employed with glass bags) depends on dust loading but is

TABLE 12-3

SECONDARY COLLECTION OF ROTARY KILN LIME DUST 3/

| Installation No.: Primary Collection Type of Secondary Collector | <u>l</u> Dust Chambers Glass Bag _ Collectors | 2 Dust Chambers 4-Stage Cyclonic Dynamic Scrubber | <u>3</u> Dust Chambers 4-Stage Cyclonic Dynamic Scrubber | <u>4</u> 9-In. Tube Cyclones ^a / Single Stage Electro- static Precipitator | 5 Dust Chambers Venturi Scrubber and Cyclonic Scrubber | <u>6</u> Dust Chambers Spray and Impingement Plate Scrubber |
|---|--|--|---|--|--|---|
| Inlet loading grains/scfm | 10.0 | 2.8 - 2 . 9 | 9.5 | 4.3 | 4-7 | 16 |
| Outlet loading grains/scfm | 0.001 | 0.071-0.080 | 0.02 | 0.22 | 0.12 | 0.3-0.4 |
| Collection efficiency | 99.99% | 97.5 % | 99.7 % | 9 5 % | 97-96.3% | 97.5 % |
| Pressure drop in secondary collector inches of water | 4- 5 | 8 | 8 | 1-2 | 15 | 5-6 |

a/ Primary collector consists of 9-in. tube cyclones. Inlet loading to cyclones, 14.5 grains/cu ft; outlet loading, 4.3 grains/cu ft; efficiency, 70%.

TABLE 12-4

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| | ESTIMATE OF ROTARY KIL | LN CONTROL COSTS 6/ | |
|-------------------------------|--|---|--------------------------|
| | Capacity Exhaust Gas Volume Exhaust Gas Temperatur Power Cost | - 350 tons/day - 100,000 cfm re - 550°F - \$0.C1/kwh | |
| Type of Collector | Installed Cost of Unit | Operating Cost/Year | Maintenance Cost/Year |
| | For 99% Effic | iency | |
| Baghouse | \$ 150,000 | \$14,000 | \$6,000 |
| Electrostatic Precipitator | 200,000 | 2,300 | 2,000 |
| Scrubber | 60,000 | 65,000 | 6,000 |
| | For 97% Effic | lency | |
| Baghouse | \$1 50,000 | \$14,000 | \$8,000 |
| Electrostatic Precipitator | 100,000 | 2,300 | 2,000 |
| Scrubber | 50,000 | 32,000 | 6,000 |

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TABLE 12-56/

HYDRATOR

| Type of System | Air Flow (cfm) | Filter Area (<u>sq. ft.</u>) | Air- Cloth <u>Ratio</u> | No. of <u>Bags</u> | No. of Compartments | Capital and Installed Cost | Type of Application |
|------------------------|--------------------------------|--------------------------------------|-------------------------------|--------------------------|------------------------|-------------------------------------|------------------------|
| Bag Filter | 13,000 | 1,750 | - | 128 | - | \$19,000 | Bagging |
| Bag Filter | 11,000 (5 in. w.g.) | 9,660 | - | 112 | - | 30,000 | Fines from cyclone |
| Bag Filter | - | 1,668 | 3.55:1 | - | - | 9,500 | Fines from pre-cleaner |
| Bag Filter | 5,000 | 1,050 | - | - | - | - | - |
| Bag Filter | 10,000 | - | - | - | 3 | 30,000 | Bagging |
| Bag Filter | 14,850 | - | - | - | - | - | - |
| Bag Filter | 4,250 | - | - | 43 | - | - | Bagging |
| Bag Filter | 6,000 | 576 | - | - | - | - | Bagging |
| Bag Filter | 5,000 | 1,050 | - | - | - | 10,000 | Quicklime grinding |
| Bag Filter | 2,500 (150°F) | 344 | - | - | - | 16,000 | Raymond Mill |
| Scrubber | - | - | - | - | - | 9,500 | - |
| Cyclone Pre-cleaner | - | | - | - | - | 10,000 | - |

Note: Bags used are cotton, dacron, and glass; dacron most common.

251

TABLE 12-6^{6/}

STONE DRYERS

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| Plant | Collecting System | Cloth- Area (<u>sq. ft.</u>) | No. of <u>Bags</u> | No. of Compartments | Air Flow (cfm) | Efficiency | Capital and Installed Cost |
|-------|---|--------------------------------------|--------------------------|------------------------|--------------------------|--------------|-------------------------------------|
| l | Cyclone and Baghouse | 2,550 | 360 | - | 15,000 at 220°F | - | \$10,000 Cyclone 36,000 Baghouse |
| 2 | Baghouse | 6,250 | 112 | 4 | 4,500-7,500 at 12 in. | - | 20,000 |
| 3 | Primary, Secondary Cyclone and Baghouse | 3,120 | 312 | 8 | 18,100 at 230°F | 99 +% | 50,000 |
| 4 | Cyclone (only) | - | - | - | 8,800 | (508 lb/hr) | 12,000 |
| 5 | 2-Stage Cyclone and Hi-Energy Scrubber | (400 gpm H ₂ 0) | - | - | 50,000 at 30 in. | 99.9% | 215,000 |

usually a 10-15 min. cycle. Design air-to-cloth ratio with one compartment out for cleaning is in the range of 1.95:1 to 2.2:1. Since kiln gases are frequently discharged hotter than can be handled directly by the bags it is usual practice to cool the gases by water spray, air dilution, or a combination. Insulation of the baghouse is not usually required unless the moisture content of the gases is quite high, as might be the case with wet feed. Bag life up to 2 years is reported. Collection efficiency is almost 100% between bag cleanings because a thin layer of dust on the bag forms an additional filtering media. Particles 5 μ and less in size are apt to be lost through the bag immediately after cleaning. Capital cost is reported to be \$1.80/cfm handled, with annual operating plus maintenance costs running \$0.20/cfm. $\frac{3}{2}$

The capital cost of \$1.80/cfm agrees reasonably well with the higher cost curves of installed cost for fabric filters given in Appendix A. Annual operating and maintenance cost of \$0.20/cfm corresponds to the "high" values given in Appendix A but this cost is largely a function of power cost.

12.5.3 Electrostatic Precipitators

While the use of electrostatic precipitators tends to be costly for the lime industry, one installation has been reported using a single stage precipitator as a secondary collector at a capital cost of \$1.25/cfm. It handles 160,000 cfm at 450-500°F inlet conditions in which 90-95% of the inlet dust is -10 μ . It is designed with a gas velocity of 3.3 ft/sec and a resident time of 5.2 sec. and has an on-stream efficiency of 95%.³/

12.5.4 Wet Scrubbers

One of the advantages of a wet scrubber is that it can include a pre-humidification section and eliminate the need for pre-cooling the gases. A typical installation for a 180-200 ton/day kiln with 40-50,000 acfm at 900-1400°F and a 5-10 grains/cu ft dust loading, would require a 9-10 ft. diameter scrubber 32 ft. tall. Scrubbing water requirement is 4 gal/1,000 cu. ft. of gas processed. Pressure drop is 8 in. of water. For the 200 ton/day kiln installation, fan brake horsepower would be 150. Collection efficiency is stated to be 99.7%. Scrubber cost is reported to be 0.50/cfm of cooled saturated exhaust gas for 304 stainless steel construction and 0.25/cfm for carbon steel.³/ The cost for carbon steel construction compares closely with purchase cost in Appendix A.

A dust removal efficiency of 96-97% has been reported for a 335 ton/day kiln using a combination Venturi scrubber and cyclonic separator. A pressure drop of 7-11 in. water was used. Inlet gas volume was 60-62,000 cfm at 350°F. Water supplied to the Venturi throat was 1,500 gpm at 50 psig pressure. Cleaned exhaust gases were discharged at 160-165°F nearly saturated with water vapor. $\frac{3}{2}$

While wet scrubbing may frequently be cheaper, problems can occur which are not present with dry collection. Examples are discharge of a hot humid gas, scale buildup, and corrosion. The presence of sulfur oxides may dictate the use of corrosion resistant alloys for wetted parts including the exhaust fan. Some producers report operating costs for a wet scrubber three times as great as for a bag filter even though initial cost is considerably less. The scrubber slurry is also a potential water pollutant if not properly confined or consumed.3/

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CHAPTER 13

PRIMARY NONFERROUS METALLURGY

13.1 INTRODUCTION

Primary nonferrous metallurgy, as used here, will include smelting and refining of copper, lead, zinc, and aluminum. The air pollution problems of the nonferrous metallurgical industry are extremely varied. However, one typical characteristic exists--in almost all the processes in the production of nonferrous metals, the particulates emitted are metallic fumes generally submicron in size. Table 13-1 summarizes particulate emissions from the primary nonferrous metals industry.

The production processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for copper, lead, zinc and aluminum smelting and refining are discussed in the following sections.

13.2 PRIMARY COPPER SMELTING AND REFINING

Copper is obtained from copper ores by smelting. The term "smelting" can be used, in a wide sense, to cover the successive operations of roasting, reverberatory smelting, coverting, and fire refining. Although there are considerable variations in practice from smelter to smelter, the basic principles are essentially the same. A simplified flow diagram of a typical smelter operation is shown in Figure 13-1.

The ores are smelted down either as they come from the mine or are subjected (in particularly the sulfur-containing copper ores) to a preparatory process of grinding and flotation. This transforms the low-percentage ores into a high-percentage copper/sulfur concentrate. The latter is subsequently smelted down either directly or after partial roasting. Roasting removes part of the sulfur giving a favorable balance of copper, iron, and sulfur for the reverberatory feed. In the reverberatory furnace the iron present as oxide combines with siliceous flux to form a slag, leaving a material known as matte, which contains copper, iron, and some sulfur, preferably combined with the copper. The matte is reduced to copper in the converter in two stages of blowing with air. The first stage eliminates sulfur, and forms the iron oxide which is slagged off by the addition of siliceous flux. The copper sulfide remaining in the converter is reduced to metal and the sulfur is eliminated as SO2 in the "finish" blowing stage. The copper at this stage is called blister copper. This crude copper undergoes further refinement by fire refining to reduce the sulfur and oxygen, and then is cast into anodes for electrolytic refining.

²⁵⁷ Preceding page blank



13.2.1 Emission Sources and Rates

Dust is emitted from all pyrometallurgical operations. The varicus phases of the process and their particulate emission potential are discussed briefly in the following sections.

13.2.1.1 <u>Roasting</u>: Copper roasting at smelters in the U.S. is slowly being phased out. The older multiple-hearth roasters have been abandoned in some plants in favor of more modern equipment.

Recent installations are generally fluid-bed roasters. These have been in use in copper smelters for about 10 years. The feed material may be sprayed into the top of the roaster as a water slurry or charged as a solid.

Multiple-hearth roasters usually operate at a temperature of about $1200^{\circ}F$. Sulfur dioxide concentration in the wet off gas is usually only 5 to 10% because of low efficiencies in the furnace and dilution by air. The dust load in the off gas is around 3 to 6% of the weight of the feed, and a large portion of the dust is recovered in the flues.

Fluid-bed roasters operate in the same temperature range as multiple-hearth roasters. However, about 85% of the feed is carried in the gas stream, and most of it is immediately recovered in cyclone collectors. The wet off gas runs 12 to 14 vol. % sulfur dioxide.

After preliminary solids collection, the gas from either type of roaster is cooled to 600°F by air dilution, water sprays, or heat exchangers before the final cleaning. $\frac{1}{2}$

The dust content of the waste gases depends on the characteristics of the copper concentrates as well as on the volume of air aspirated by the roasting furnace. Another factor of importance in hearth furnaces is the extent to which the concentrates remain continuously in suspension when descending from the upper to the lower hearths. The size and number of the apertures in the hearths has an influence on the creation of dust in the furnace, and consequently also on the dust content of the waste gases.

13.2.1.2 <u>Reverberatory Furnaces</u>: The reverberatory furnace melts the metal-bearing charge and forms the matte and slag. The charge is introduced through openings in the side wall or in the roof. $\frac{1}{2}$

Collection and recovery of dust from the furnace gas is a substantial problem. The heavier particles settle below the waste heat boilers, and into the hoppers of the balloon flues or settling chambers. Practically all copper smelters have a main collector system that includes drag or screw conveyors that remove the dust from the various places where it accumulates. The dust is then moved to locations where it can be worked back into the system. The amount of dust will depend upon variables such as the fineness of the charge, the degree of agitation in charging and working, and specific gravity.

13.2.1.3 <u>Copper - Matte Converter</u>: Molten matte produced in the reverberatory furnace is transferred in ladles to the converters by overhead cranes. The function of the converters is to oxidize and separate the iron and sulfur from the matte. Air is blown into the liquid matte through openings called "tuyeres." The oxidation reactions supply enough heat to maintain the converter at a temperature of about 2250°F and no fuel is required. The sulfur dioxide is carried out with the other flue gases. Silica flux is added to combine with the iron oxide to form a fluid iron silicate slag. The slag is skimmed from the converter and returned to the reverberatory furnace. Additional matte is added to the converter and the process repeated until a suitable charge of copper sulfide has been accumulated. Blowing is then continued without further matte additions until the remaining sulfur has been eliminated. The resulting blister copper is usually more than 99% pure. It is removed from the converter to be cast or further refined.

Dust loads in converter gases may amount to 10 to 20 tons/day/ unit. About 75 to 85% of these solids settle in the flue system. The remaining 15 to 25%, composed of the smaller particles, is largely removed in dust collectors. $\underline{1}/$

The dust content of the gases depends to a large extent on the chemical composition of the copper matte. An increase in the operating temperature of the converter causes higher volatilization of the metals and consequently higher dust content in the raw gas.

13.2.1.4 Fire Refining: Blister copper, the end product of the converter, contains about 0.04% sulfur and requires further refining in order to meet most purity specifications for fabricated copper products. Of the 16 copper smelters in the U.S., five produce blister copper only. The others fire-refine part or all of the blister copper for anodes or other shapes. $\frac{1}{2}$

Furnaces commonly used are either of the reverberatory or tilting cylindrical type. The type of furnace used depends on the operational continuity at the particular plant.

13.2.1.5 <u>Summary of Emission Rates</u>: Table 13-1 summarizes the emission rates from the various processes involved in the production of primary copper. Limited data on control efficiency and degree of application of control were found. The emission totals in Table 13-1 are considered as conservative estimates.

13.2.2 Characteristics of Effluents from Primary Copper Production

The chemical and physical properties of effluents from primary copper smelters are summarized in Table 13-2. Particulate emissions from the furnaces are predominantly metallic fumes of submicron size. The fumes are difficult to wet and readily agglomerate. In addition, they are cohesive and will bridge and arch in hoppers and other collection bins.

13.2.3 Control Practices and Equipment for Copper Smelting and Refining

Copper sulfide concentrates received at the smelter are normally roasted in multiple-hearth roasters to remove moisture, to burn off part of the contained sulfur, and to preheat the material before smelting.

One copper smelter is using a fluidized roaster, and the gases are cleaned in a Peabody scrubber prior to entering the sulfuric acid manufacturing process. $\frac{3}{4}$ In recent years the roasting step has been eliminated at many smelters. $\frac{4}{4}$

The value of volatilized elements, as well as air pollution considerations, dictates efficient collection of fumes and dusts from process off gases. Balloon flues may serve as gravity collectors, and cyclones may be used also. For collection of the finer particulates, electrostatic precipitators are most often used. Collection efficiencies up to 99.7% for copper dust and fume are attained by careful conditioning of flue gases. $\frac{4}{}$

One installation which used an electrostatic precipitator to clean the gases from a copper smelter has been described. This system was revised to separately clean the roaster, reverberatory and converter gas streams in the electrostatic precipitator system. A baghouse was added for further cleaning of the combined reverberatory and converter gas streams at the exit of the precipitator. $\frac{14}{7}$

TABLE 13-1

PARTICULATE EMISSIONS PRIMARY BONFFERIOUS METALS BIDUSTRIES

| | | Quantity | of Material | Emission Factor | Effici- ency of Control (C _C) | Applica- tion of Control (Ct) | Net Control $(C_c \cdot C_t)$ | Emissions (tons/yr) |
|--------|-------------------------------------|------------------|------------------|--------------------------------|--|--|-------------------------------------|------------------------|
| I. A. | luminum | | | | | | | |
| A | Preparation of Alumina | | | | | | | |
| | 1. Grinding of Bauxite | 13,000,000 | tons of bauxite | 6 lb/ton of bauxite | - | - | 0.80 | 8,000 |
| | 2. Calcining of Hydroxide | 5,840,000 | tons of alumina | 200 lb/ton of alumina | - | - | 0.90 | 58,000 |
| B | . Aluminum Mills | | | | | | | |
| | Soderberg Cells | | | | | | | |
| | a. Horizontal stud | 800,000 | tons of aluminum | 144 lb/ton of aluminum | 0.40 | 1.0 | 0.40 | 35,000 |
| | b. Vertical stud | 700,000 | tons of aluminum | 84 lb/ton of aluminum | 0.64 | 1.0 | 0.64 | 10,000 |
| | 2. Pre-Bake Cells | 1,755,000 | tons of aluminum | 63 lb/ton of aluminum | 0.64 | 1.0 | 0.64 | 20,000 |
| С | . Materials Handling | 3,300,000 | tons of aluminum | 10 lb/ton of aluminum | 0.90 | 0.35 | 0.32 | 11,000 |
| | | | Total fro | om primary aluminum industry | | | | 142,000 |
| II. C | opper | | | | | | | |
| A | · Ore Crushing | 170,000,000 | tons of ore | 2 lb/ton of ore | 0.0 | 0.0 | 0.0 | 170,000 |
| B | . Roasting | 40% of 1,437,000 | tons of copper | 168 lb/ton copper | 0.85 | 1.0 | 0.85 | 7,000 |
| С | . Reverberatory Furnace | 1,437,000 | tons of copper | 206 lb/ton copper | 0.95 | 0.85 | 0.81 | 28,000 |
| D | • Converter | 1,437.000 | tons of copper | 235 lb/ton copper | 0.95 | 0.85 | 0.81 | 33,000 |
| E | . Fire Refining | | | | | | | |
| F | . Slag Furnaces | | | | | | | |
| G | . Materials Handling: Ore, Limest | ione | | | 0.00 | 0.70 | 0.70 | F 000 |
| | Slag, etc. | 1,457,000 | tons of copper | om urimary copper industry | 0.90 | 0.35 | 0.32 | 243,000 |
| | | | 10001 110 | Ga primary copper inducery | | | | 243,000 |
| III. Z | inc | | | 1 | | | | |
| A | • Ore Crushing | 18,000,000 | tons of ore | 2 lb/ton of ore | 0.0 | 0.0 | 0.0 | 18,000 |
| В | . Roasting | | | 0.000 33 4 | 0.00 | | 0.00 | 15 000 |
| | 1. Fluidized-Bed, Suspension | 75% of 1,020,000 | tons of zinc | 2,000 10/ton zinc | 0.98 | 1.0 | 0.98 | 15,000 |
| | 2. Ropp, Multiple-nearth | 504 of 1,020,000 | tons of zinc | 190 lb/ten gine | 0.85 | 1.0 | 0.85 | 4,000 |
| с ъ | Distillation | 60% of 1,020,000 | tons of zinc | | 0.55 | 1.0 | 0.35 | 15,000 |
| л Г | Materials Handling | 1 020 000 | tons of zinc | 7 lb/ton zinc | 0.90 | 0.35 | 0.32 | 2 000 |
| 5 | , proceeding | 1,01.0,000 | Total fr | om primary zinc industry | 0100 | 0.00 | 0.02 | 57,000 |
| | | | | | | | | |
| IV. L | ead Ore Crushing | 4 500 000 | tons of ore | 2 lb/ton ore | 0.0 | 0.0 | 0.0 | 4 000 |
| R | Sintering | 467.000 | tons of lead | 520 lb/ton lead | 0.95 | 0.90 | 0.86 | 17,000 |
| ć | . Blast Furnace | 467.000 | tons of lead | 250 lb/ton lead | 0.85 | 0.98 | 0.83 | 10.000 |
| D. | . Drossing Kettle | , | | - | | | | , |
| E | . Softening Furnace | | | | | | | |
| F | . De-Silvering Kettles | | | - | | | | |
| G. | Cupeling Furnaces | | | - | | | | |
| H | . Refining Kettles | | | - | | | | |
| I | Dross Reverberatory Furnace | 467,000 | tons of lead | 20 lb/ton lead | - | - | 0.50 | 2,000 |
| J | Materials Handling | 467,000 | tons of lead | 5 lb/ton lead | 0.90 | 0.35 | 0.32 | 1,000 |
| | | | Total fr | om primary lead industry | | | | 34,000 |
| | | | Total fr | om nonferrous metals industrie | ·:: | | | 476,000 |

4/6,000

.

| s. <u>Instigulate</u> (Part | EFTLIDET CHARACTERISTICS FRIDARY NONFERRASS METALS INDUSTRIES* | | | | | | | | | | | |
|--|--|--------------------|--|------------------|---|------------------|--------------------|--|--|--|--|--|
| Source | Particle Size | Solids Loading | Chunical Composition | Particle Density | Electrical Resistivity | Moisture Content | loxicity | | | | | |
| Commers Nonterrous Reffie | | | | | | | | | | | | |
| Copyer Romating Formate | 15 < 10 | (č. 1 | Cu: 7, S: 10, Pe: 26* | | | | | | | | | |
| b. Blust turnace | | 6.5* | Cu: 4.4, Zn: 12.5, S: 7.5* | | | | | | | | | |
| o. Severberatory Curnace | - 5 1 ∝ 57 | 1-0 | Cu: 6.2. Zn: 13.0, S: 13.5* Traces of elements cor- responding to composi- tion of ore: Oxides of arsenic, antimony, alum: num illicos sulfates. | | | | | | | | | |
| 5. Copper matte converter converter contract ing formate (conditional formate formate | 19 c 44 | 5, ™ | Cu: 1.2, Zn: 18.0, 5: 10 (clsc see reverseratory furn Cu: 7, S: 1.5* | ● ■C●} | | | | | | | | |
| /, leat o. Winter machine | | J_87_6,0* | Pc: 40-65, Zn. 10-90, S: 8-12* Traces of elements cor- responding to composi- tion of mixture; axiat of arsonic, cadmium, seleniam, ani tellurium Also cold and silver. | ı 8. | Sco Figures 13-2 and 13-3 for detailed date | | Po: 0.15 2n: 15 | | | | | |
| b. Blaat turnace | 3.03-5.3 | 1-11 | Sulfates, oxides, lend sulfate, coke dust, PoD, ZnC, CdD, PbyO,. | | See Figure 15-4 for detailed data | | | | | | | |
| Reverteratory furnace | | C. 4-4. 4* | | | | | | | | | | |
| Short revolv- ing rever- beratory furnere | | 1.3-5.0* | | | | | | | | | | |
| 1. Dine | | | | | | | | | | | | |
| <pre>c. practer (1) Sopp reas (2) Wiltiple- mearth reaster (1) Juppendum reaster (1) Finit-tes mouter [>, Finit- column reaster protect</pre> | unspect3300 ter Bosster, BB2co Agalysis:]4 ≪5, 31 ≪10 70 ≪20 1 | 5 – 4; 5 | ZnS | 5.7 | | | | | | | | |
| 5. Sinter machine | 100 <10* | 0.4-4.5 | Zn: 5-25; Pc: 30-55, Cd: 2-15 - 5: 8-13 | | | | | | | | | |
| c. Horizontal | Mieron ti submicron | 0.04-0.13* | Zn: 5C-70*, 9u: 0-3 | | Figures 13-5 and 13-6 di resistivity for tlag funing plant and melting plant | ve | 2n0: 15 | | | | | |
| a, Vertical muffle formace | 103 <10• | 0.9* | Zn: 68-70°; Ph: 4-5 | | | | | | | | | |
| Rotary furnace | 90 <10 * | 9-22• | Zn: 65, Pb: 8, S: 1.5 | | | | | | | | | |

TABLE 13-2

See Coding Key, Table 5-1, Chapter 5, p. 45, for units for individual effluent properties.
 Terman data.

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TABLE 13-2 (Continued)

A <u>Estimulate</u> (Part 1)(Concluded)

| Source | | Farticle Size | Solids Londing | Chemical Composition | Particle Density | Electrical Resistivity | Hoisture Content | Toxicity |
|---------------------|--|--|---|--|------------------|------------------------|--|----------|
| 4, ціці с. Б. | rinum Pauxite drywr Bauxite kiln | 10-30 < 10 Bacco Analysis 10-16 <5 Avg. 13 <5 20-29 <10 Avg. 25 <10 31-43 <20 Avg. 37 <20 43-55 <40 Avg. 49 <40 | 20-60 100-300 | AlgCs a 99 3102: 0.005-0.015 FrgCs: 0.005-0.02 NagC: 0.6-0.80 | | | Contined MpO 0.05-0.15 Adsorted MpO 0.20-0.50 | |
| v . | Feduction cell | Renge in Hise down to Bub- micton Levels | 0.03-2.0 | AlgOg, tar, carbon, fluorides, and vari- ous impurities Also and Table 13-3 | | | | |
| 1. | Refining and costing Parneces | Range in size down to sub- miston levels | 2-20 (Sigh velue during chloring fluxing) | Al ₂ 0 ₃ , AlCl ₃ , impuritie Also see Table 13-4 | 8 | | | Acidic |

4. Instituiate (Part II)

| S | Durce | Solutility | Wettacility | <u>.</u> | Hygroscopic Characteristics | Flarmability or Explosive limits | Handling Che | recteristics | Optical Properties | Odor |
|----|-------------------|----------------|--------------|----------|--------------------------------|-------------------------------------|-----------------------------|--------------|-----------------------|------|
| ٤. | Copper Refining | | Jifficult to | vet | | | Agglomerates Will bridge | and arch | | |
| :. | lend Hofsning | | - | t. | | | | - | | |
| 3. | lin: Pefining | | | • | | | 9 | n | | |
| 4. | Alurinam Refining | Allery - 3 Hge | | | | | Corrosive, s | brasive | | |

Carrier Gas

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| <u>8 </u> | Flow Rate | Traperature | Moisture Content | Chemical Composition | Toxicity | Corresivity | Olor | Flammability Limits | uptical <u>Properties</u> |
|---|------------------------|-------------|---------------------|--|----------|-------------|------|------------------------|------------------------------|
| Primary Konferrous Metals | | | | | | | | | |
| 1. Copper a. Roasting furnace | 4) 60+131 6) 47.3° | 600-890 | | \$0 ₂ : ۹• | | | | | |
| 1. Blast Surnace | a) 21.2 5) 75.5* | 248* | | CO2: 6.5* | | | | | |
| Reverbera- tory furnace | ы) СС-460 6) 71+ | 350-7EC | 6-1 0 | 0 ₂ : 5-6, 00 ₂ : 10-17, N ₂ : 72-75, CC: 0-0.2, SOp: 2-2 | | | | | |
| d. Copper matte converter | ∎) 102-750⊕ b) 366⇒ | 300-650 | | 50 ₂ : | | | | | |
| c. copper refin- ing formann (coal dust | s) 16* | 410- | • | | | | | | |

(cost in fired)

TABLE 13-2 (Concluded)

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. <u>Contine Gas</u> (Contines)

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| <u> </u> | <u>u. </u> | | <u>Iemperature</u> | Noisture Content | Chemical Composition | Texicity | <u>Corrosivity</u> | <u>Cdor</u> | Flammability Limits | Optica. <u>Properties</u> |
|----------|--|--|--|---------------------|--|---|--|-------------|------------------------|---|
| :. | baa a. Sinter ga hine | a) 140== b) 130== | 250-600 | | SO ₂ , O ₂ , N ₂ , CO ₂ , H ₂ O, possible traces of NT and SLT. | | | | | |
| | b. Plast furnace | a) 6-16 195** D) 180** | 150-250 | | Typical analysis: CO2: 4.7, O2: 15.0, CO: 1.3, SO2: 0.14 S-: balance | | | | | |
| | Severbergtory furnace Ohort revolving reverbergtory furnace | a) 1-3 b) 3.5-17.5* (c) 35.3-106* | 1400-1800 (Purnade outle | et) | | | | | | |
| | in: - Scarter (.) Popp | a) 25-30 | 730+900 | | SD.: 0.7-1.0, 0p. No. | | | | | |
| | roacter (2) Mainipin- hearth | 6) 5-6 | 500-520 | | 202. and HaC Sol: 4.5-6.5. 02, N2, 202 and HaC | | | | | |
| | rdaster (3) Euspension reactor (4) Fluid-bed | a) 10-15 a) 6-10 | 550-600 | | 50 ₂ : 10-13, C ₂ , M ₂ , CO ₂ , and H ₂ C SO ₂ : '+12, C ₂ , M ₂ , | | | | | |
| | roster (r) Fluid- 1910- | | | | ວິດ _ຂ and X ₂ 0 ຣປຊະ 11-12, C ₂ , N ₂ , ວິດ _ເ and X ₂ 0 | | | | | |
| | reaster E. Linter machine | b)]40• | 320-700 | Dew Point* | SU2: 4.5-74 | SOgt 5 | | | | |
| | - Pirilintal Per vy | x) 3.500-5.100 (condenser wast gas including extrapeous 407) | e | | | III CONT | | | | |
| | | oF 420-540* /flue ass) | | | CC ₂ : _2−17• | | | | | |
| | to Systema nation Date nation | 4.) - 140 0 | | | 002: 2.5- 3.0 * | | | | | White szcke |
| | el Rutary | 5) 85-530° | 1,000-1,363 | | 40 <mark>2: 10=</mark> | | | | | |
| - | A record a. Bagolic grown r. Bagolic grown . Electric clic | <pre>1: 100-150 1: 25-135 2: 5: 4: 0: 0: 0: 0: 0: 0: 0: 0: 0: 0: 0: 0: 0:</pre> | 110-100 250-720 | 30-45. 40-50 | CO2, O2, Nn, H2C C32, H3, CC, SU3, fluorides, hydro- carboxs. | 502: 5, irritat 00: 100 H01: 5 012: 1 Fluorides: | Acidie, cor- rotive | | | |
| | <pre>2. Foffining and acting fur- mate</pre> | | Purnace Dic- change: 1300 1800 Stack Dischar 200-500 | | CO ₂ , O ₂ , M ₂ , M ₂ C (prior to Ci ₂ fluxing) CO ₂ , O ₂ , M ₂ , M ₂ C, HCl, Cl ₂ (during Ci ₂ fluxing) | | Aridic, for- resive (sur ing Cl _p fluxing) | - | | Dense, white plume during chiorine fluxing |

Perman lata.
Cunadian data.







- * Figure shows percent water vapor by volume.
- Figure 13-3 Apparent Resistivity of Lead Fume from Sintering Plant $\frac{17}{2}$

266





Figure 13-4 - Resitivity of Lead Dross Fume Under Varying Conditions of Temperature and Moisture in Gas <u>18</u>/



- * Figure shows percent water vapor by volume.
- Figure 13-5 Apparent Resistivity of Lead Fume from Lead Blast Furnace <u>16</u>/

267



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* Figure shows percent water vapor by volume.

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Figure 13-6 - Apparent Resistivity of Lead Fume from Slag Treatment Plant16/

TABLE 13-3

COMPOUNDS FOUND IN ALUMINUM REDUCTION CELL EXHAUST STREAMS12/

| | Category | Chemical Compound | Chemical Formula |
|----|--------------------|----------------------------|---------------------------|
| 1. | Fluorides | Sodium fluoride | NaF |
| | Particulate form | Aluminum fluoride | AlF3 |
| | | Calcium fluoride | CaF_2 |
| | | Fluoroaluminate (Cryolite) | NazAlF6 |
| | Gaseous form | Carbon tetrafluoride | CF42/ |
| | | Hydrogen fluoride | HF |
| | | Silicon tetrafluoride | \mathtt{SiF}_4 |
| | | Hexafluorcethane | ^C 2 F 6 |
| 2. | Other particulates | Carbon | С |
| | (Nonfluoride) | Aluminum oxide | A1203 |
| 3. | Other gases | Carbon monoxide | coª/ |
| | | Hydrogen sulfide | H ₂ S |
| | | Hydrocarbons | <u>⊳</u> ∕ |

<u>a</u>/ Especially during periods of anode effects.
 <u>b</u>/ Too numerous to mention; type and quantity will depend upon cell employed.

269

TABLE 13-4

ATMOSPHERIC POLLUTANTS FROM SECONDARY SOURCES²/IN ALUMINUM PLANTS¹²/

| | Atmospheric Po | ollutants |
|---|--|---|
| Source | Gaseous | Particulate |
| Rew materials handling | | |
| Alumina unloading and transfer | | AloOz |
| Cryolite unloading and transfer, grinding | | Na2AIF6, AlF3 |
| Pot lining operation | | |
| Anthracite coal grinding and transfer | | Coal dust |
| Coal and pitch mixing | hydroc arbons | |
| Anode preparation (prebake plants, only) | | |
| Coke unloading, transfer and grinding | | Coke dust |
| Pitch unloading and transfer | | Pitch dust |
| Mixing of coke and pitch | hydrocarbons | |
| Anode baking furnaces | SO ₂ , CO, hydrocarbons, AF | Carbon dust, particulate |
| Cleaning of baked anodes | | Coke dust |
| Cleaning of copper rods and steel stubs | | Copper and iron |
| Electric arc cast iron furnace | | Iron oxide |
| Paste making (Soderberg plants, only) | hydrocarbons | Carbon dust |
| Aluminum refining | | |
| Ingot casting furnaces | Cl ₂ , HCl | AlCl ₃ , Al ₂ O_3 |
| Chlorine fluxing | | |

a/ i.e., excluding the pot line and monitor emissions.

270

The application of control methods for copper smelter operations has been described in a translation of a 1960 German study.²/Significant parts of this study are included in the following paragraphs. However, it should be noted that German practice does not necessarily correspond to present-day practice in U.S. smelters. Table 13-5 summarizes operating data for dust control equipment reported in Reference 2.

13.2.3.1 <u>Cloth Filters</u>: Cloth filters are utilized for secondary dust collection from converter gases. Depending on the purpose of utilization, the following types of fabrics are employed:

> Cloth woven from natural fibers (wood, cotton); Cloth woven from synthetic fibers (Redon, Pan, etc.)

The dust content of the exhausted air is strongly influenced by the air-to-cloth ratio (ft^3 of raw gas per ft^2 of filter surface) as well as by the structure and density of the filter weave. In order to maintain the full nominal rating of the filter in continuous operation, cleaning of the filter cloth is of the greatest importance.

The disadvantage of all cloth filters is the high wear and expensive replacement, the high cost of maintenance and the high consumption of energy due to the pressure drop of 2-5 in. w.g. However, with filters properly maintained, efficiencies up to 99.9% can be attained.

13.2.3.2 <u>Centrifugal Separators</u>: Centrifugal separators installed on furnaces generally have maximum efficiencies of 80-85% and are therefore usually employed for primary removal of coarse dust.²/

13.2.3.3 <u>Electrostatic Precipitators</u>: Electrostatic precipitators, usually preceded by mechanical collectors, are near-universally applied to the control of particulates from copper smelting. The equipment is normally more massive and rugged than counterparts in the power or other industries, and dust-handling techniques are far more positive. In the 50,000 to 2,000,000 cfm flow ranges under consideration, installed costs for combined mechanical collector-electrostatic precipitators would be \$6.00 to \$3.00, respectively. Mechanical collectors are typically of the large-diameter (24 in. or more) multicyclone type.

Mild-steel construction is accommodated by maintaining sufficient gas temperatures to preclude corrosion, with temperatures ranging from 300 to 650°F on converters and from 600 to 900°F on roasters. Actual collection efficiency usually is reported in the 98.5 to 99.5% range. $\frac{20}{}$

TABLE 13-5

OPERATION DATA FOR DUST COLLECTORS APPLIED TO PRIMARY COPPER SMELTING AND REFINING2/

| - | Type of Separator | Maximum Efficiency* (%) | Draft Required <u>in. water</u> | Utilization |
|----|-------------------------------------|-------------------------------|---------------------------------------|---|
| 1. | Dust chambers | 30-60 | < 0.2 3 - 6 | Beyond sintering machine and shaft furnace |
| 2. | Cyclones ≤ 16 in. in diameter | 85-95 | 3-4 | For secondary purification beyond reverberatory furnaces |
| 3. | Electrostatic precipitators | 96-99 | 0.2-0.6 | For higher demands and fine dust beyond roasting, sintering and shaft fur- naces |
| 4. | Cloth filters | 99 %+ | 2-6 | For dry air beyond coolers for converter gas. Effi- ciency depends on weave |

a/ Largely dependent on type of dust, content of dust, particle-size distribution, gas and operating factors.

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13.3 PRIMARY LEAD SMELTING AND REFINING

All primary lead smelters in this country use essentially the same processing steps, although there are differences in the equipment used and the details of operation. The principal process steps are sintering, reduction in a blast furnace, and refining. Refining includes operation of the dross reverberatory furnace. Smelter operations usually include cadmium recovery and slag fuming for zinc recovery.

Lead sulfides are converted to oxides of lead and sulfur in the sintering step at a relatively low temperature. The oxidized solid material is then reduced with coke in the blast furnace at a high temperature to form impure metal and slag. A preliminary refining operation is performed on the impure lead from the blast furnace. Lead bullion, 95 to 99% pure, is the principal product of lead smelting operations.

There are a number of secondary products. Some, such as zinc oxide products and cadmium dusts, may be ready for marketing as they leave the plant, and some, such as slag, matte, or dusts, may be shipped to other plants for extraction of values, primarily zinc, cadmium, silver, and copper. These other products vary from plant to plant, as one plant may put out several finished products, while another may ship only lead and unrefined materials.

Figure 13-7 shows the overall process of the operation.

13.3.1 Emission Sources and Rates from Primary Lead Smelting and Refining

13.3.1.1 <u>Sintering Machines</u>: Sintering is a universal practice in the lead-smelting industry. Its purpose is to remove sulfur by roasting and at the same time sinter to produce a calcine that is consolidated in a strong and porcus mass suitable for reduction in a blast furnace. The main chemical reactions taking place on the sintering machine are the oxidation of lead and other metal sulfides with oxygen.

Sintering machines are continuous conveyors made of grate-bar pallets joined together. They are known as Dwight-Lloyd machines. Most of the older and smaller machines are of the downdraft type. A sectionalized windbox installed beneath the pallet line is used to regulate the burning rates in the machine. Newer installations usually have a single large updraft machine with the windbox located above the pallets. Emission points include the windbox and discharge points.

Sulfur dioxide concentration in the sinter machine off gas may be 0.8 to 1.8% by volume. Gas volumes run 100 to 220 scfm/sq ft of bed



Figure 13-7 - Typical Flowsheet of Pyrometallurgical Lead Smelting 19/

area. When the off gas is to be fed to a sulfuric acid unit, the machine is operated to produce a smaller volume of gas with 4 to 6% or more of sulfur dioxide. The dust and fume load carried by the gas is usually from 5 to 20% of the feed to the machine. $\frac{1}{2}$

13.3.1.2 <u>Blast Furnace</u>: The purpose of the blast furnace is to reduce the lead oxide in the sinter to metallic lead. The reducing agent is carbon monoxide derived from coke fed into the furnace. Dilution of the flue gas at the top of the furnace is necessary, since without it the gas would have a temperature near 1100° to 1300°F and contain 25 to 50% carbon monoxide. The dilution air burns the carbon monoxide to carbon dioxide, but the volume is large enough to also cool the gas. $\frac{1}{2}$

13.3.1.3 <u>Lead Refining</u>: The lead-refining process in a primary smelter consists of the dross reverberatory furnace and lead refining kettles. The product is lead bullion. The dross reverberatory produces also matte and speiss, which are shipped to a copper smelter for recovery of the large percentage of copper they contain.

The dross furnace usually operates only 50 to 70% of the time the refinery operates. A very small amount of sulfur oxide is emitted. Matte and speiss both contain sulfur, but most of this remains in the material that is shipped from the lead plant. A layer of dross on the hot material in the furnace permits oxidation of only a small portion of the sulfur. Particulates emitted from these operations would be principally metallic fumes. $\underline{l}/$

13.3.1.4 Other Smelter Operations: Some lead smelters operate such other equipment as cadmium roasters, slag fuming furnaces, and deleading kilns. The slag furnace recovers zinc oxide from blast furnace slag.

13.3.1.5 <u>Summary of Emission Rates</u>: Table 13-1 summarizes the emission rates from the various processes involved in the production of primary lead. Limited emission data were found for various processes in primary lead production, and the totals in Table 13-1 are considered as conservative estimates.

13.3.2 Characteristics of Effluents from Primary Lead Production

The chemical and physical properties of effluents from primary lead smelters are summarized in Table 13-2. Particulate emissions from primary lead production are similar in character to those from copper processing. The metallic fumes are submicron size, difficult to wet, readily agglomerate, cohesive, and will bridge and arch in hoppers.

A typical sample of lead blast furnace dust contains many different kinds of particles, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic compounds and a host of other compounds containing metals associated with lead ores. The major constituents are (1) light red-orange to red fragments of litharge; (2) yellow, rounded particles of massicot; (3) red birefringent, fragments of Pb304. Also present are a variety of vitreous iron-lime-silicate slag particles; these can have almost any color (yellow, green to brown).

13.3.3 Control Practices and Equipment for Lead Smelting and Refining

The sulfur content of lead concentrates is reduced by sintering them on Dwight-Lloyd sintering machines. Dust and fume are recovered from the sinter machine gas stream by settling in large flues and electrostatic precipitators or baghouses.5/ Collection efficiencies are up to 96% for precipitators and 99.5% for baghouses.5/

Blast furnace gases, after cooling, may be cleaned in baghouses using wool or fiberglass bags. The collected dust from the blast-furnace operation contains up to 65% lead and usually appreciable quantities of cadmium and arsenic. Therefore, it is recycled back to the sintering machine. Lead refineries also have baghouses for recovery of fume from softening furnaces and cupeling furnaces. $\frac{5}{2}$

The processes and control methods for lead smelter operations have been described in a translation of a 1961 German study.⁶ Table 13-6 summarizes some of the more pertinent data from this study. However, German practice may not correspond to current practice in U.S. smelters.

TABLE 13-6

LEAD SMELTER CONTROL EQUIPMENT⁶/

| | Cont | rol Device | Efficiency | | |
|--------------------------|--|--|------------|----------------|--|
| Process | Primary | Secondary | Primary | Secondary | |
| Sinter Machine | Centrifugal | Electrostatic pre- cipitator, bag filter | 80-90 | 95 - 99 | |
| Blast Furnace | Centrifugal | Electrostatic precipitator | 80-90 | 95-99 | |
| Reverberatory Furnace | Waste heat boilers, tubular coolers | Electrostatic precipitator, bag filter | 70-80 | 95 - 99 | |
13.4 PRIMARY ZINC SMELTING

Since practically all zinc ores as mined are too low in zinc content for direct reduction processes, they must first be concentrated. After concentration, the first step in the extractive metallurgy of zinc is virtually always roasting the concentrate. If the roasted concentrate, or calcine, is to be subjected to high-temperature reduction with carbon, it is usually first sintered in order to minimize dusting loss, volatilize impurities, and permit better circulation of reducing gases around the sintered particles. If the calcine is to be reduced electrolytically, it is dissolved directly in the spent electrolyte, consisting primarily of dilute sulfuric acid, just returned from the electrolytic cells.

Figure 13-8 illustrates a simplified flow diagram for a zinc smelter.

13.4.1 Emission Sources and Rates from Primary Zinc Smelting

13.4.1.1 <u>Zinc Ore Roasting</u>: Zinc sulfide concentrates are usually converted to zinc oxide calcines by a roasting process. There are 12 plants in the United States roasting sulfide concentrates. 1/ Two of these use the old Ropp roasters, which produce a roaster gas too low in sulfur dioxide for recovery by an acid plant. One plant uses multiplehearth roasters that produce a much-diluted waste gas with < 1% sulfur dioxide, also too low for recovery by an acid plant. Nine plants recover a large part of the sulfur with acid plants. One of these uses multiplehearth furnaces only for the first stage of a two-stage roasting process. Roasting capacity in the remaining plants is about equally divided between fluid bed and suspension roasters.

Operating conditions for zinc-sulfide concentrates vary from plant to plant according to the composition of the raw material and the specific use of the roaster calcine. Higher roasting temperatures (1800°F and over) eliminate more cadmium, and increase the formation of ferrites. Excess oxidizing air results in lower temperatures and good sulfur elimination, but also lowers the sulfur dioxide concentration in the roaster gas. $\frac{1}{2}$

Depending on the type of furnace, the gases escaping from the furnace contain greater or lesser amounts of dust of different composition and grain size. Table 13-7 lists several types of roesters and some operating conditions.



Figure 13-8 - Zinc Smelting Flow Diagram

TABLE 13-7

TYPICAL ZINC ROASTING OPERATIONSa/1/

| Type of Roaster | Operating Temp. (°F) | Feed Capacity (tons/day) | Dust in Off Gas Percent of Feed |
|---|-------------------------|--------------------------------|------------------------------------|
| Multihearth | 1,200-1,350 | 50-120 | 5-15 |
| Multihearth ^b / | 1,600-1,650 | 250 | 5-15 |
| Ropp ^C / Fluid-bed <u>d</u> / | 1,200 | 40-50 | 5 |
| Dorr-Oliver Fluid-bed <u>b</u> / | 1,640 | 140-225 | 70-80 |
| Dorr-Oliver | 1,650 | 240-350 | 75-85 |
| Fluid-bed | | | |
| Lurgi | 1,700 | 2 4 0 | 50 |
| Suspension | 1,800 | 120-350 | 50 |
| Fluid-column | 1,900 | 225 | 17-18 |

a/ Dead roast except where noted otherwise.

b/ First stage is a partial roast in multihearth, second stage.

is a dry-feed dead roast in Dorr-Oliver fluid bed.

c/ Partial roast.

d/ Slurry feed.

13.4.1.2 <u>Sintering</u>: Sintering in the zinc industry is used mainly to agglomerate the roaster calcine for subsequent processing. The process is sometimes used with only raw sulfide concentrates or a mixture of calcine and raw concentrates as feed.

Sintering machines have continuous conveyors made of grate-bar pallets, upon which the feed material is placed and processed. Downdraft machines are universally used in the zinc industry. The downdraft is produced by sectionalized wind boxes installed beneath the line of travel of the pallets. This construction permits draft regulation in separate areas of the grate. The gases may be recirculated from one end of the machine to the other.l/

With air at three to five times the theoretical amount to burn the coke and residual sulfur, the temperature of the combined exit gas ranges from 500° to 700°F. Sinter exit gas is further cooled by air dilution and water sprays to condition it for cleaning in dust collectors. 13.4.1.3 <u>Calcining</u>: Calcining is a heat-treating process that is used for oxidized materials, e.g., oxide ore concentrates; material from roasting of sulfide ore concentrates. It may be called nodulizing, since hard nodules of random sizes are produced when the calcining is done in a rotary kiln. The nodulized kiln product is subsequently treated for zinc extraction. Sulfur oxides are evolved only when roaster calcine that contains small amounts of sulfur is being processed, and in such cases the waste gas from the kiln may have from 0.1 to 0.2% sulfur dioxide. The waste gas also contains some fume, which is removed in bag filters and treated for recovery of lead and cadmium. $\frac{1}{2}$

13.4.1.4 <u>Metal Extraction</u>: Roasting, sintering, and calcining are preliminary steps to one of the extraction methods: pyroreduction or leaching and electrolysis. Pyroreduction distillation or retorting of the sinter or calcine is performed in horizontal or vertical retorts, electrothermal open or submerged arc furnaces, or blast furnaces. Horizontal retorts are small ceramic cylinders that are mounted horizontally in racks that hold several rows of retorts mounted one over the other. They are fed with coal and sinter and produce liquid zinc metal, as do the larger and more modern vertical retorts. Vertical retorts make a by-product carbon monoxide gas that is used as fuel in other parts of the plant. Particulate emitted is zinc-oxide fume.

Zinc fuming can be either an extraction or a pre-extraction operation. In this step, zinc is reduced to metal by carbon or carbon monoxide, vaporized, and reoxidized to form a zinc-oxide fume which is collected in bag filters. The zinc oxide collected may be fairly pure, in which case it is a final product. If it contains appreciable quantities of lead and cadmium it is usually treated further. $\frac{1}{2}$

13.4.1.5 <u>Summary of Emission Rates</u>: Table 13-1 summarizes the emission rates from the various processes involved in the production of primary zinc. The roasting operations produce about 40% of the particulate emissions, while ore crushing and materials handling account for nearly 45% of the total.

13.4.2 Characteristics of Effluents from Primary Zinc Production

The chemical and physical properties of effluents from primary zinc smelters are summarized in Table 13-2. Particulate emissions comprise metallic fumes from furnace and coarse dust from mechanical processes. The metallic fumes are difficult to wet, readily agglomerate, and will bridge and arch in collector bins.

13.4.3 Control Practices and Equipment for Zinc Smelting and Refining

For efficient recovery of zinc, the sulfur content of the concentrate is reduced to 2% by roasting. Multiple-hearth or Ropp roasting may be followed by sintering, or double-pass sintering may be used alone. Sintering in zinc smelters produces SO_2 which is converted into sulfuric acid by the contact process. The sinter plant gases can be precleaned by electrostatic precipitator, baghouses, or wet scrubbers.2/ The collection of sintering fume involves a large volume of gases in the range of 1,300,000 scf/ton of zinc product. Zinc smelter sintering fume is difficult to collect efficiently by electrical means because of its inherently high electrical resistivity. This requires close control of gas temperature and moisture content to maintain efficient collection.8/ Horizontal-flow, plate-type precipitators have been installed on most of the newer zinc sintering machines. Moisture and/or steam is normally added to improve dust resistivity for optimum precipitation. Mild-steel construction is common, and installed costs for base collectors of 50,000 cfm would be \$3.50/cfm.20/

Fluid-bed roasters have been used to process agglomerated feed. Exhaust gases were cleaned in a waste-heat boiler, cyclones, and an electrostatic precipitator in series. The metallic composition of the dust is a function of roasting temperature, Figure 13-9.9

The fume-recovery facilities at a Canadian smelter operation have been described.10/ Data for the facilities are shown in Tables 13-8 and 13-9. These facilities used electrostatic precipitators for controlling the emissions from zinc-roasting and lead-sintering operations. The zinc roaster gases entered the precipitator at 420°F without pretreatment. The lead sintering gases required conditioning in a spray tower.11/ The precipitators were very versatile, but the paramount problem was corrosion caused by condensed vapors. The Doyle scrubber (Table 13-8) operates on the principle of high velocity impingement of the dirty gas into water. Recovery efficiencies were in the range of 98 to 99+%. The installed costs (Table 13-9), are 1957 year costs, but are two to three times higher than general cost figures given in Appendix A. However, the costs in Table 13-9 include gas pretreatment, inlet and outlet flues, and all accessories such as rectifiers, dust conveyors, pumps, liquid cyclones, and instrumentation.

13.5 PRIMARY ALUMINUM PRODUCTION

Aluminum is produced by the electrolysis of alumina (Al₂C₃) in fused cryolite (AlF₃ - 3 NaF). Essentially all the alumina used is extracted from bauxite. Alumina recovery from bauxite consists of separating the alumina from the various impurities of bauxite, a process



Figure 13-9 - Dust Composition vs. Roasting Temperature in Zinc Processing9/

TABLE 13-6

| | | | | | Gat Conditio | LCE 5 | | | | | | Plant Ferformance | | | |
|----------------------------------|----------------|-------------|------------------|-------------|--------------|------------------|------------------|-------------|-----------------------|-----------------|-------------|-------------------|------------|---------|------------|
| | | | | | | | inlet | | | East Conditions | | Other | | | |
| | | hut.et | | | | | | Dew | Significant | Load | Predominant | Pressure | Calculated | H.P./ | |
| | Volume | Cemp. | Volume | Teny. | Percent | Velume | VCINE | Point | Gas Com- | Mg/Cu | 5:ze | Jrop | Ges H.P./ | , 1,000 | Percent |
| Type of Equipment | <u>at_37P</u> | (°F) | a. Teng | <u>(t)</u> | Air Leak | at Temp. | at NTP | <u>(*F)</u> | ponent (1) | <u>rd</u> / | Microns | <u> </u> | 1,000 CFM | CTM | Efficiency |
| Bugheuses | | | | | | | | | | | | | | | |
| Lead Blast Furnames | .95,000 | 200 | 27 8,00 0 | 225 | 10 | 262,000 | 177,000 | 95 | S02 0.07 | 195 | < 5 | 6.0 | 1.7 | 1.5 | 99.0 |
| Sing Funing | ,48,000 | <u>:</u> .) | 210,000 | 250 | 15 | 153,000 | 127,000 | 35 | 502 C.09 | 268 | < 2 | 6.0 | 1.7 | 1.1 | 99.7 |
| Silver Rofinery | 7,400 | ::0 | 9,200 | 155 | 12 | ₿,700 | 6,600 | 45 | CO2 3.0 | 5 6 | < 1 | 2.0 | 0.6 | 1.8 | 99.7 |
| Silver Befinery | 9°5) 0 | ຼາຍວ | 12,700 | 200 | 12 | 11,700 | 8,200 | ao. | 0215 002 3.0 | 320 | < 1 | 2.0 | 0.6 | C.6 | 99.8 |
| And a share to a strength of the | 6 101 | 74 | 8.310 | 195 | 12 | 7 660 | 5 450 | 110 | 2 10 | 6.0 | - 1 | 4.5 | 1.5 | 6 2 | 97 5 |
| Tool from a | | 30 | 14.550 | 110 | 10 | 15 700 | 1,000 | 45 | | 194 | 20 | 3.0 | 0.9 | 0.5 | 95.0 |
| West Crashing | 42,000 | 50 | , | - 14 | • • | 10,700 | ,200 | 4 .3 | | 124 | C U | 5.0 | 0.3 | 0.5 | ل. دو |
| (Tim: Disstant) | 7 103 | 85 | 8 675 | · ac | 12 | 7 341 | 6 600 | 10 | | 97 | ≜ 30 | 3.0 | 0.9 | | 38.0 |
| Your Restors: | 5 400 | 180 | 7 7 3 | 200 | 15 | 6 000 | 4,000 | 52 | | 145 | - 10 | 3.5 | 0.9 | 0.5 | 90.0 |
| | 0,000 | 150 | | | | | | | | | | | | | |
| Electrostatic Precip | itater: | | | | | | | | | | | | | · | |
| Leas Sintering | 140,000 | 135 | 380,000 | 150 | 15 | ; 60,00 0 | 185,000 | 130 | 502 2.0 | 130 | < , | 0.10 | 0.03 | 1.4 | \$7.0 |
| Zin Sensting Kit 92 | 96,000 | 390 | 157,000 | 470 | 70 | 147,000 | 78,000 | 150 | 80 ₂ 6.5 | 510 | 5 | 0.08 | 0.02 | 1.3 | 90.0 |
| 2:4. 00.00 | | | | | ····· | | | | | | | | | | |
| <u>of tener</u> | | | | | | | | | | | | | | | |
| Cas Invite | 9.500 | : აა | | . 10 | 6 | 11,000 | 9,000 | 95 | 204 2.0 | 600 | 50 | 3.0 | 0.9 | 0.3 | 91.0 |
| Ster Brattars | - 9 | 67.0 | 81.500 | 250 | | 90,000 | 74,200 | 170 | 80. 7.5 | 1.000 | 20 | 6.5 | 1.9 | 0.4 | 87.5 |
| Pilet F ant File | 1,200 | 630 | 1.620 | 690 | Ŀ | 2,833 | 1,140 | | co, | 220 | 10 | 5.0 | 1.4 | | 75.0 |
| Dy. Not firsters | | | | | | | | | - | | | | | | |
| Sinter Plant Dryers | 67,000 | ÷- | 22.150 | 276 | #11 | 105,000 | 67,000 | 167 | 50 ₂ -0.0? | 250 | 60 | 8.C | 5 3 | 0.5 | 97.0 |
| Sinter Filmt Ventination | 155,000 | 75 | -60,JOC | 39 | Sal. | 185,000 | 1 58,0 00 | 76 | | 100 | 15 | в.0 | 2.3 | ¢.7 | 99 . O |
| | | | | | | | | | | | | | | | |
| Refiner; No fing | | | | | | | | | | | _ | | | | |
| Arts'e | 5.700 | .ið | 7,050 | 142 | N11 | 7,400 | 5,700 | .30 | | 22 | 5 | 9.2 | 2.6 | 2.1 | 96.2 |
| Zini Suloni ie Pi hu an | 1.470 | ê2 | 5 E 0 | 90 | ¥1. | 5,250 | 4,470 | 74 | | 100 | æ | 9.0 | 2.3 | •• | 95.7 |
| Coal Drynes | .0,a00 | ez | .2.600 | 144 | NEL | 12,000 | 10,800 | 93 | 002 2.0 | 65 | 10 | 8.5 | 2.4 | | 95.0 |
| Pilot Plant Kilm | 1,5.0 | 60 | 1,860 | 2 74 | Bi. | 2,260 | 1,610 | | cc ₂ 1.5 | ace | 12 | 9.1 | 2.5 | •• | 96.4 |

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| TABLE 13-8 (Concluded) |
|------------------------|
|------------------------|

| | | | | Tr | eatment F. | lent | | | | |
|-----------------------------------|-----------------|---------------------|-----------------------------|--------------------------|--------------------------|------------------------|---------------------------|-----------------------|---------------------------------------|--------------------|
| Type of Equipment | No. of Units | Components/ Unit | Bags/ Component | Tetal No. of Bags | Bog Diameter (in.) | Bag Length (ft.) | Total Sq. Ft. Cloth | Ratio ^C | Cleaning Cycle (min.) | Fabric |
| Bagherasen | | | | | | | | | | |
| Lead Blast Furnaces | 20 | 1 | 396 | 7,920 | 5 | 10) | 107,700 | 2.4 | 15 | Orion |
| Sing Furing | 16 | 10 | 18 | 2,880 | 5 | 10 | 54,000 | 3.5 | 9 | Orlog |
| Silver Refinery No. 1 | 2 | 4 | 25 | 200 | 5 | 10 | 3,750 | 2.3 | 2 | Woel |
| Silver Refinery No. 2 | 2 | 6 | 25 | 400 | 5 | 10 | 7,500 | 1.6 | 5 | Orlon |
| Antimonial Lead Plant | 4 | 1 | 25 | 100 | 3 | 10 | 1,875 | 4.1 | 15 | Orlon |
| Coal Crushing Calcine Elevator | 3 | 1 | 144 | 432 | 5 | 10 2 | 5,920 | 2.5 | 15 | Cotton |
| (Zinc Reasters) Priot Plant | 3 2 | 1 1 | 120 120 | 360 360 | 5 S | 10 4 92 | 4,860 4,320 | 1.6 1.6 | 15 15 | Cotton Orlon |
| <u>Cottrelis</u> | No of Units | Seconds/ Unit | Gas Velocity (ft/sec) | Continuing Time (sec. |) <u>Hires</u> | Plates | Veltage | × | aterial of Construction | <u> </u> |
| Lead Sintering No. 78 | Í 5 | 4 | 4.5 | 8.5 | Iron | Aluminum | 60,000 | 6 in. line wood | Erick wal d dust hop en derking | l, brick- Fers, |

21n- Presting No. 92/ 4 2 4.0 5.0 Iron Iron 60,000 Brick construction with sand seals

| | Nc. of | CFN/ | Material of | Total Water Flow | pH of Effluent | 1/5 | Nozzle Velocity |
|---------------------|--------|--------------|--|------------------------|-------------------|-------|--------------------|
| Doyle Wet Strutters | Units | Unit | Censtruction | <u>GPM</u> | Counterflow | Ratic | (ft/sec) |
| Sinter Plant Pryers | 3 | 36 ,COO | Lesd with 31688 ducts and nozzle | 120 | 3 | 0.29 | 150 |
| Sinter Plant | | 2,500 | | | | | |
| Wentilation | 30 | tu 20,000 | Steel and lead | 189 | 4 | 0.17 | 150 |
| Refinery Meiting | | | | | | | |
| Kattle | Ë | 4,000 | Mild steel, neoprepe lined | 6 | 2 to 3 | 6.13 | 155 |
| Zin: Sulphide | | | | | | | |
| Fachucas | • | 5,000 | Wood with lead duct and nozzle | é | 4 | 0.17 | 150 |
| Joal Dryers | 1 | 12,000 | Mild steel | 12 | ε | 0.15 | 152 |
| Pilot Plant Kiln | 1 | 2,000 | 316 Stainless steel | 3 | 3 | ĉ.24 | 160 |

 \underline{a}^+ Gas then to absorption plants for further cleaning and SO₂ recovery. b/ At 55% efficiency. f/ inlet volume at temperature civided by square feet of cloth. g/ inlet volume at temperature.

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No. of Material of (hits Construction <u>Cyslenss</u> Coal Drying 2 Dine Roasters 15 Pilot Plant Kiln 1 Mild steel Mild steel Mild steel

TABLE 13-9

COSTS FOR CLEANING METALLURGICAL GASES (1957 DATA10/)

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| | | | | | Operating and | Cost Items Included | | | | | |
|----|--|--------------------------------------|-------|------------------------------|----------------------------------|---------------------|--------------|----------|-------------------------|--|--|
| | Plant | $\frac{\texttt{Inle}}{\texttt{CFM}}$ | t | Installed Cost \$/ACFM | Maintenance $\phi/1,000$ Cu. Ft. | No. of Fans | Pretreatment | Building | Tons of Dust/ Day | | |
| 1. | Blast furnace baghouse | 262,000 | 225 | 4.35 | 0.19 | 4 | Cooling | Yes | 70 | | |
| 2. | Slag fuming baghouse | 193,000 | 250 | 4.80 | 0.26 | 3 | Cooling | Yes | 250 | | |
| 3. | Sintering electro- static precipitator | 160,000 | 150 | 5.10 | 0.22 | 1 | Humidifying | Yes | 15 | | |
| 4. | Zinc roaster electro- static precipitator | 147,000 | 420 | 4.65 | 0.13 | l | Nil | Yes | 50 | | |
| 5. | Four tadanac dryer cyclones | 38,800 | 300 | 1.93 | | 2 | Nil | No | | | |
| 6. | Sinter dryer scrubbers | 106,000 | 275 | 1.90 | | 3 | Nil | No | | | |
| 7. | Sinter ventila- tion scrubber | 3,000 | 100 | 2.23 | | 1 | Nil | No | | | |
| 8. | All sinter scrubbers | 292,000 | | | 0.07 | 20 | Nil | No | 20 | | |

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accomplished by chemical means. For this purpose, advantage is taken of the amphoteric properties of the aluminum ion, which permit the metal to be solubilized in the form of an alkaline aluminate, particularly the form of sodium aluminate.

The Bayer process, shown in Figure 13-10, is used in most cases to recover the alumina. As shown in Figure 13-10, following separation and washing hydrated alumina is fed to large rotary furnaces, similar to cement kilns, wherein the alumina is calcined at about 1200°C. This operation is necessary not only for the purpose of eliminating the 45% of water (including the 30% combined water present in the hydrated material), but also for giving some of the alumina the crystalline α (or corundum) form, which is most advantageous for electrolysis. These furnaces or kilns are significant sources of particulate emissions. The calcined alumina for aluminum production obtained from these kilns is in the form of a white powder consisting of aggregates which range in size up to about 100 μ , and which are made up of monocrystals of anhydrous alumina at various stages of crystallization.

The alumina is next sent to a primary aluminum processing plant where the alumina is converted to the metal by electrolysis. The heart of the operation is the electrolytic dell where direct current dissociates alumina into oxygen and molten aluminum metal. These cells are called "pots" and are arranged to form potlines having several hundred cells per potline. Each cell requires 40,000 to 100,000 amp. of current under normal operating conditions. As shown in Figure 13-11 (prebaked anode cell), the molten aluminum collects at the bottom of the bath above a carbon lining which acts as the cathode. Oxygen migrates to the carbon anode, forming carbon dioxide or carbon monoxide at high cell temperatures which usually reach 940°C.

Periodically aluminum metal is withdrawn, and fresh alumina feed and bath chemicals added by piercing the frozen crust of the bath. Crustbreaking agitates the bath and is a time of increased particulate and gaseous emissions. Thermal buoyancy of heated air plays a large part in sweeping finely divided alumina and bath fumes out of the cell. Ducts over the cells capture some of the escaping fumes, but some elude capture and are emitted into the building atmosphere and find their way to the atmosphere through roof ventilators or "monitors," also shown in Figure 13-11.

While all aluminum production employs the basic Hall-Heroult process, several variations in cell construction have evolved, based upon the method of ancde manufacture. It is important to understand the differences in cell construction because the type of cell employed will affect the types and quantities of pollution generated. The types of cells are: (1) the prebake cell; (2) the horizontal stud Soderberg cell; (3) the vertical stud Soderberg cell. Figures 14-12, 13 and 14 illustrate the various cells.







Figure 13-11 - Aluminum Cell (Prebaked Anode Type) $\frac{12}{}$



In a prebake anode plant, pitch and coke are mixed, pressed and baked before use in the cell. The carbon anodes are rectangular in cross section and supported by copper or aluminum hangers to the electrical busbars overhead.

The other types of cells bake anodes at the cell itself by introducing a carbon paste directly and using the heat of the melt to form the carbon anode. Prebaking of the anode is therefore avoided, and continuous operation of the cell is possible. Known as the Soderberg cell, one type, the vertical stud Soderberg cell, is shown in Figure 13-14. Paste is added to the top of the cell and slowly carbonized as it moves toward the bath. Metal studs carry electric current to the carbonized portion through the top, and are positioned vertically with respect to the anode: hence, its name. Cell construction allows gases liberated by the cell to be easily collected and burned. Both vertical stud and horizontal stud Soderberg exhausts are rich in hydrocarbons from the baking operation.

Hooding requirements for the horizontal stud Scderberg, shown in Figure 13-13, are much more difficult because of the stud positions along the side of the electrode rather than at the top. Continuous consumption of the anode forces repositioning of the studs and necessitates easy access to the anode. Requirements for easy anode access complicate fume collection and do not allow burning of gas and tar at the cell itself, as is practiced with the vertical stud Soderberg cell.

13.5.1 Emission Sources and Rates from Primary Aluminum Production

Little information is available about amounts of particulate emissions from aluminum production plants. The major source of particulate emissions is the reduction cells, as discussed below. Secondary sources are summarized in Table $13-4.\frac{12}{}$ Secondary sources include raw materials handling, pot lining operations, anode preparation (prebake plants), cleaning operations, and aluminum refining.

13.5.1.1 <u>Reduction Cells</u>: Reduction cell emissions can be divided into roof monitor emissions and the potline control system emissions. $\frac{12}{}$ The roof monitor emissions are emitted at the building height along the entire length of the building and may be considered a line source. Potline control system emissions are emitted from stacks. $\frac{12}{}$

Actual emissions vary widely from plant to plant, depending upon age, cell type, operating procedure, and efficiency of the hoods over the cells. 13.5.1.2 <u>Anode Furnace</u>: The anode furnace is a source of fluoride, sulfur dioxide, and particulates in prebake plants. Sulfur dioxide emissions will depend upon the sulfur content in the pitch and the coke of the anode.

13.5.1.3 Casting Furnace: Aluminum casting furnaces also emit particulate pollutants. In the casting furnace aluminum from the primary cells is refined by heating and by chlorination. Products of the reaction are aluminum chloride, aluminum oxide and heavy metal chlorides liberated from impurities. Free chlorine and hydrochloric acid are likely to be present in the off gas.

13.5.1.4 <u>Summary of Emission Rates</u>: Table 13-1 summarizes the emission rates from the various stages in the production of primary aluminum. Emissions from the reduction cells currently total about 65,000 tons/ year.

13.5.2 Characteristics of Effluents from Frimary Aluminum Production

The chemical and physical properties of effluents from primary aluminum production are summarized in Table 13-2. Particulates emitted from the refining and casting furnaces range in size down to submicron levels. The particulates are abrasive and corrosive. Flucrides, both gaseous and particulate, are a component of emissions from the reduction cells.

13.5.3 Control Practices and Equipment for Primary Aluminum Production

The control of emissions from the on-site operations of bauxite drying and alumina calcining involve high dust concentrations which frequently dictate the use of multicyclones for preliminary particulate collection, usually followed by electrostatic precipitators. Fabric filtration can be used if close temperature control is practiced. Collection efficiencies of 99.7+% have been reported for such systems. $\frac{20}{2}$

Reported process flows of from 25,000 to 250,000 acfm result in small-to-moderate sized installations. Installed costs for combined multicyclone/electrostatic precipitators would range from \$4.60/cfm for the lower volumes, through \$2.30/cfm for the higher, at 99+% overall collection efficiencies. These costs exclude auxiliaries.^{20/}

Control of fluoride and particulates from aluminum cell rooms can be classed as:

- (1) Capture of cell effluents by potline hooding,
- (2) Subsequent collection of captured pollutants in scrubbers, etc.
- (3) Scrubbing of roof "monitor" emissions.

Because the choice of electrolytic cell determines the design of hooding and collectors, controls will be discussed separately for the prebake and Soderberg cells. Most of the following discussion and information is from the report "Air Pollution from the Primary Aluminum Industry" by the Washington State Department of Health. 12/

13.5.3.1 Vertical Stud Soderberg Cell: The vertical stud Soderberg cell captures cell effluents most effectively because placement of the anode studs in a vertical position allows a metal skirt to be fixed to the lower end of the steel anode jacket. The skirt reaches down to the encrusted bath and effectively encloses the fuming bath. Gases are, therefore, drawn off with little dilution by air and are concentrated enough to allow combustion of the tarry hydrocarbons. During burning, hydrocarbons are reportedly reduced from 3 to 0.1% by volume, and most fluoridated carbon compounds converted to hydrofluoric acid. The effective oxidation of tar is a great aid to subsequent collection because tar comtamination and plugging of ducts are avoided. After burning, exhaust fumes from each pot are sent to a central header fan and control equipment. One piece of control equipment will commonly treat exhaust fumes from 15 pots.

Control devices used for vertical stud Soderberg cells have included multiclones and spray-type scrubbers. The scrubbers use high pressure sprays to contact countercurrently the gases and particulate. Such a system can remove 95% of the fluorides entering the control system, but no figures for total particulate collection efficiencies are reported. Exhausts may be treated by bag filters coated with lime or alumina, or by electrostatic precipitators, but the residual tar creates a fouling problem in the collection system.

A recent addition to the family of collectors is the sieve plate scrubber shown in Figure 13-15. The device has been put into operation in Norway. A three-plate tower has removed 97% of the hydrogen fluoride, 80% of the solid fluoride particles and 70% of the total particulate in incoming gas streams. Higher absorption efficiencies are possible with the addition of a fourth plate. The design allows self-cleaning of the plates by the use of sprays directed at the underside of each plate where heavy tar and particle deposition occur. High-velocity droplets, impelled by the air flowing through the restriction, are blown against the plate and are forced to the top by the air stream, thereby preventing plugging of the sieves. Particulate collection is by impingement on the plates and the water droplets. The tower produces hydrofluoric acid used as recirculation liquer for the first plate.

Another collection system is shown in Figure 13-16. The system incorporates dry cyclones, an electrostatic precipitator and two scrubbers.



Figure 13-15 - Schematic Drawing of Cross-Sectional View of the New Sieve-Plate Gas Scrubber12/



Figure 13-16 - Purification Installation for Cell Gases $\frac{12}{}$

The system achieves 99.9% gaseous fluoride collection, but particulate efficiencies were not given. When a scrubber is used for both gaseous and particulate fluorides, the particulates are frequently more difficult to collect, and dictate the power requirements of the scrubber.

13.5.3.2 Horizontal Stud Soderberg Cell: Effective capture of all effluents for a horizontal stud Soderberg cell is much more of a problem, because open channels are required for replacement and readjustment of the studs. As a result, hooding is less complete; therefore, larger volumes of air are entrained. Large volumes of exhaust air create a dilute mixture of hydrocarbons. Because burning is not possible, a tar-fouling problem occurs in ducts and control equipment. Cyclones or multiclones and bag houses have fouled too easily to be an effective answer to control with horizontal stud Soderberg cells. Where electrostatic precipitators are attempted, the plates require water flushing to prevent fouling by tars. Existing controls have consisted of scrubbers, either grid packings in a vertical scrubber or the high-velocity spray type. The lack of primary collectors makes these scrubbers especially susceptible to plugging by particulate matter.

To solve this problem, the Alcan Company developed the floating bed scrubbers whose principle is shown in Figure 13-17. A bed of light polyethylene spheres is shown at rest with no air-liquor flow. The bed becomes fluidized upon operation and the spheres are free to rotate and agitate. Liquor flows down through the interstices, contacting the gases in the air stream, while at the same time washing the spheres. Most importantly, the constant motion of the spheres prevents accumulation of tars on the spheres. Collection efficiencies for the floating bed scrubber are detailed in Table 13-10 for a single bed installation having pressure drops 4 to 6 in.

TABLE 13-10

COLLECTION EFFICIENCIES FOR THE FLOATING BED SCRUBBER USED ON HCRIZONTAL STUD SODERBERG CELL

Substance

Collection Efficiency (%)

90+

98+ 80-90ª/

Total fluorides Hydrogen fluorides Particulates

a/ Anticipated efficiency at higher pot ventilation rates of 3,600 scfm and when doors are closed.



Figure 13-17 - The Floating Bed Scrubber Developed for Horizontal Stud Soderberg Cell Exhausts¹²/

A second floating bed can be added, increasing the collection efficiencies and the pressure drop another 4 in. of water. However, an additional bed will require use of a larger horsepower fan to overcome increased pressure drops.

In summary, control problems of the horizontal stud Soderberg cell have lessened its economic advantage over the prebake cells. Additional research to overcome the hydrocarbon fouling problem will be needed.

13.5.3.3 <u>Prebake Cells</u>: The prebake potline operation requires an on-site carbon-anode baking plant. Particulate emissions from these ovens include tars and inorganic ash. Detarring by electrostatic precipitation has been reported at over 99.9% abroad. Close temperature control is required both to fractionally condense the volatile tars, as well as to maintain free-flowing properties of the precipitate. Detarring gas temperatures of from 115°F to 160°F have been reported.²⁰/

Hooding for prebake cells is similar to the vertical stud Soderberg, but ventilation rates are much greater. One exception to this generalization is the Pechiney process which employs no local exhaust ventilation over cells at all, but instead relies upon roof-monitor emissions control to collect pollutants.

Particulate emissions from prebake pots contain none of the tar found in the horizontal stud Soderberg; instead, "dusting" of the carbon anode produces carbon particles in addition to alumina, etc. Current controls have consisted of dry-type cyclones or electrostatic precipitators followed by wet scrubbers. Scrubbers are 12 to 15 ft. in diameter and 40 to 60 ft. high with internally mounted spray headers.

The newest controls being developed have relied upon a dry absorption of fluoride gases (and perhaps particulates) upon finely divided alumina powders. The alumina dust and any other particulate are then collected in a baghouse, and the catch is sent to the cell as the feed. A solid particle coating of alumina on the inside bags also aids in fluoride collection. Dry collection avoids all the plugging and high water costs of scrubbing towers, while allowing the dust to be returned directly to cells in a dry form. Performance data are extremely scarce on this unit as it is still in the development stages, but total particulate collection of 99% and gaseous fluoride efficiencies of 95% have been estimated.

13.5.3.4 Efficiency of Current Potline Controls: Efficiency data for current and prototype control devices are summarized in Table 13.11. Existing particulate control efficiencies vary from 40 to 60%, except where an electrostatic precipitator is used in conjunction with other devices.

| Type of | Existing | Est. Removal | Efficiencies, % | | Latest | Est. Removal | Efficiencies,% |
|-----------------|---|----------------------|---|----|--|----------------------|----------------|
| Cell | Collectors | Fluorides <u>a</u> / | Particulates | | Collectors | Fluorides <u>a</u> / | Particulate |
| H.S.២∕ | Soderberg Spray scrubbers | 80-90 | 40-50 | 1. | Floating bed scrubber ^C / | 90 | 80-90 |
| · | | | | 2. | Wetted plate electrostatic (with condi- tioning of flue gases) | 90 | 99 |
| ?rebake | Multiclones Dry electrostatic precipitators | . 0 | < 60 90 | 1. | Fluidized alumina con- tacts cell exhausts, fol- lowed by collec- tion in alumina | 99 | 96 -9 8 |
| | Spray scrubbers | 80-90 | 40-50 <u>d</u> / < 10 ^e / | 2. | Counterflow packed scrubber | 90 | 95 |
| v.s. <u>f</u> / | Soderberg multi- clones | 0 | < 60 | | Sieve plate scrubber | 95 | 70 |
| | Spray scrubbers | 80-90 | 40-50 | | | | |

TABLE 13-11

 \vec{b} / H.S. = horizontal stud. c/ One section of bed employed. e/ When used after e.s.p. f/ V.S. = vertical stud.

297

0

13.5.3.5 <u>Roof Monitor Controls</u>: Pot fumes that escape collection by the hooding are emitted through roof vents, called monitors. The sources of building ventilation air are usually adjustable louvers located in the building wall along the side to cool the building and sweep contaminants away from worker's breathing zones. Air may also enter through gratings in the floor. The volume of monitor discharges will depend upon the louver adjustment as well as wind speed and temperature difference. Air turnover in the building approaches 30 to 40 changes per hour.

Most aluminum plants presently have no monitor controls. Where controls have been applied, filament mats or screens are placed in the path of monitor fumes and wetted by sprays. Figure 13-18 shows a roof monitor scrubber--no fans are employed. Efficiency of gaseous fluoride collection is reported at 60-70%. No efficiencies for particulate collection have been reported. However, it is doubtful that much, if any, total particulate collection occurs, given the low pressure drop of the scrubber.



Figure 13-18 - Roof Scrubbers12/

A more advanced version of the spray chamber scrubber has been reported in the German literature. The spray mats are preceded by electrostatic filters to remove particulate and spray scrubbers dispensing water over wire mesh. Nozzles are positioned so as to clean the mesh of particulate matter and prevent clogging. Ninety percent removal of gaseous fluoride is reported, but no figures are given for particulate matter. Exhaust fans are mounted at the outlet of the spray chamber.

For the plant practicing no hooding ventilation (Pechiney process) and instead emitting all fumes from the monitor, washers appear to be similar to the German roof monitors. However, no electrostatic prefilter is present, and the sprays are horizontal rather than vertical. No collection efficiencies have been supplied for the Pechiney process controls.

13.5.3.6 Other Sources: In addition to roof monitors and potlines, aluminum plants also emit particulates and gases from auxiliary operations. Data on emissions and possible control systems for other sources are even scarcer than for the reduction cell exhaust. In prebake plants, the anode furnace is a source of fluoride, sulfur dioxide, and particulate emissions. In the prebake furnace, carbon anodes are baked for periods of two or three weeks prior to their use in the reduction cell. Natural gas is usually employed to bake the anodes. Existing controls consist of the spray scrubber, which is efficient in removing fluorides and fairly efficient for control of sulfur dioxide, but the controls are, unfortunately, very poor for particulate emissions control. In fact, one plant in Washington State using Pease Anthony scrubbers on the bake ovens emitted an effluent plume with a No. 3 and No. 4 Ringelmann rating because the relatively inefficient scrubbers cannot touch the fine smoke fume. Incineration, followed by medium pressure drop scrubbing, has been suggested, but natural-gas costs for incineration are regarded by aluminum companies as being prohibitively high. Particulate emissions for an uncontrolled anode furnace are reported at under 5 lb/ton of aluminum produced. Sulfur dioxide emissions will depend upon the sulfur content in the pitch and the coke of the anode.

Aluminum casting furnaces also emit particulate and gas. In the casting furnace aluminum from the primary cells is refined by heating and by chlorination. Products of the reaction are aluminum chloride, aluminum oxide and heavy metal chlorides which are given off as fume. Free chlorine and hydrochloric-acid may also be present in the gases from the casting furnaces. Control of emissions from the casting furnaces present many of the same problems that are present with reduction cell exhausts. One potential control device is a multistage floating bed scrubber.¹³/ In this system, caustic is used as the scrubbing medium, not only to effect particulate matter removal, but also to react with the acid gases. Reportedly, the particulate can be lowered to 0.04 grain/scf.¹³/

One piece of data on uncontrolled units estimates emissions at 4 lb/ton of aluminum, expressed as chloride. Uncontrolled units would emit a characteristic white plume.

Other miscellaneous sources in aluminum reduction plants are raw materials unloading in transfer operations which have been controlled by baghouse collectors. One Washington plant has also calculated that coke dust emissions from a coke calciner have been controlled to a 0.8 lb/ton when cyclones are used.

13.5.3.7 <u>Control Costs</u>: Literature data on the cost of control devices for the aluminum industry are sparse. One plant manager in Washington State produced information that a recent installation of a new potline resulted in an expenditure of 14% of the capital cost for control devices. However, these devices do not meet regulations currently being imposed or contemplated by regulatory agencies in Washington State.

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CHAPTER 14

CLAY PRODUCTS

14.1 INTRODUCTION

The clay product, or ceramic, industries have as their finished materials a variety of articles that are essentially silicates. These products may be classified as: (1) whitewares; (2) heavy clay products; (3) refractories; (4) enamels and enameled metal; and (5) glass. The three main raw materials used in making common ceramic products are: (1) clay, (2) feldspar, and (3) sand. In addition, a wide variety of other minerals, salts, and oxides (borax, soda ash, cryolite, alumina, chromite, and magnesite) are used as fluxing agents and special refractory ingredients.

Clay or ceramic products are manufactured by a series of processes involving grinding, screening, calcining, blending of the raw materials, forming, drying or curing, firing, and final cutting and shaping. Particulate emissions occur during handling of raw materials, grinding, calcining, screening and blending, and during cutting and shaping operations. Meager data were found for emission rates from these sources. The particulate air pollution potential of this industry group is not well defined.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for the major portions of the clay products industry are discussed in the following sections.

14.2 MANUFACTURING PROCESSES

14.2.1 Ceramic Clay

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding and blending of the desired ore varieties (Figure 14-1). The basic raw materials in ceramic clay manufacture are kaolinite $(Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O)$ and montmorillonite (Mg, Ca) $0 \cdot Al_2O_3 \cdot 5SiO_2 \cdot nH_2O$) clays. These clays are refined by separation and bleaching, blended, kiln dried, and formed into such items as whiteware, heavy clay products (brick, etc.) and various stoneware and other products, e.g., diatomaceous earth used as a filter aid $\frac{2}{2}$



Figure 14-1 - Ceramic Clay Manufacturing Processes2/

Halide bleaching for preparation of kaolinite utilizes the reactivity of the halide to remove the chemically active and unwanted constituents of the clay ore leaving behind a purified white product suitable for ceramics manufacture. Figure 14-1 includes a schematic diagram of this process. $\underline{2}/$

The manufacture of filter and activated clays includes grinding and wet or acid treating, followed by drying and regrinding. The drying is accomplished in rotary kilns, which reduce moisture content from 15-20% to 10%.

Ceramic clay is manufactured from a mixture of wet talc, whiting, silica clay, and other ceramic materials. This mixture is dried in a spray dryer.

14.2.2 Heavy Clay Products

The manufacture of brick and related products such as clay pipe, pottery, and some types of refractory brick involves the grinding, screening, blending of raw materials, forming, drying or curing, firing, and final cutting or shaping.²/ Bricks are manufactured by one of three processes: the soft-mud, the stiff-mud, or the dry process. The soft-mud process consists in molding the clay mixture containing 20-30% water in molds coated with a thin layer of either sand or water to prevent sticking. The molded brick is then burned. This soft-mud process is used for firebrick.¹/

In the stiff-mud process, the clay is just wet enough (12-15%) to stick together when worked. The clay is forced out through a die in a screw or auger machine. \underline{l} / The extruded clay bar passes along a short belt conveyor onto a cutting table, on which a frame with a number of wires automatically cuts the bar into appropriate lengths. The bricks are then burned. \underline{l} /

The stiff-mud process is employed for the manufacture of practically every clay product, including all types of brick, sewer pipe, drain tile, hollow tile, fireproofing, and terra cotta. The greater percentage of clay ware is made by the stiff-mud process. $\frac{1}{2}$

In the dry-press process the water content is from 4-7%, which makes the clay relatively nonplastic. The brick unit is molded at pressures around 5 tons/sq in. and then dried.

The drying and firing of bricks, both common and refractory, is accomplished in many types of ovens. The most popular type is the long tunnel oven in which the bricks, loaded on steel carts, pass countercurrently against the heat flow. Total heating time varies, but is usually 50-100 hr. for 9 in. refractory bricks. Normally gas or oil fuel is used for heating, but coal may be used. Temperatures up to about 2000°F are used in firing common brick.

14.2.3 Refractories

Refractories are those materials which are used to withstand the thermal, chemical, and physical effects that occur in furnaces. Refractories are sold in the form of firebrick, silica brick, magnesite brick, chromite brick, magnesite-chromite brick, zirconia refractories, and others. In making a refractory, the main material is selected on the basis of the thermal, chemical, and mechanical conditions to be encountered in service applications. \underline{L}

The usual operations in manufacturing refractories include grinding and screening, calcining, mixing, pressing or molding and repressing, drying, and burning. Usually the most important single property required is high-bulk density, which affects many of the other important properties.

The multiplicity of refractory products results in a highly variable process flowsheet. Depending upon the desired product, raw materials may be calcined or dried prior to mixing and blending. Figure 14-2 illustrates an overall flowsheet for a typical plant producing a kiln-fired refractory. $3^{/}$ The decision to calcine or dry the raw material depends upon its end use. The type of clay, refractory brick, and ultimate density are among the factors that influence the decision. $3^{/}$

Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia, melting the mixture in an electric-arc furnace at temperatures of 3200-4500°F, pouring into molds, and slowly cooling to the solid state. Fused refractories are less porous, and more dense than kiln-fired refractories.2/

Castable refractories are employed in glass furnaces, as linings of hot zones of rotary kilns, in boiler furnaces exposed to severe duty, and in metallurgical equipment such as forging furnaces. $\frac{1}{2}$

14.3 EMISSION SOURCES AND RATES

14.3.1 Ceramic Clay

Particulate emissions occur from raw materials handling, grinding, drying, and firing kilns. Fluorides and acid gases may also be emitted in the drying process. Factors affecting emissions include type and quantity of material processed, the type of grinding (wet and dry), the temperature





of the drying kilns, ges velocities in the drying kilns, the flow direction in drying kilns, and the amount of fluorine in the ores.^{2/} Insufficient data exist to determine if there is a correlation between dryer types and emissions.

14.3.2 Heavy Clay Products

Particulate emissions occur during handling of raw materials, grinding, screening, and blending, and during cutting and shaping operations. Fluorides, largely in a gaseous form, are also emitted from brick manufacturing operations.²/

The extent of raw material handling and processing greatly affects the dust emissions from this phase of the manufacturing process. Emissions when firing and/or curing the formed bricks are affected by the temperature in the ovens and the type and quantity of trace components in the brick. Thus, sulfur and/or fluoride compounds may be emitted when the bricks are subjected to high temperatures. The type of fuel used to heat the ovens also has a direct bearing on the combustion emissions.

14.3.3 Refractories

Particulate emissions in kiln-fired refractory plants occur from raw materials handling, crushing, calcining, drying, mixing, and burning operations. Emissions from the calcining and drying operations depend upon the type and quantity of material charged, kiln and dryer types, and final moisture content.

Particulate emissions from the manufacture of castable refractories are created by the drying, crushing, handling, and blending phases of this process, the actual melting process, and in the molding phase. Fluoride emissions, largely in the gaseous form, may also occur during the nelting operations. Particulate emissions are affected by the amount of material handling and pre-treatment required before melting, and by the components in the melt. Generally, increasing concentrations of silicon will cause increased particulate emissions.

14.3.4 Summary of Emission Rates

Table 14-1 presents a summary of emission rates from the manufacture of clay products. Current emissions are estimated at 467,000 tons. Data available on emission rates, processing variations, and control equipment practices and utilization are meager, and emission figures in Table 14-1 are considered to be engineering estimates.

TABLE 14-1

PARTICULATE FMISSIONS CLAY FRODUCTS

| | | | | Efficiency | Application | Net | Defectors | |
|-----|--------------------------|------------------------|------------------|------------|-----------------|---|-----------|--|
| | Source | Quantity | Emission Factor | | $\frac{Ct}{Ct}$ | $\frac{C_{c} \cdot C_{t}}{C_{c} \cdot C_{t}}$ | tons/yr | |
| I. | Ceramic Clay | 7,870,000 tons | | | | | | |
| | A. Grinding | 60% of ceramics | 76 lb/ton prod. | | | 0.60 | 72,000 | |
| | B. Drying | 100% of ceramics | 70 lb/ton prod. | | | 0.60 | 110,000 | |
| 11. | Refractories | 3,440,000 tons | | | | | | |
| | A. Kiln-Fired | | | | | | | |
| | 1. Calcining | 20% of kiln-fired | 200 lb/ton prod. | | | 0.64 | 25,000 | |
| | 2. Drying | 30% of kiln-fired | 70 lb/ton prod. | | | 0.64 | 13,000 | |
| | 3. Grinding | 100% of kiln-fired | 76 lb/ton prod. | | | 0.64 | 47,000 | |
| | B. Castable Refracts. | 550,000 tons | 225 1b/ton prod. | | | 0.77 | 14,000 | |
| | C. Dead-Burned Magnesite | 125,000 tons | 250 lb/ton prod. | | | 0.56 | 7,000 | |
| | D. Mortars | 120,000 tons | | | | | | |
| | 1. Grinding | • | 76 lb/ton prod. | | | 0.60 | 2,000 | |
| | 2. Drying | | 70 lb/ton prod. | | | 0.60 | 2,000 | |
| | E. Gunning Mixes | 250,000 tons | 76 lb/ton prod. | | | 0.60 | 4,000 | |
| III | · Heavy Clay Products | 23,700,000 tons | | | | | | |
| | A. Grinding | 20% of heavy clay | 76 lb/ton prod. | | | 0.60 | 72,000 | |
| | B. Drying | 30% of heavy clay | 70 lb/ton prod. | | | 0.60 | 99,000 | |
| | | Total for Clay Product | s | | | | 467,000 | |

Note: Values reported for net control are assumed numbers.

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14.4 EFFLUENT CHARACTERISTICS

Limited data were found on the chemical and physical properties of effluents from clay products manufacture. Available data are presented in Table 14-2.

Emissions from the electric-arc furnace are condensed fume and consist of very fine particles, largely 2 μ or smaller.²/ Kaolin and bauxite particulates emitted from rotary calcining kilns range from 25-40 wt. % less than 10 μ , while particulates from a magnesite kiln may be 50 wt. % < 10 μ .

14.5 CONTROL PRACTICES AND EQUIPMENT

Common control techniques for the ceramic clay manufacturing processes include settling chambers, cyclones, wet scrubbers, electrostatic precipitators and bag filters. Cyclones for the coarser material followed by wet scrubbers, bag filters or electrostatic precipitators for dry dust are the most effective control techniques.

A variety of control systems may be used to reduce both particulate and gaseous emissions from heavy clay products manufacturing. Almost any type of particulate control system will reduce emissions from the materials handling process. However, good design and hooding are required to capture the emissions. Fluoride emission can be reduced to very low levels by using a water scrubber. $\underline{2}/$

The general types of particulate controls may be used on the materials handling aspect of refractory manufacturing. However, emissions from the electric-arc furnace are largely condensed fume and consist of very fine particles, largely 2 μ or smaller. Baghouses may be used to control particulate emissions from the furnace.1/

Multicyclones, baghouses, and electrostatic precipitators have been used on rotary and vertical kilns in kiln-fired refractory plants. $\frac{3}{2}$

TABLE 14-2

EFFLUENT CHARACTERISTICS - MANUFACTURE OF CLAY PRODUCTS*

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A. Particulate

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| | Source | Particle Size | Solids Loading | Chemical Composition | Particle Density | Electrical Resistivity | Moisture Content | Toxicity |
|-------|-----------------|-----------------|----------------|----------------------|---------------------|---------------------------|---------------------|-----------------|
| Refra | <u>ictories</u> | | | | | | | |
| a. | Bauxite calcine | 25-40 < 10 | | | | | | |
| | kiln | | | | | | | |
| Ъ. | Magnesite cal- | | | | | | | |
| | cine kiln | 5 0 < 10 | | | | | | |
| c. | Electric arc | | | | | | | |
| | furnace | 100 < 2 | | | | | | |

B. <u>Carrier Gas</u>

| | Source | | Flowrate | Tempera- ture | Moisture Content | Chemical Composition | Toxicity | Corro- sivity | <u>Odor</u> | Flammability or Explosive Limits | Optical Properties |
|-------|--------------|----|--------------------------|------------------|---------------------|-------------------------|----------|------------------|-------------|--|-----------------------|
| Ceram | ic Clay | | | | | | | | | | |
| a. | Rotary dryer | a) | 23.8 (one dryer) | 66 | | | | | | | |
| Ъ. | Kiln and | | | | | | | | | | |
| | cooler | a) | 23.9-27.3 (two units) | 159-160) | | | | | | | |
| c. | Spray dryer |) | 10.5 (one unit) | 244 | | | | | | | |

* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

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CHAPTER 15

FERTILIZER MANUFACTURE

15.1 INTRODUCTION

Fertilizer consumption has increased so rapidly in the past quarter century that manufactured fertilizer has become the major product of the chemical industry throughout the world. The primary manufactured fertilizers are phosphates, nitrates, ureas, and sulfates.

The pollution potential of a fertilizer plant can be divided into separate types: coarse dust, wet solids, odorous or corrosive gases, and vapors. Emissions result from roasting, acidulation processes, drying, granulation, and blending operations.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for each major fertilizer category are discussed in the following sections.

15.2 PHOSPHATE FERTILIZERS

15.2.1 Phosphate Rock Preparation

Phosphate rock preparation involves beneficiation to remove impurities, drying to remove moisture, and grinding to improve reactivity. Phosphate rock deposits have widely varying compositions and properties. The presence of a high content of organic matter is undesirable. Organic matter tends to stabilize a foam blanket on the surface of the acid reactors, and it produces a slimy gypsum filter cake which is slow filtering and difficult to wash. Organics are removed by roasting the rock between 1200 and 1600°F. The roasting is done in a variety of furnaces.

Usually, direct-fired rotary kilns, 25-100 ft. long, 8-10 ft. in diameter, are used to dry phosphate rock (Figure 15-1). These dryers use natural gas or fuel oil as fuel and are fired countercurrently. From the dryers, the material may be ground before storage and is finally conveyed to large storage silos. Emissions from these processes consist primarily of fine rock dust, but some sulfur dioxide may be present in the dryer exhaust from the combustion of sulfur in the fuel.



Figure 15-1 - Flow Diagram of Phosphate Rock Storage and Grinding Facilities, Noting Potential Air Pollution Sources

Other points of emission in a phosphate rock grinding and preparation plant are transfer points on conveying systems and discharge points at storage hoppers and silos.

15.2.2 Wet Process Phosphoric Acid

Wet-process acid is produced by treating fluorapatite $[Ca_{10}(PO_4)_6F_2]$ or phosphate rock, with sulfuric acid. Phosphoric acid is formed, calcium sulfate is precipitated and filtered off, and the acid is concentrated from about 32% P_2O_5 to about 54% P_2O_5 . Virtually all the wet-process acid produced in this country is used in the manufacture of various phosphate fertilizers.⁶/

Most current process variations for producing wet-process phosphoric acid depend on decomposition of phosphate rock by sulfuric acid under conditions where gypsum $(CaSO_4 \cdot 2H_2O)$ is precipitated. Several variants of this process are offered by various contractors. The Dorr-Oliver, St. Gobain, Prayon, and Chemico processes are among the better known.⁶/ In spite of the number of contractors in the field, new plants do not seem to differ fundamentally among themselves. In addition, several general trends are evident, such as the use of single-tank instead of multiple-tank reactors, one or two large horizontal tilting-pan filters, large plants of 1,000 ton/day capacity and more, and closed systems where atmospheric emissions are minimized. Figure 15-2 is a flow diagram of a modern, wet-process phosphoric acid plant.⁶/

Finely ground phosphate rock is metered accurately and continuously into the reactor, and sulfuric acid is added. The single-tank reactor illustrated in Figure 15-2 is a circular, two-compartment system wherein reactants are added to the annular volume and the central volume is used for growing gypsum crystals. Some years ago, plants were built with several separate reaction tanks connected by launders, which are channels for slurry flow. The tendency now is to use a single tank with several compartments. In some of these designs, the slurry flows over and under a series of baffles.

Proper crystal growth depends on maintaining sulfate ion concentration within narrow limits at all points in the reaction slurry. The proper sulfate ion concentration appears to be slightly more than 1.5%. Lower levels give poor crystals that are difficult to filter; higher concentrations interfere with the reaction by causing deposition of calcium sulfate on unreacted rock. Good reactor design will prevent sudden changes of sulfate ion concentration, will maintain this concentration and temperature near optimum, and will provide sufficiently long holdup time to allow growth of large, easily filterable crystals without the formation of excessive crystal nuclei.



Figure 15-2 - Flow Diagram Illustrating Wet-Process Phosphoric Acid $Plant^{6/2}$

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Concentrated sulfuric acid is usually fed to the reactor. If dilute acid is used, its water content must be evaporated later. The only other water entering the reactor comes from the filter-wash water. To minimize evaporation costs, it is important to use as little wash water as is consistent with practical H_3PO_4 recoveries.

Considerable heat of reaction is generated in the reactor and must be removed. This is done by blowing air over the hot slurry surface or by vacuum flash cooling part of the slurry and sending it back into the reactor. Modern plants use vacuum flash cooling. Figure 15-2 illustrates this method of cooling.

The reaction slurry is held in the reactor for periods up to 8 hours, depending on the rock and on reactor design, and is then sent to be filtered. The circular, horizontal, tilting-pan vacuum filter is illustrated in Figure 15-2. Older and smaller plants may use other types of filters.

In washing the resultant gypsum cake on the tilting-par filter, wash water flow is countercurrent to the rotation of the cake, and heated fresh water is used to wash the "cleanest" cake. These filters can be built in very large sizes, and designs are now approaching 1,000 ton/ day P_2O_5 capacity.

The 32% acid from the filter generally needs concentrating for further use. Current practice is to concentrate it to 54% by evaporation in two or three vacuum evaporators.

15.2.2.1 Emissions from Wet-Process Phosphoric Acid Manufacture: Emissions from wet-process phosphoric acid manufacture consist of rock dust, fluoride gases, particulate fluoride, and phosphoric acid mist, depending on the design and condition of the plant. Fluorine exists as various compounds in the collection equipment; as fluorides, silico-fluorides, silicon tetrafluoride, and mixtures of the latter and hydrogen fluoride, the mole ratio of which changes in the vapor with the concentration of fluorosilicate in the liquid and with temperature. Because of the complex chemistry, the composition of emissions is variable.

The reactor, where phosphate rock is decomposed by sulfuric acid, is the main source of atmospheric contaminants. Acid concentration by evaporation provides another source of fluoride emissions. The filter is a third source of fluoride emissions. For circular filters, and for filters of the Georgini pan-filter type, most of the emissions are at feed and wash points. Emissions from filters are not large and can be controlled by the use of hoods, vents, and scrubbers. In addition to these three main sources of emissions, there are many miscellaneous minor sources. These include vents from such sources as acid splitter boxes, sumps, and phosphoric acid tanks. Collectively, these sources of fluoride emissions are significant, and they are often enclosed and vented to a suitable scrubber.

15.2.3 Normal Superphosphate Production

"Normal superphosphate" is the term applied to the fertilizer produced by reacting sulfuric acid with phosphate rock. Normal superphosphate contains from 16 to 21% phosphoric anhydride ($P_{2}O_{5}$).

While there have been developments and refinements, the three basic steps in the production of normal superphosphate have remained the same over the years (Figure 15-3). Sulfuric acid and rock are intimately mixed, dropped into a den, held for sufficient time to allow the slurry mixture to set into a solid porous form, and stored to permit the acidulation to go to completion. Plants are described as batch or continuous, depending upon the type of den used. Over 75% of U.S. plants use the batch process.

Following the curing period, three alternates are available: (1) the product can be ground and bagged for sale; (2) the cured superphosphate can be sold directly as run-of-pile product; or (3) the material can be granulated for sale as granulated superphosphate or used as a component of granular mixed fertilizer.

For the latter alternative, normal superphosphate is blended with some or all of the following ingredients--ammonia, sulfuric acid, phosphoric acid, triple superphosphate, potash. Steam or water is added, if needed, to aid in granulation. The mixture is then passed through a rotary dryer, which removes sufficient moisture to eliminate the chance of the pellets binding together. From the dryer the material passes through a rotary cooler and is conveyed to storage bins for sale as a bagged or bulk product.

The gases released from the acidulation of phosphate rock contain silicon tetrafluoride, carbon dioxide, steam, and sulfur oxides. From 20 to 28% of the total fluoride in the phosphate rock is evolved in the acidulation and curing operation. Curing building emissions are not usually controlled in normal superphosphate plants.

Vent gases from a granulator-ammoniator may contain ammonia, silicon tetrafluoride, hydrofluoric acid, ammonium chloride, and fertilizer dust. Emissions from the dryer will include gaseous and particulate fluorides, ammonia, and fertilizer dust. Some emissions will also contain sulfur oxide, especially if high-sulfur oil is used as fuel to the dryer. Emissions from the cooler will contain primarily fertilizer dust, and may also include traces of the aforementioned pollutants.



Figure 15-3 - Flow Diagram of Normal Superphosphate Plant, Noting Potential Air Pollution and Sources. Control devices are not shown.

15.2.4 Triple Superphosphate Production

"Triple superphosphate" is the popular name for the product resulting from the reaction between phosphate rock and phosphoric acid. Unlike normal superphosphate, the production of triple superphosphate is usually a continuous operation in large plants located near phosphate rock deposits. The phosphate rock is ground to a fineness ranging from 80% through a 100-mesh screen to 95% through a 200-mesh Tyler screen. Although either furnace or wet process phosphoric acid may be used as the acidulant, at the present time wet-process acid is used almost exclusively. Concentrated acid with a P₂O₅ content of 50-55% is used. Fluoride content of wet-process acid may be as high as 1-2%.

Two major processes are used in the production of triple superphosphate (Figure 15-4). The first uses a mixing cone to achieve intimate contact between the acid and rock. The resulting mix falls to a conveyor belt which moves the material to the curing building. On its way to the curing building the mix is passed through several mixers or blungers (pug mills) to aid in the contact of the rock and acid as well as to release fluorine vapors. Fluoride-containing fume is collected along the entire length of the belt by a tight hocd over the belt, the blungers, and the mixer. After curing for 30-60 days, the product can be sold as run-ofpile (ROP), or it can be granulated in separate equipment.

With the increased demand for granulated products, a second process has been introduced to produce granulated fertilizer directly. In one commercial process, the acid and phosphate rock are placed in mixing tanks, fed through a blunger for intimate mixing and release of some of the effluent gases, and then dried in a rotary dryer using oil or gas as fuel. The product is a directly granulated material which is rather hard and dense and normally not amenable to ammoniating.

Most triple superphosphate is of the nongranular type. The exit gases from a plant producing the nongranular product will contain considerable quantities of silicon tetrafluoride, some hydrogen fluoride, and a small amount of particulates. In cases where ROP triple superphosphate is granulated or mixed as a granulated-mixed fertilizer, one of the greatest problems is the emission of dust and fumes from the dryer and cooler. Screening stations and bagging stations are a source of fertilizer dust emissions in this type of process.



PHOSPHATE ROCK

Figure 15-4 - Flow Diagram for Production of Run-of-Pile and Granular Triple Superphosphate, Noting Potential Air Pollution Sources

15.2.5 Diammonium Phosphate Production

In the manufacture of diammonium phosphate the initial reaction between ammonia and phosphoric acid takes place in a reactor tank lined with acid brick (Figure 15-5). Both acid from the gas scrubbers and fresh acid are used as feedstock. In many plants some 93% sulfuric acid is used to control the composition of the final product. The relative amounts of phosphoric and sulfuric acid usually depend on the purity of the incoming phosphoric acid. The product of the reactor is pumped as a slurry to a rotary ammoniator. In the ammoniator additional ammonia is sparged underneath the mixing bed to achieve a final mole ratio of 1.8 to 2.0. While the equipment is rotating, agglomeration takes place and the ammoniation is completed. Diammonium phosphate granules are discharged from the ammoniator to a rotary dryer, thence through a screening station and a rotary cooler to storage. Fines and oversize particles from the screening station are recycled back to the ammoniator for product control.

The major pollutants from diammonium phosphate production are fluoride, particulates, and ammonia. Dust-producing areas are the cage mills, where oversized product from the screens is ground before being recycled to the ammoniator. Dust from these points is usually vented through cyclone collectors, and then to either an impingement or a venturi scrubber. Vent gases from the reactor and ammoniator tanks, which contain high quantities of ammonia, are usually scrubbed with acid to recover the residual ammonia.

15.2.6 Granulation

Granulation is a method of processing that has been widely adopted as a means of improving the storage and handling properties of fertilizer materials and mixtures by increasing their normal particle size to material that will largely be retained on a 16-mesh sieve, and which includes particles in the range of 1 to 4 mm in diameter.

In the granulation of ammonium phosphate fertilizer, a gypsumacid slurry is obtained by by-passing the filter in a phosphoric acid plant (Figure 15-6). Ammonia is introduced into this slurry and into acidulated phosphate from the acidulation tank. The mixture then flows to the dryer.

After the dryer, the product is screened. Large lumps are crushed and recycled to the granulator along with the fines passing the screens.



Figure 15-5 - Flow Diagram of Diammonium Phosphate Plant, Noting Potential Air Pollution Sources



Figure 15-6 - Flow Diagram of the Slurry Granulation Process in the Manufacture of Fertilizer, Noting Potential Air Pollution Sources

Water scrubbers of various types are used for recovery of ammonia and ammonium salts, which are then recycled to the process. The greater portion of the ammonia is recovered. However, ammonium salts are not easily recovered because of their very fine size.

In nonslurry granulation, part or all of the neutralization reaction is carried out in the granulation vessel. The number of sources of air pollution is reduced by elimination of the reaction tanks. This method of granulation is widely used for mixed fertilizers based on superphosphates.

Dust from granulation is mainly from dryers and coolers. Dust from screens, hammermills, and materials handling also is important since the granulation process involves recirculation of material to build up the size of granules. The manufacture of salt grades (fertilizers containing potash) produces a fume of NH_4Cl which is composed of particles < 5 μ and is difficult to collect. The amount of chloride fume produced depends on the raw materials used; ammoniating solutions and sulfuric acid tend to increase the amount of fume.

15.2.7 Emission Rates from Phosphate Fertilizer Manufacture

Particulate emission rates from the various processes comprising phosphate fertilizer manufacture are summarized in Table 15-1. Both fluoride particulate and fertilizer dust are included in the emissions. Dust losses from materials handling operations are estimated at 2 lb/ton of granulated material.

15.3 AMMONIUM NITRATE FERTILIZER

Commercial processes for the manufacture of ammonium nitrate depend almost entirely on the neutralization of nitric acid with ammonia in liquid or gaseous form (Figure 15-7). Synthetic ammonia, as the anhydrous liquid, and nitric acid produced from the oxidation of ammonia are used.

Essentially three steps are involved in producing ammonium nitrate: neutralization, evaporation of the neutralized solution, and control of the particle size and characteristics of the dry product.

TABLE 15-1

PARTICULATE ENERSICHS PHOSPHATE ROCK AND MARUFACTURE OF FERTILIZER

| | | | | Rfficiency | Applica- tion of | Net | |
|------|---|--|---|--------------|---------------------|--------------------|------------|
| | Summan | | | of Control | Control | Control | Emissions |
| | Source | Quantity of Material | EBIOSION PACTOR | | <u>t</u> | L _c .ct | C SCR5/VP; |
| I. | Phosphate Rock | 61,300,000 tons per year | | | | | |
| | A. Dryer | | 12 1b/ton of end product | 0.94 | 1.0 | 0.94 | 14,000 |
| | C. Materials handling | | 2 16/ton of end product | 0.90* | 0.25* | C.22 | 30,000 |
| | D. Calcining | | 60 1b/ton of and product | 0.95 | 1.0 | C.95 | 8,000 |
| 11. | Ammonium Nitrate | 2,800,000 tons of NH4303 gramules | | | | | |
| | A. Evaporator B. Brilling Scher | | 1 1b/ton of end product | | | | |
| | C. Dryer and cooler | | M IN THE OF ENA PICASE | | | | |
| | D. Materials handling | | | | | | |
| | 1. Elevators a borts | | | | | | |
| | b. heads | | | | | | |
| | 2. Conveyors | | | | | | |
| | transfer points discharge to bins, silos | | | | | | |
| | 3. Shipment of product | | | | | | |
| | a. bagging b, bulk loading | | 1 1b/ton (controlled) | | | | |
| | - | Total for Ammonium Nitrate | Assume 1% of and product | | | | 28,000 |
| 111. | Ursasame as Ammonium Nitrate | 1,000,000 tons of (NH4)2CO granules | Assume 1% of product | | | | 10,000 |
| IV. | Phosphate Fertilizers | | | | | | |
| | A. Rock pulverizing B. Fluoride marticulate from | 17,000,000 tons of phosphate rock 4 370,000 tons of P.G. from phosphate | 6 lb/ton of rock | 0. 90 | 1.0 | 0.80 | 13,000 |
| | acid-rock reaction | ruck | 48 lb. partic./ton of PaC. | 0.95 | C.95 | 0.90 | 9,000 |
| | 1. Wet-process reactor | | - · · · · · · · · · · · · · · · · · · · | | | | |
| | 2. Filter 3. Wixers supernhominate macufacture | | | | | | |
| | C. Fre-neutralizer | | | | | | |
| | D. Granulating equipment | 18,000,000 tons of granular material | | | | | |
| | 2. Gradulator | - | 0.5 1b/tun | | | | |
| | E. Dryer | | 105 | | | | |
| | F. Cooler | | 90 15/1on | 0.05 | 0.05 | 0.90 | 169,000 |
| | 3. Screens | | 133 | 0.55 | 0.35 | 0.50 | 155,505 |
| | H. Mills | | | | | | |
| | I. Materials Handling | | | | | | |
| | 1. Unicading of rav-materia: shimments | | | | | | |
| | a. phosphate rock | | | | | | |
| | b. potash | | | | | | |
| | conveyors transfer points | | | | | | |
| • | b. discharge to bins, silos | | | | | | |
| | 3. Elevators | | | | | | |
| | b. heada | | | | | | |
| | | | 2 1b/ton of granular mat | erial | | | 18,000 |
| | 4. Shipment of product | | | | | | |
| | a. bagging machines | 50% of 18,000,000 tans | 1 lb/ton (controlled) | | | | 4,000 |
| | b. bulk loading | | | | | | |
| ٧. | Ammonium Sulfate | 2,700,000 tons | 15 of product* | | | | 27,000 |
| | B. Drying | | | | | | |
| | C. Shipping | | | | | | |
| | 1. Bagging machines 2. Bulk losding | | | | | | |
| | and a second producting | Total for Phosphate Rock and | Fertilizer | | | | 528,000 |
| | | - | | | | | , |

· Assumed.

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Figure 15-7 - Flow Diagram of the Process for Manufacture of Ammonium Nitrate, Noting Potential Air Pollution Sources

15.3.1 Neutralization

Direct neutralization is practiced when pure reactants are used in an aqueous medium. The reaction of ammonia with nitric acid is strongly exothermic; both reactants are volatile at the resulting elevated temperatures. This condition must be controlled to prevent loss of materials. Usually a slight excess of nitric acid, the less volatile of the two reactants, is maintained during neutralization.

15.3.2 Evaporation

Procedures vary depending on the water content of the reactants and the control of temperatures. In methods formerly in wide use, the neutral ammonium nitrate solution was evaporated to a high degree of concentration, with subsequent cooling and granulation of the product. Other processes carry the evaporation to a lesser degree of concentration and complete the separation of the solid ammonium nitrate by crystallization or, more frequently, by continuous evaporation in specially designed apparatus.

15.3.3 Control of Particle Size and Properties

Various procedures, such as graining, flaking, and spraying, have been practiced over the years to obtain nitrate particles or grains for the final product. The method that has been adopted by the great majority of plants is prilling. Prilling is spray drying of a concentrated solution.

The prilling step is followed by rotary or fluidized-bed drying and cooling. The product prills may then be coated with a clay material, to prevent caking, in a rotary coating drum. These drying and cooling operations use large quantities of heated air which entrains the dust and fines. However, the emissions from these operations are usually controlled with low pressure drop wet scrubbers using dilute salt solutions to collect the material and recycle it back to the process.

The prilling operation may be as large an emission source as the drying and cooling operations. In the prilling process losses are dependent upon the velocity of the air in the prilling tower. Total fines lost from the process can be kept to < 1% of the product.

15.3.4 <u>Emission Rates from Ammonium Nitrate Fertilizer Manufacture</u>

Particulate emission rates from the manufacture of ammonium nitrate fertilizer are summarized in Table 15-1. Limited data were found for particulate emissions from nitrate fertilizer manufacture, and the emission totals in Table 15-1 are considered as conservative estimates.

15.4 UREA FERTILIZER

The commercial production of urea is based on the exothermic synthesis of ammonium carbamate with its subsequent dehydration to urea. Ammonia and carbon dioxide are reacted together in a high-pressure reactor to form a melt containing urea, ammonium carbamate, and water, along with some unreacted ammonia. Depending upon the particulate process used, the temperature of the melt in the reactor is maintained between 175°C and 210°C and the pressure between 170 atm. and 400 atm.

Eight processes are currently used in the manufacture of urea. The method of treating the off gas (ammonia and carbon dioxide) from the carbamate-urea reactor represents the major differences among the variety of competing processes for the manufacture of urea. Figures 15-8 and 15-9 illustrate two methods of final preparation.

The aqueous solution of urea from any of the processes must be concentrated to remove the excess synthesis water as well as traces of dissolved synthesis gases and then filtered to remove any solid impurities.

15.4.1 Emission Rates from Urea Fertilizer Manufacture

Emission rates for urea fertilizer manufacture are summarized in Table 15-1. No detailed data were found on emission rates, and an emission factor of 1% of the end product was used to estimate the particulate emissions.

15.5 AMMONIUM SULFATE

Most ammonium sulfate produced is a by-product of coke-oven operations. Sulfuric acid is used to scrub the ammonia out of the cokeoven gas and the scrubbing produces an ammonium sulfate solution. The solution is further concentrated, and crystals of ammonium sulfate are extracted in a centrifuge. The crystals are then dried. Since all other operations are carried out in the wet state the only potential source of particulate emission is the dryer. The dryer is usually controlled by cyclones or wet scrubbers.



Figure 15-8 - Sketch of Manufacturing Process for Crystalline Urea Product





15.6 CHARACTERISTICS OF EFFLUENTS FROM FERTILIZER MANUFACTURE

The chemical and physical characteristics of effluents from fertilizer manufacture are summarized in Table 15-2. Particulates emitted from phosphate fertilizer production equipment are hot, moist, partially water-soluble, corresive, hydroscopic, disagreeable to the sense of smell, and have a tendency to stick to and build up on almost any surface. Dusts emitted from superphosphate dryers are about 12 wt. $4 < 10 \mu$.

15.7 CONTROL PRACTICES AND EQUIPMENT IN FERTILIZER MANUFACTURE

Control equipment which has been used in various phases of fertilizer manufacture include cloth filters, electrostatic precipitators, and mechanical systems for dust; wet collectors for dust, gases, and flucride mists. $\frac{1}{}$ Wet scrubbers are probably the most common piece of dust and fume collection equipment being utilized in fertilizer plants. $\frac{2}{}$

15.7.1 Control Equipment

15.7.1.1 <u>Wet-Process Phosphoric Acid</u>: Because the principal atmospheric contaminants generated in the process are gaseous fluorides, vapor scrubbing is universally employed to control emissions. Specific devices used for control include Venturi scrubbers, impingement scrubbers, and various kinds of spray towers. Fluoride removal efficiency of these devices varies widely, and staging may be required for satisfactory control. Plugging, or difficulty in removing precipitates and dust, may also be experienced.<u>6</u>/

Table 15-3 summarizes the results of Public Health Service tests conducted on 10 wet-process phosphoric acid plants in various parts of the country. $\frac{6}{2}$ For nine of these plants, the range of gaseous fluoride emissions from various types of collectors was 0.006 to 0.17 lb. of fluoride per ton of P₂O₅ produced. The concentration range of gaseous fluorides in the gases from collectors was 3 to 40 ppm, and 0.0011 to 0.0147 grain/scf for eight of the 10 plants. Public Health Service stack-test data agree reasonably well with results from plant questionnaires and information from miscellaneous sources, both of which are tabulated in Table 15-4. $\frac{6}{2}$

Scrubber efficiency is affected substantially by the loading of the gas stream. Heavy loading enhances scrubber efficiency, and light loading reduces scrubber efficiency. Therefore, scrubber-exit-gas concentration is a better indicator of overall plant emission control than is scrubber efficiency. The best criterion of plant performance is the weight of emission per ton of P_2O_5 produced. $\frac{6}{7}$

TABLE 15-2

EFFLUENT CHARACTERISTIC - FERTILIZER MANUFACTURE

| À. | Pa | <u>rticulate</u> (Fart I) | | | | | | | |
|-----------|------------------|--|--|----------------|--|----------------------------|--------------------------|---------------------|---|
| | <u>.</u> | | Particle Size | Solids Londing | Chemical Corposition | Particle <u>Density</u> | Electrical Properties | Moisture Content | Toxicity |
| Fe. 1: | 1111 .du51 | izen Try | | | | | | | |
| 1. | Р.,- Го 1, | kophate estilizer Philppate | | | | | | | |
| | | rock (1) Rrok dryer | | | Rock dust, typical com- position: P205, 32.5; SiO2, 11.0; A1203, 2.C; MgC, 0.7; CaO, 45.5; Fe203, 0.6. | | | | |
| | | (2) Brik grinder (3) Rouster or | | | Rock dust, see rock dryer | | | | |
| | | calciner (a) Fluid bed roaster | (Dust from cyclone collector) 26 < 1, 81 < 5, 36 < 10, 100 < 25 | э . В | | | | | |
| | ۰. | Wet-piccess acid (1) Peactor or | | 0.47-3.7 | Fluoride, sold mist | | | | Fluorides are toxic |
| | ۲. | digestor (2) Filter Superphosposte | | 0.017 | Fluoride, acid mist | | | | Fluorides are toxic |
| | | production (1) acid reactor (den) | | 0.09-0.15 | ೫2 ⁵ 17 ₆ , 510 ₂ | | | | Irritating to eyes, nose, and throat |
| | | (2) Granulator- acconistor | | | NHgCl, fertilizer dust | | | | |
| | | .3) Dryer | EAHCC m.malysis: 1-12.2 < 5, wyg. 6.3 < 5; 2-26 < 10, wyg. 12 < 10; 3-46 < 20 myg. 22 < 20; 5-55 < 30, avg. 29 < 30; 6-61 < 40, wyg 34 < 40 | 0.7-4.0 | Fliorides, fertilizer, Ca, MG, P, Fe, and Al compounds | 1.6-2.5 | | | Fluoride - toxic |
| | | 40 Onelen | EAHCO analysis (1 test): 6.2 < 5, 11. < 10, 20 < 20, 24.1 < 50, 32 < 40 | 1 | Fertilizer dust | 2.2 | | | |
| | | (5) ła _{ce} nie | LAHCG analysis (1 test): 2 < 5, 3 < 1 5.8 < 20, 14 < 30 31 < 40 | 0. | | | | | |
| | ٦. | Triple super- pousphats pro- duction | | | | | | | |
| | | Acid reactor Granulator Dryon Dryon | | | Flueride Pluoride, fertilizer dust Flueride, fertilizer dust | | | | |
| | е. | 4) Cooler Diammonium production (1) Dryet (2) Cooler | | | fluoride, Tertlilzər dusl | | | | |
| 2. | Arran fe | wrium nitrate riilizer | | | | | | | |

* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

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TABLE 15-2 (Concluded)

A. Particulat+ (Part 11)

| 110 | cira | <u>.</u> | <u>Solubility</u> | <u>Wettebility</u> | Hy <u>Char</u> | proscopić Acteriatica | Flammability or <u>Explosive limits</u> | Handling Cha | racteristics | <u>P</u> | Optical roperties (| Mer |
|-----------|-----------------------------|---|--|--------------------|-------------------|--------------------------|---|---|---|----------|-------------------------------------|-----------------------|
| Te- Ir | t 11 i dust | zer ry | | , | | | | | | | | |
| 1. | Pho co r, c. 1. | <pre>sphate sphate sphate reck veck veck superploas production (1) Acid reac- tor (den) (2) Pryer Triple super- phosphate production Diamponium procychate production</pre> | Contains H2O soluble com- ponents Contains H2O sol uble components | | Hyg | rescopic | | Wet silica f are corrosi Corrosive, m erates | Huoriće flakes ve to materials ticky, agglom- | Ta | t5-colored tust | |
| Б. | <u>Ca</u> | rrier Gas | | | | Ma 4 | | | | | T1 | 6 -44-23 |
| | <u>5eu:</u> | rce | Flow Bate | Temperature | Pressure | <u>Content</u> | Chemical Composition | Texicity | Corresivity | Oder | Flowmability or Explosive Limits | Optical Properties |
| Fe: Ti | rtili idust | izer try | | | | | | | | | | |
| 1. | Pho fe | esphate rtilizer Phoiphate rock (1) Rock dryer (2) Rock srind (N) Roaster or onleiner Pluid ted roaster Wei-proces | *: (a) 50 | 300 | | Wet bulb temp. 165 | 002, 02, X21 H20, S02 | | | | | |
| | | BCID (1) Reactor or | (a) 2-16 | 96-150 | | | Fluorides | Toxic | | | | |
| | | (2) Filter | (a) 3.4-19.6 | 90-95 | | | Fluorides | Texic | | | | |
| | с. | Superchosphate production (1) Acid re- actor (den) (2) Granulator | - | | | | ಕೆ1F ₄ , CO ₂ , ಸ್ವರಿ, SO _X ಗಳ್ಳ, S1F ₄ , :೮ | Texic | Corresive Corresive | | | |
| | đ. | (4) Cecler Triple super- phosphate | (a) 16.5 (1 unit) | 201 | | | Fluorides, NH3, 30 _x , CO ₂ , N ₂ , O ₂ | Toxic | | | | |
| | ۴, | production (1) Acid react (2) Granulator (3) Dryer (4) Cooler Diarmonium phosphate production | 9r | | | | Fluoride NH5, fluoride NH5, fluoride Fluoride | Texte Toxie Toxie Toxie | | | | |
| | | (1) Reactor (2) Asconiator (5) Dryer (4) Cooler | | | | | Eiz Nig, fluorides Nig, fluorides Nig, fluorides | Texic Texic Texic | | | | |

TAFLE 15-3

SUMMARY OF EMISSION DATA ON PERFORMANCE OF CONTROL6/ EQUIPMENT IN WET-PROCESS PROCEPHORIC ACID PLANTS2/

| Plant Number | 1 | 2 | 3 | <u>4</u> | <u>5</u> | <u>6</u> | <u>7</u> | <u>8</u> | 9 | <u>10</u> |
|--|---------------------------------|--------------------------------------|---|---|---|--|---|---|------------------------|---|
| Collector type | Rectangular spray chamber | Square hori- zontal spray duct | Venturi scrub- ber, water- actuated | Venturi scrub- ber, water- actuated | Spray cross- flow packed scrubber | Two impinge- ment scrub- bers in series | Spray cross- flow packed scrubber | Spray cross- flow packed scrubber | Cyclone spray tower | Spray cross- flow packed scrubber |
| Gaseous fluo- ride entering collector per ton of P2O5 produced, pound | 1.265-2 .16 | Not deter- mined | 0.21-0.31 | 0 .49-0.6 7 | 0.078-0.087 | 0.013-0.016 | 1.20-1.48 | 0.05-0.06 | 0.85-1.00 | Not deter- mined |
| Gaseous fluo- ride emitted from collec- tor per ton P ₂ O ₅ produced, pound | 0.52-0.63 | 0,072-0,101 | 0.027-0.047 | 0.028-0.038 | 0.006-0.018 | 0.006-0.011 | 0.10-0.17 | 0.0170-0.022 | 0.047-0.082 | 0.135-0.157 |
| Collection ef- ficiency, \$ | 57-72 | | 64.2-87.0 | 92-96 | 80-92.4 | 15-62 | 86-93 | 56.7-68.4 | 90.4-95.3 | |
| Concentration of gaseous fluoride emitted from collector, grain/scf | 0.075-0.090 | 0.0026-0.0035 | 0.0104-0.0147 | 0.018-0.023 | 0.0011-0.0032 | 0.0020-0.0037 | 0.0054-0.0088 | 0.0022-0.0029 | 0.0016-0.0029 | 0.0120-0.014 |
| Parts per million | 202-243 | 7.0-9.4 | 28-40 | 49-62 | 3.0-8.6 | 5.4-10.0 | 15-24 | 5.9-7.8 | 4.3-7.8 | 32-38 |
| Particulate emitted from col- lector per ton P ₂ O ₅ produced, pound | | | | | | | | | | |
| Total par- ticulates | 0.28-0.50 | 0.36-0.47 | 0-0,029 | | | | | | | 0.29-0.36 |
| Efficiency, 🖇 | | | 98.5-100 | | | | | | | |
| Insolube par- ticulate fluorides | 0,0006-0,008 | 0-0.0013 | None found | | | | | | | 0.006-0.09 |
| Efficiency, 🖇 | | | 100 | | | | | | | |
| Soluble par- ticulate fluorides | 0,050-0.094 | 0 .00 75-0.0 3 6 | 0.0023-0.0029 | | | | | | | 0.070-0.14 |
| Efficiency, 🖇 | | | 94.0-97.0 | | | | | | | |

a/ Plants 1-10 were tested by National Air Pollution Control Administration.

TABLE 15-4

SUMMARY OF EMISSION DATA ON PERFORMANCE OF CONTROL EQUIPMENT⁶/ IN WET-PROCESS PHOSPHORIC ACID PLANTS^a/

| Plant Number | <u>11</u> | <u>12</u> | <u>13</u> | <u>14</u> | <u>15</u> | <u>16</u> |
|---|-------------------------------------|-------------------|-------------------------------------|-------------------------------------|-------------|--|
| Collector type | Venturi scrubber, water-actuated | Cyclonic spray | Spray cross-flow packed scrubber | Spray cross-flow packed scrubber | Impingement | Packed tower, two- stage cyclonic scrubber, in paral- lel |
| Gaseous and water-soluble particulate fluoride entering collector per ton of P ₂ 0 ₅ produced, po | 2.0 und | 7.6 | 0.53 | 77 | 0.037 | 0.0073 |
| Gaseous and water-soluble particulate fluoride emitted from collector g per ton of P ₂ 0 ₅ produced o pound | 0.26 | 1.23 | 0.044 | 0.038 | 0.0087 | 0.00035 |
| Efficiency, % Concentration of gaseous | 87 | 84 | 92 | 99.9 | 24 | 1 |
| and water-soluble par- ticulate fluoride emitted from collector | | | | | | |
| Grain/scf | 0.058 | 0.031 | 0.0032 | 0.0019 | | |
| Parts per million | 167 | 87 | 9 | 5 | | |

a/ Information on plants 11 through 13 acquired through private communication; information on plants 15 and 16 acquired through questionnaire.

15.7.1.2 Acidulation Precess - Superphosphate: Acidulation of ground phosphate rock with H_2SO_4 to produce superphosphate results in emissions consisting of silicon tetrafluoride, dilute fluosilicic acid, CO_2 , steam, and $SO_2.3^{-/}$ An injector-type gas scrubber was reported to be only 80% efficient for controlling these emissions, allowing H_2SiF_6 and traces of SO_2 and SO_3 as a mist to be discharged into the air. $4^{-/}$ This unit subsequently was replaced by a low-velocity cell type, wet scrubber which was reported to achieve 100% removal of silica fluoride. $4^{-/}$

Current practice is to scrub gases with either copious quantities of water or with dilute fluosilicic acid. Spray towers, grid-packed towers, and high-velocity jet scrubbers have been used. $\underline{3}/$

15.7.1.3 <u>Triple Superphosphate</u>: Water scrubbers are the primary method for controlling emissions of gaseous fluorides from triple superphosphate production. Packed towers, venturi scrubbers, wet-pad and impingement scrubbers and cyclonic scrubbers have been investigated.⁵/ A cyclonic scrubber system was reported to eliminate 97% of the total fluorides liberated by all sources in one plant producing triple superphosphate.⁵/

15.7.1.4 <u>Granulation</u>: Control of emissions from fertilizer granulation involves collection of dry dust from rotary dryers, rotary coolers, and gas and dust from liquid-solid reactor units. Various highduty cyclones have been used for removal of dust in exist gases. Efficiencies of 94-96% have been reported in British plants. $\underline{3}$ / It is also customary to supplement cyclones by a wet scrubber to further reduce dust content and to remove acid constituents. $\underline{5}$ / A multiple-tube collector, operating with 5 in. w.g. pressure drop, has been reported to remove 100% of all dust > 14 u. $\underline{4}$ /

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CHAPTER 16

ASPHALT

16.1 INTRODUCTION

Asphalt is a raw material for several industries. Two of the more important with regard to air pollution are hot-mix asphalt paving plants and asphalt-roofing manufacturing facilities.

The preparation of hot-mix asphalt paving involves proportional feeding of cold aggregates, heating and drying of aggregates to predetermined levels of moisture content and temperature, and uniform mixing and coating with hot asphalt to produce a specific paving mix. After mixing, the hot paving mixture is discharged into trucks which transport it to the paving site. Dust sources are the rotary dryer, hot-aggregate elevator, vibrating screens, hot-aggregate storage bins, weigh hopper, mixer, and transfer points. The major dust source is the rotary dryer. $\underline{l}/$

The manufacture of asphalt roofing felts and shingles involves saturating a fiber media with asphalt by means of dipping and/or spraying. While not always done at the same site, an integral part of the operation is the preparation of the asphalt saturant. This preparation consists of oxidizing the asphalt and is accomplished by bubbling air through liquid asphalt for 8-16 hr. This operation is known as "blowing." The principal particulate emission sources are the saturator and blowing operations.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for the hot-mix asphalt paving and the asphalt roofing industries are discussed in the following sections.

16.2 AIRBLOWN ASPHALT

Asphalt is a dark brown to black, solid or semi-solid material found in naturally occurring deposits or as a colloidal suspension in crude oil. Analytical methods have been used to separate asphalt into three component groups--asphaltenes, resins, and oils. A particular grade of asphalt may be characterized by the amounts of each group it contains. The asphaltene particle provides a nucleus about which the resin forms a protective coating. The particles are suspended in an oil that is usually paraffinic but can be nephthenic or naphtheno-aromatic. Over 90% of all asphalt used in the United States is recovered from crude oil (Kirk and Othmer). The method of recovery depends upon the type of crude oil being processed. Practically all types of crudes are first distilled at atmospheric pressure to remove the lower boiling materials such as gasoline, kerosene, diesel oil, and others. Recovery of nondistillable asphalt from selected topped crudes may then be accomplished by vacuum distillation, solvent extraction, or a combination of both. $\underline{1}$ / Economical removal of the gas-oil fraction from topped crude, leaving an asphaltic product, is occasionally feasible only by airblowing the crude residue at elevated temperatures. Excellent paving-grade asphalts are produced by this method. Another important application of airblowing is in the production of highquality specialty asphalts for roofing, pipe coating, and similar uses. These asphalts require certain plastic properties imparted by reacting with air. $\underline{1}/$

Airblowing is mainly a dehydrogenation process. Oxygen in the air combines with hydrogen in the oil molecules to form water vapor. The progressive loss of hydrogen results in polymerization or condensation of the asphalt to the desired consistency. Blowing is usually carried out batchwise in horizontal or vertical stills equipped to blanket the charge with steam, but it may also be done continuously. Vertical stills are more efficient because of longer air-asphalt contact time. The asphalt is heated by an internal fire-tube heater or by circulating the charge material through a separate tubestill. A temperature of 300° to 400°F is reached before the airblowing cycle begins. Air quantities used range from 5 to 20 cu ft/min/ton of charge. Little additional heat is then needed since the reaction becomes excthermic. Figure 499 in Reference 1 depicts the flow through a typical batch-type unit.

16.2.1 Effluents and Control Methods

Effluents from the asphalt airblowing stills include oxygen, nitrogen and its compounds, water vapor, sulfur compounds, and hydrocarbons as gases, odors, and aerosols. An estimate of particulate emissions for asphalt blowing associated with asphalt roofing manufacture is given in Table 16-1.

Control of effluent vapors from asphalt airblowing stills has been accomplished by scrubbing and incineration, singly or in combination. Most installations use the combination. Essential to effective incineration is direct-flame contact with the vapors, a minimum retention time of 0.3 sec. in the combustion zone, and maintenance of a minimum combustion-chamber temperature of 1200°F. Other desirable features include turbulent mixing of vapors in the combustion chamber, tangential flame entry, and adequate instrumentation. Primary condensation of any steam or water vapor allows use of snaller incinerators and results in fuel savings. Some of the heat released by incineration of the waste gases may be recovered and used for

TABLE 16-1

PARTICULATE EMISSIONS - ASPHALT

| Source | Quantity of <u>Material</u> | Emission Factor | Efficiency of Control (C _C) | Application of Control (Ct) | Net Control $(C_c \cdot C_t)$ | Emission (tons/yr) |
|--|--|----------------------------|---|-----------------------------------|-------------------------------------|--------------------------|
| I. Asphalt Roofing A.Blowing B.Saturator | 6,264,000 tons/year (asphalt used in roofing manufacturer) | 4 lb/ton 4 (controlled) | | | 0.50 | 3,000 1 4,00 0 |
| II. Hot-Mix Paving Plants | 251,000,000 tons/year (hot-mix asphalt) | | | | | |
| A. Dryer | | 32* | | | | |
| B. Bins, weigh | | 8 | | | | |
| hopper, etc. | | 40 | 0.97 | 0.99 | 0.96 | 201,000 |
| | | Total for | Primary User | s of Asphalt | | 218,000 |

* Prior to any control equipment.

341

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generation of steam. Catalytic fume burners are not recommended for the disposal of vapors from the airblowing of asphalt because the matter entrained in the vapors would quickly clog the catalyst bed. $\frac{1}{2}$

16.3 HOT-MIX ASPHALT PAVING PLANTS

Generally, a hot-mix asphalt plant consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins and conveying equipment. Hot-mix plants can be classified according to permanence of location or according to the method of measuring and mixing the hot aggregate and asphalt. Portable plants are designed to be readily dismantled and transported on trailers from one job site to another, whereas permanent (or stationary) plants are set up for efficient operation in a relatively permanent location, usually in a metropolitan area. $\frac{3}{2}$

With regard to the final mixing process, plants are either of the batch or continuous-mix type. Both types of plants have the same pattern of material flow up to the point of measuring the aggregate from the hot bins into the mixer. In the batch-type plant, the operator weighs out the correct quantity of aggregate from each hot bin in succession into the mixer. The total batch of aggregate is then dry mixed in the pugmill for a prescribed time, during which time the operator proceeds to accumulate another batch in the weigh hopper. When the dry-mix cycle is complete, hot asphalt is added to the mixer by either metering or weighing the correct amount. The hot asphalt may be sprayed or dumped into the pugnill, and upon completion of the proper mixing cycle, the hot-mix asphalt is delivered through a hopper into trucks hauling to the job site. Figure 16-1 shows a typical batch plant and identifies potential sources of air pollutants.3/

The continuous-mix plant transfers a preblended mixture of the dried and graded aggregate from the gradation unit by means of a bucket elevator to the mixer. Dry mixing in the mixer is not required, as it is in the batch plant. The hot asphalt is sprayed on the aggregate as it falls from the top of the elevator into the mixer. The length of the mixing cycle in a continuous-mix plant is governed by an adjustable dam at the discharge end of the pugmill; the hot-mix asphalt flows over the dam into the discharge hoppers. Mixing time can be varied without changing the hourly tonnage output by varying the height of the adjustable dam. In Figure 16-2 a typical continuous plant is shown with potential sources of pollutants identified. $\underline{3}/$



Figure 16-1 - Asphalt Batch Mix Plant $\frac{3}{}$



Figure 16-2 - Asphalt Continuous Mix $Plant^{3/2}$

16.3.1 Emission Sources and Rates

Pollutants released to the atmosphere during the operation of a hot-mix asphalt paving plant are both particulate and gaseous in nature. The major source of dust is the rotary dryer. However, while dust from the rotary dryer is the greatest source, dust collected from the vibrating screens, the bucket elevator, storage bins, and weigh hopper is also significant. In some plants, the dryer dust problem is handled separately from the other sources. However, the trend is to combine both the dryer and ventline or fugitive sources together with a single collector fan system.

Dust loadings and particle-size distribution vary widely from plant to plant. The dryer design and operation, particle-size distribution of feed materials, and the specific grade of asphalt mix will have a very marked effect on emissions.

Studies in the Los Angeles area indicated that stack emissions increase linearly with an increase in the amount of -200 mesh material processed and that emissions were higher when the dryer was oil-fired rather than gas-fired. $\frac{4}{}$

A study conducted in Germany provided extensive test data on the influence of feed composition, plant size, and control techniques on emissions. $\underline{10}$ / The quantity and particle size of dust in the waste gases from the drum dryer was found to extend through a wide range and to depend largely on whether the starting material was washed, unwashed, or processed in mixed components. Completely washed raw material caused the lowest dust load. Values ranged between 9.7-17.2 grains/scf. Mean value was 13.2 grains/scf.

In processing partly washed and partly unwashed raw material, dust contents measured during production of fine concrete were about 30.8 grains/scf.

Processing unwashed raw material resulted in maximum dust levels in waste gases. Dust content rose sharply with increasing proportion of fine particles in the materials for base, binder, and fine concrete manufacture. Measured values ranged from 19-72 grains/scf. $\frac{10}{}$

Table 16-1 summarizes emission levels from hot-mix asphalt paving plants. Currently paving plants emit about 200,000 tons/year of particulate matter.

16.3.2 Characteristics of Hot-Mix Asphalt Plant Effluents

The chemical and physical properties of hot-mix asphalt plant effluents are summarized in Table 16-2. Particulate pollutants involved in asphalt plant operations include stone dust, fly ash, soot, and unburned droplets of fuel oil. Stone dust is caused by the release of dust from the surface of the larger aggregate particles due to the heat and vibration of the dryer and other components of the plant and to some extent to the fracture of aggregate during the drying and screening processes.

Particulates emitted from the dryer have a highly variable particle size and may range from 10-90 wt. % < 10 μ .

16.3.3 Control Practice and Equipment for Hot-Mix Asphalt Plants

Total ventilation requirements for the rotary dryer and the secondary dust sources vary according to the size of plant. For a 6,000 lb/ batch plant, 22,000 scfm is typical, of which \sim 3,000 scfm is required for the secondary sources. Table 16-3 and Figure 16-3 illustrate test data on air pollution equipment serving two hot-mix asphalt paving plants. $\underline{1}/$

A typical asphalt plant dryer effluent will contain 20-30 grains/ cu ft. $\frac{5}{}$ However, the loading can vary widely as shown in the table of effluent characteristics. Test data for some Florida asphalt plants are given in Table 16-4. $\frac{6}{}$

The dust carried cut of the dryer into the dust collection system increases rapidly with a rise in drum gas velocity. Figure 16-4 shows the effect of increasing drum gas velocity on the dust carry-out for a typical aggregate. $\frac{3}{2}$

16.3.3.1 <u>Cyclones</u>: The collection of asphalt plant dusts is usually by means of cyclones for the primary dust collection followed by a higher efficiency type of secondary collector. One recently installed control system consisting of cyclones followed by low-pressure drop wet scrubbers is reported to attain 99.89% overall collection efficiency.⁷/ Measurements of cyclone-scrubber systems on 14 asphalt plant dryers showed > 98.0% efficiency.⁹/ Comparative cost data are presented in Table 16-5.³/ The ranges shown for installed cost and power consumption are in good agreement with general cost curves and equations presented in Appendix A. Therefore, these curves could be used for a more accurate estimate of costs if the total gas flow is known.

16.3.3.2 Electrostatic Precipitators: Electrostatic precipitation units do not find much application to asphalt plants since they have a rather high first cost. $\frac{3}{2}$

TABLE 16-2

EFFLUENT CHARACTERISTICS - ASPHALT*

| A. | Particulate | | | | Particle Flectricu | 1 | |
|----|--|---|---|---|---------------------|---------------------|---------------------------------------|
| | Source | Particle Size | Solids Loading | Chemical Composition | Density Resistivi | ty Moisture Content | Toxicity |
| I | . Hot-Mix Asphalt Batch Plants | | | | | | |
| | 1. Rotary Dryer | Highly variable, extreme range: 13-91 < 10, 32- 99 < 20, 55-100 < 44 Bahco Analysis: (2 sample 19-24 < 5; avg. 22 < 5 30-44 < 10; avg. 36 < 10 45-60 < 20; avg. 53 < 20 64-75 < 40; avg. 69 < 40 | Extreme range: 11-200 Typical range: es) 20-70 Avg.: 30 | Stone dust, fly ash, soot, and unburned droplets of oil | 2.6 (avg. value) | | N.T. |
| | 2. Vent Line (Fugitive Sources) | 39-46 < 10, 61-87 < 20, 86-99 < 44 | 23-82; avg.: 53 | i | | | |
| 1 | I. Asphalt Roofing Manu- facture | | | | | | |
| | 1. Saturator | | 0.42-0.77 | Hydrocarbon or óil mist | | | |
| в. | Carrier Gas | 1 | Moisture | | | Flammability or | Optical |
| | Source Flow | Rate <u>Temperature</u> | Content Chemical | Composition Toxicity | Corrosivity Odor | Explosive Limits | Properties |
| 1 | . Hot-Mix Asphalt Batch Plants | | | | | | |
| | Rotary Dryer (a) 7.7-4 Avg.: (b) 3.9-2 Avg.: | 6 85-525 20 Avg.: 240 4.6 9 | Dew point CO ₂ , NO _X , 140-160 | №2, 0 ₂ , CO CO - 100 | | | |
| | 2. Vent Line (a) 2.8-3.7 | 200-215 | | | | | |
| 1 | I. Asphalt Roofing Manufacture | | | | | | |
| | 1. Saturator (a) 10-20 | 135-217 | 2.7-6.4 | | | | 50% opacity over saturator tank |

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 16-3

| <u>DUST ANI</u> ASPI | FUME DISCHAF | RGE FROM | | | |
|-----------------------------|--------------|----------|--------------------|--------|--|
| Test No. | <u>C-42</u> | 26 | <u>C-537</u> | | |
| Batch Plant Data | | | | | |
| Mixer capacity, 1b. | 6,00 | 00 | 6,000 | | |
| Process weight, lb/hr** | 364,00 | 00 | 346,000 | | |
| Dryer Fuel | Oil, PS | 300 | 0il, P S 30 | 0 | |
| Type of mix | City street, | surface | Highway, sur | face | |
| Aggregate feed to drier | | | | | |
| + 10 mesh, wt. % | 70.8 | | 68.1 | | |
| - 10 to + 100 mesh | 24.7 | | 28.9 | | |
| - 100 to + 200 mesh | 1.7 | | 1.4 | | |
| - 200 mesh | 2.8 | | 1.6 | | |
| Dust and Fume Data | Vent Line* | Dryer | Vent Line* | Dryer | |
| Gas volume, scfm | 2,800 | 21,000 | 3,715 | 22,050 | |
| Gas temperature, °F | 215 | 180 | 200 | 430 | |
| Dust loading, lb/hr | 2,000 | 6,700 | 742 | 4,721 | |
| Dust loading, grain/sef | 81.8 | 37.2 | 23.3 | 24.98 | |
| Sieve analysis of dust | | | | | |
| + 100 mesh, wt. % | 4.3 | 17.0 | 0.5 | 18.9 | |
| -100 to $+200$ mesh | 6.5 | 25.2 | 4.6 | 32.2 | |
| - 200 mesh | 89.2 | 57.8 | 94.9 | 48.9 | |
| Particle size of - 200 mesh | | | | | |
| C - 5 microns, wt. % | 19.3 | 10.1 | 18.8 | 9.2 | |
| 5 - 10 microns, wt. % | 20.4 | 11.0 | 27.6 | 12.3 | |
| 10 - 20 microns, wt. % | 21.0 | 11.0 | 40.4 | 22.7 | |
| 20 - 50 microns, wt. % | 25.1 | 21.4 | 12.1 | 49.3 | |
| > 50 microns, wt. % | 14.2 | 46.5 | 1.1 | 6.5 | |

* Vent line serves hot elevator, screens, bin, weigh hopper and mixer.
** "Process weight"--a process weight definition is given in Rule 2 j, of the Rules and Regulations of the Los Angeles County Air Pollution Control District.



Figure 16-3 - Test Data on Air Pollution Control Equipment Serving Two Hot-Mix Asphalt Paving Plants (Vent Line Serves Screens, Hot Bins, Weigh Hopper, and Mixer)1/
TABLE 16-4

FINDINGS OF FLORIDA ASPHALT PLANT TESTING PROGRAM 6/

| | | | Before Cyclone | | After Cyclone | | Scrubber Outlet | |
|------------|-------------------------|------------|----------------|---------|---------------|-------------|-----------------|----------------|
| | | Production | (gr/cu | | (gr/cu | | (gr/cu | |
| Nam | e of Asphalt Plant | (tph) | ft) | (lb/hr) | ft) | (1b/hr) | <u>ft)</u> | <u>(1b/hr)</u> |
| | | | | | | | i | |
| 1. | Houdaille Duval | | | | | | | |
| | Asphalt Plant | 96 | - | - | 0.51 | 240 | - | - |
| 2 | Recia Acobelt | 90 | _ | _ | _ | _ | 2 30 | 509 |
| <i>C</i> • | Dasie Aspilaro | 50 | _ | _ | _ | - | 2.30 | 000 |
| 3. | (a) Jaxon Const. Co. | 120 | 21.2 | 6,830 | 5.42 | 1,883 | 0.765 | 205 |
| | (b) Jaxon Const. Co. | - | - | - | - | - | 0.433 | 116 |
| ٨ | Floride Four Const | Co | 33 7 | 12 000 | 15.0 | 3 120 | - | _ |
| 4. | Fiorida Four Const. | | JJ • 1 | 12,000 | 10.2 | 2,120 | - | - |
| 5 | Dunn Const Co | 99 | _ | _ | 14.5 | 2,550 | 0 370 | 54 0 |
| 0. | | 55 | | | | | 0.301 | 43.9 |
| | | | | | | | 0.283 | 41.4 |
| 6. | Mac Asphalt | 200 | - | _ | _ | - | 0.229 | 26.8 |
| | | | | | | | 0.349 | 40.6 |
| 7. | Florid a Hot Mix | 120 | - | _ | 9.47 | 1,020 | 0.135 | 25.7 |
| | | | | | 5.73 | 6 20 | 0.227 | 43.2 |
| 8. | Rubin Const. | 140 | - | - | - | - | 0.279 | 8.34 |
| | | | | | | | 0.297 | 8.15 |
| | | | | | | | 0.311 | 8.55 |

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Figure 16-4 - Effect of Drum Gas Velocity on Dust Emission³/

TABLE 16-5

COMPARATIVE COSTS OF DUST COLLECTORS 3/

| Type | Installed Cost (\$/cfm) | Power Consumption (kw/l,COO cfm) | Pressure Drop (in. water) |
|------------------------|----------------------------|--|---------------------------------|
| Primary | | | |
| Settling chamber | 0.1 | 0.1 | 0.1 - 0.5 |
| Cyclone, large dia. | 0.1 - 0.2 | C.1 - 0.5 | 0.5 - 3.0 |
| Cyclone, medium dia. | 0.2 - 0.3 | C.3 - 0.8 | 1.0 - 4.0 |
| Secondary | | | |
| Cyclone, multiple | 0.3 - 0.6 | 0.5 - 2.0 | 2.0 - 10.0 |
| Filter, cloth tubular | 0.3 - 2.0 | 0.5 - 1.5 | 2.0 - 6.0 |
| Precipitator, electric | 0.6 - 3.0 | 0.2 - 0.6 | 0.1 - 0.5 |
| Scrubber, spray tower | 0.1 - 0.2 | 0.1 - 0.2 | 0.1 - 0.5 |
| Scrubber, wet cyclone | 0.3 - 1.0 | 0.6 - 2.0 | 2.0 - 8.0 |
| Scrubber, packed tower | 0.3 - 0.6 | 0.6 - 2.0 | 0.5 - 10.0 |

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16.3.3.3 <u>Fabric Filters</u>: Fabric filters provide excellent collection of fine particles with little or no visible emissions. Although fabric filters frequently are more expensive than wet scrubbers, they collect dry "fines" which may be usable in high-grade asphaltic concrete mixes. In addition, they obviate the need for holding ponds and preclude water problems.<u>2</u>/

Filters are subject to operating difficulties when installed in an intermittent process such as asphalt dryers. $\frac{5}{}$ Precautions must be taken to prevent overheating and to prevent condensation during shutdowns.

The air-to-cloth ratios for fabric filters will vary from 3.5:1 to 6.25:1. Reverse air supply is normally heated, and the collector housing insulated, to prevent condensation. $\frac{8}{2}$

16.3.3.4 Wet Collectors: Wet collectors are in wide use in the asphalt paving industry and generally give good results without serious maintenance problems. The scrubbing liquid from these collectors requires a settling pond of adequate size. This pond should be at least 6 ft. deep and hold at least 2 hr. discharge of the scrubber. The sludge collected in the pond must be pumped or dredged out and removed to an appropriate disposal area avoiding any chances for stream pollution.3/

The effect of scrubber water/gas ratio on stack emissions is a very important factor as shown in Figure 16-5.4/ The best utilization of water is achieved up to a ratio of 6 gal/1,000 scf of gas. Above this ratio, efficiency still increases but at a lesser rate as illustrated in Figure 16-5.

16.4 ASPHALT ROOFING MANUFACTURE

Asphalt-saturated felt is manufactured in high-speed, continuously operating machines, referred to as asphalt saturators. An integral part of the operation is the preparation of the asphalt saturant. This preparation consists of oxidizing the asphalt and is accomplished by bubbling air through liquid (450-500°F) asphalt for 8 to 16 hr. The industry refers to this operation as "blowing." The time required for blowing depends on the desired properties of the saturant. It had been the practice to blow the asphalt in horizontal stills where the material loss ranges from 3 to 5%. -1/ Most of this material is recovered by venting the exhaust gases through oil knock-out tanks which are an integral part of the process. The recaptured mist is not reintroduced into the saturant but is used for other products such as cut-back asphalt. Thus, in horizontal stills, it requires \sim 1.05 tons of asphalt to produce 1.00 ton of saturant. However, most roofing manufacturing firms are currently using vertical stills from which the material loss is 1 to 2% over a 1-1/2 to 5 hr. cycle. $\frac{11}{2}$



at Average Aggregate Fired Rate in the Dryer Feed

After blowing, the saturant is transported to the saturation tank or spray area. Figure 16-6 is a schematic drawing of an asphalt roofing saturator. The asphalt saturator consists of a dry looper, an asphalt spray section, a saturating tank, and a wet looper. The felt is continuously fed from rolls into the dry looper where it is arranged over rollers into a series of vertical loops used as live storage in the process to permit maintenance of feed at a uniform rate to the saturating process during roll changes. The liquid asphalt at 400°F to 450°F may then be sprayed on one side of the felt. This spray of hot asphalt drives moisture in the felt out the unsprayed side and prevents the moisture from forming blisters when the felt is saturated. After being sprayed, the felt passes through a tank of molten asphalt that saturates the felt. The saturated felt then enters the wet looper where the material is arranged over another set of rollers into long, vertical loops to permit cooling of the asphalt. The web of saturated felt is then rolled up from the discharge end of the wet looper for use as roofing felt or building paper, or a small quantity of bituminous material and mica schist or rock granules is applied to the surface to make composition roofing paper and shingles. $\underline{1}$

16.4.1 Emission Sources and Rates

The main sources of particulate emissions are the saturator and "blowing" stills. The relatively high application temperature results in the vaporization of the lower boiling components of the asphalt. Vaporization of moisture in the felt also occurs. These vaporization processes produce a highly opaque mist. Additional vapors and mists are emitted from the saturated felt in the wet looper. The mass emission rate is a function of felt feed rate, felt moisture content, number of sprays used, and asphalt temperature. $\underline{1}/$ Table 16-1 presents the emission rates for asphalt roofing manufacture. Limited test data are available on emission rates, and emission totals for roofing manufacture in Table 16-1 are conservative estimates.

16.4.2 Characteristics of Asphalt Roofing Manufacture Emissions

The chemical and physical properties of asphalt roofing manufacture effluents are presented in Table 16-2. Limited data were found on the properties of effluents from asphalt roofing manufacture. Although no quantitative data were found on particle size for particulates emitted from the saturators, the particles are formed by condensation processes, and, therefore, are likely to be of the order of $l \mu$.



Figure 16-6 - Schematic Drawing of an Asphalt Roofing Felt Saturator $\underline{1}'$

16.4.3 Control Practices and Equipment for Asphalt Roofing Manufacture

Common methods of air pollution control at asphalt saturating plants include complete enclosure of the spray area and saturator followed by good ventilation through one or more collection devices including combinations of wet scrubbers, and two-stage low-voltage electrical precipitators, or cyclones and fabric filters.

Hoods for collecting the emissions should be installed so that there is a single continuous enclosure around the points of emission, extending down to the floor. Since operating personnel must have access to the saturator for operating adjustments, doorways or other provisions for entrance in the hood must usually be supplied. These should be kept as small as possible. In addition, openings in the hoods must be provided for the entrance of felt and exit of the saturated material. These openings should be as close to the floor as possible. Experience indicates that a minimum indraft velocity of 200 fpm is required at all hood openings. Air volumes handled by the exhaust system vary with hood design and saturator size but are about 10,000 to 20,000 scfm. The large volume of air required in controlling the saturator equipment generally makes incineration impractical.

16.4.3.1 Electrostatic Precipitators: The low-voltage, or twostage, electrical precipitator preceded by a spray scrubber as a precleaner gives relatively high collection efficiency as well as substantial reduction in the opacity of the saturator effluent. Table 16-6 shows the test results on a scrubber precleaner followed by a two-stage precipitator. $\pm/$

16.4.3.2 Fabric Filters: Baghouse filters are occasionally used as air pollution control devices for asphalt saturators, but their use is limited as a result of maintenance problems associated with filter bag upkeep and their high power requirement. Oil collected by the filter fabric is oxidized and polymerized by the air stream, causing plugging of the fabric and increasing the pressure drop across the filter unit. The air volume handled by the exhaust system then decreases because of increased pressure drop and results in loss of mist capture at the saturator's hood openings.

16.4.3.3 Scrubbers: Spray-type scrubbers have met with limited success as air pollution control devices for saturators. Some spray scrubbers may have an efficiency, based on weight removed, as high as 90%, but the scrubber's effluent may be from 50 to 100% opaque. This opaque discharge is due to the extremely low collection efficiency of spray scrubbers for particles < $l\mu$ in diameter. These small-diameter particles, when emitted from the scrubber discharge, cause maximum light scattering and, therefore, high opacities. Table 16-7 shows the results of tests made on a scrubbing system venting an asphalt saturator. $\frac{1}{2}$

TABLE 16-61/

EMISSIONS FROM A WATER SCRUBBER AND LOW-VOLTAGE TWO-STAGE ELECTRICAL PRECIPITATOR VENTING AN ASPHALT SATURATOR1/

| | Scrubber Inlet | Precipitator Inlet | Precipitator Outlet |
|---------------------------------------|----------------|--------------------|---------------------|
| Volume, scfm | 20,000 | 20,234 | 20,116 |
| Temperature, °F | 139 | 85 | 82 |
| Emission rate, grains/scf lb/hr | 0.416 71.4 | 0.115 20 | 0.058 10 |
| Water vapor, percent | 3.7 | 4.9 | 4.8 |
| Collection efficiency | Scrubber, 71% | Precipitator, 50% | Overall, 86% |

TABLE 16-71/

EMISSIONS FROM A WATER SCRUBBER VENTING AN ASPHALT SATURATOR³/

| | Scrubber Inlet | Scrubber Discharge |
|---------------------------------------|----------------|--------------------|
| Volume, scfm | 12,000 | 12,196 |
| Temperature, °F | 138 | 82 |
| Emission rate, grains/scf lb/hr | 0.535 55 | 0.0737 7.7 |
| Water, percent | 2.7 | 4.2 ⁸ / |
| Collection efficiency, percent | | 86 |

a/ At 3.7 volume \$\$ of water, vapor is saturated air. Other qualitative tests run simultaneously showed no particulate water.

Theoretical evidence indicates that Venturi-type scrubbers remove contaminants with particle sizes of < 1 μ in diameter, but the initial equipment cost and high energy requirements of the Venturi scrubber make its use economically unattractive compared with other forms of air pollution control equipment.¹/ However, such devices may be necessary if high efficiency collection is required to comply with air pollution regulations.

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CHAPTER 17

FERROALLOY MANUFACTURE

17.1 INTRODUCTION

Ferroalloys are used for deoxidation, alloying, and graphitization of steel. In the nonferrous metal industry, silicon is used primarily as an alloying agent for copper, aluminum, magnesium, and nickel. Ferrosilicon, in the form of 75% ferrosilicon, is used as a reducing agent in the production of magnesium by the Pidgeon process.²/ Manganese is the most widely used element in ferroalloys, followed by silicon, chromium, and phosphorus. Others include molybdenum, tungsten, titanium, zirconium, vanadium, boron, and columbium.

The production of ferroalloys has many dust or fume producing steps. Materials-handling operations and crushing and grinding generate coarse dust, while the pyrometallurgical steps release metallic fumes. The manufacturing process, particulate emission sources, emission rates of individual sources, chemical and physical properties of effluents, control practices, and control equipment are discussed in the following sections.

17.2 FERROALLOY PRODUCTION

There are four major methods used to produce ferroalloy and highpurity metallic additives for steelmaking. These are (1) blast furnace, (2) electric smelting furnace, (3) alumino silico-thermic process and (4) electrolytic deposition. The choice of process is dependent upon the alloy produced and the availability of furnaces. Ferromanganese is the principal metallurgical form of manganese. This product contains 80% or more of manganese, the balance being mainly iron. It is produced in the blast furnace or electric-arc furnace and is available in several grades. A few steel companies produce ferromanganese for their own use since they have their own ore sources and suitable blast furnaces available.

The coke-burning blast furnace, even with high blast temperature (1800 to 2000°F), is not a completely efficient smelter for ferroalloys of manganese, chrome and silicon since the waste slags are relatively high in unreduced Mn and Cr oxides, and not much more than 20% silicon can be reduced economically. This is due to the limitation of temperature generation at the tuyere plane.

361

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The submerged arc, or the roofed-in open bath electric smelter with intense heat zones (4000 to 5000° F) near the arc can more effectively complete the reduction of the oxides; hence, higher overall yields of the various metallic components and with more general flexibility and control over the operation than is possible in the coke blast furnace. For these reasons the electric furnace is more often used for the production of ferro-alloys.

Metallic silicon and aluminum are intense deoxidizers and are often used as reducing agents in the so-called metallothermic reduction processes for ferromolybdenum, ferrovanadium, ferrotitanium, a combination of carbon and aluminum as reductant for ferrozirconium, and the aluminothermic reduction of ferrocolumbium.

Since the reduction of oxides by silicon, and particularly aluminum metal, is exothermic, quite often enough heat is given off by the reaction, so that the ferroalloys can sometimes be smelted outside the furnace.

The pure metals of manganese, nickel, copper and chromium, etc., are most often produced by electrofinning via the electrolytic bath. In the case of manganese, for example, the ores are calcined and leached, usually to form $MnSO_4$, mixed with ammonium salts and delivered in solution to bath. The pure manganese collects as a film about 1/8 in. thick on the cathode, is removed, melted and cast to ingots of 99.7-99.9% Mn.

The blast furnace and electric smelting furnace production method are the major sources of air pollution, and these methods are discussed in more detail in the following paragraphs.

17.2.1 Ferromanganese Blast Furnaces

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Ferroalloys are produced in the blast furnace by carbon reduction of manganese ore and iron ore in the presence of coke and limestone. Ferromanganese blast furnaces are usually smaller than pig-iron furnaces and the hot-blast temperatures are lower, approximately $1100-1200^{\circ}$ F. The ferromanganese furnaces are blown at a much slower rate and therefore operate without hanging or slipping. Because of the freedom from these mechanical troubles, the shape of ferromanganese furnaces has not been given the same consideration as that of a pig-iron furnace. Oxygen enrichment of the blast has been tried on a commercial scale with a marked increase in furnace capacity. 1/

There are no rigid specifications for ores used for producing ferromanganese. The use of a particular ore depends on its cost and grade in comparison with other ores available at a specific point. A mixture of a number of different ores is generally charged to the blast furnace, and they are so proportioned as to meet definite specifications for the final alloy composition. Blending a number of ores improves the physical character of the charge. Low-silica ores are preferred since the volume of slag increases with increased silica in the charge, causing losses in manganese, increased fuel consumption, and loss of tonnage.

The physical structure of the ore is important to economical blast furnace operation. Dust losses are curtailed by mixing hard, coarse ores with fine ores. Although some of the dust is recovered from the flue gases and recharged into the furnace as briquets, there is always a loss of manganese due to the deposition of dust in stoves and boilers.

The physical character of the ore is important with relation to resistance to gas flow. Although large amounts of coarse coke tend to form porous columns offering little resistance to gas flow, fine ore particles do not, which makes it difficult to get a uniform distribution of gas throughout the charge. Nonuniform gas distribution interferes with furnace efficiency as it affects the heat exchange between solid and gas. In pigiron furnaces, the limit of capacity is reached when the air pressure is so high that it interferes with the settling of the charge, but in ferromanganese furnaces, the loss of manganese by volatilization is what limits the capacity.

Low blast pressure characterizes the operation of a ferromanganese blast furnace. The silicon is easily controlled and no problem is presented by sulfur. Low fuel consumption and the maximum manganese recovery in the metal are the chief operating goals. High manganese recovery is favored by (1) small slag volume, (2) a basic slag, (3) high blast temperatures, and (4) coarse ores.

Although a large amount of fuel is used, the temperatures of ferromanganese furnaces are lower than those of pig-iron furnaces. Several factors are influential in causing this lower temperature. The reducing reaction between MnO and solid carbon or CO is highly endothermic, and since the slag is formed at a comparatively low temperature and is fluid just above its melting point, it carries a relatively small amount of heat down into the furnace crucible. A chilling effect is caused by the large thermal head between the relatively cold slag and the tuyeres in this zone. The result is that the slag reaches the combustion zone at a low temperature. Since the region below the tuyeres depends chiefly on the slag and metal for its supply of heat, this means comparatively low temperatures in the crucible. The low free-running temperature of the ferromanganese slag is not conducive to the high-temperature needs for the reduction of manganese oxide, and a longer time is required. The requisite time interval is accomplished by bringing fresh slag into the crucible at a lower rate; the low blast pressure effects this.

17.2.2 Electric-Arc Furnaces

The majority of ferroalloy furnaces are termed submerged arc, although the mode of energy release in many cases is resistive heating.²/ Raw ore, coke, and limestone or dolomite mixed in proper proportions constitute the charge for the electric-arc furnace process. A large supply of electric power is necessary for economical operation. Important operating considerations include power and electrode requirements, size and type of furnace, amount and size of coke, and the nature of slag losses.

Submerged-arc furnaces generally operate with continuous power except for periods of power interruption or mechanical breakdown of components. Operating times average 90 to 98%. The electrodes operate 3 to 6 ft. above the hearth, and are submerged 3 to 5 ft. below the mix level so that some heat exchange and mass transfer can occur between the reaction gas and the mix. The products produced in this type furnace are chiefly: $\frac{2}{}$

- 1. Silicon Alloys Ferrosilicon (50 to 98% Si) and CaSi
- 2. Chromium Alloys High carbon FeCr in various grades and FeCrSi
- 3. Manganese Alloys Standard FeMn and SiMn

There are a smaller number of furnaces which do not operate with deep submergence of the electrodes and produce a batch melt which is usually removed by tilting the furnace. Mix additions and power input would usually be cyclic. Examples of products produced in this type of furnace are:

1. Manganese Ore - Lime melt for subsequent ladle reaction with silicomanganese to produce medium carbon and low carbon ferromanganese

2. Chrome Ore - Lime melt for subsequent ladle reaction with ferrochrom-silicon to produce low carbon ferrochrome

3. Special Alloys, such as Aluminum - Vanadium, Ferrocolumbium

17.3 EMISSION SOURCES AND RATES

The production of ferroalloys has many dust or fume producing steps. Particulates are emitted from raw material handling, mix delivery, crushing, grinding, and sizing, and furnace operations. The dust resulting from the solids-handling steps does not present a difficult control problem. Emissions from furnaces vary widely in type and quantity, depending upon the particular ferroalloy being produced, type of furnace used, and the amount of carbon in the alloy. In the operation of a blast furnace, a large quantity of dense fume may be emitted to the atmosphere. The amount and types of particles which make up this fume are different from those commonly found in the gases from blast furnaces producing basic pig iron.³/ One type, comprising about 20% of the dust present, consists of particles above 20 μ in size, which appear to originate in the disintegration of coke and ore in the furnace burden. The other type, which accounts for 80% of the solids present in the gas, is a typical fume varying in size from 0.1 to 1.0 μ . This material is formed by a process of vaporization and condensation. Particulate emissions can be reduced by raw materials choice and sound operating practices.

The conventional submerged-arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide.¹/ Other sources of gas are moisture in the charge materials, reducing agent volatile matter, thermal decomposition products of the raw ore, and intermediate products of reaction. The carbon monoxide normally accounts for about 70 vol. % of the gases. The gases rising out the top of the furnace carry fume or fume precursors and also entrain the finer size constituents of the mix or charge. Submerged-arc furnaces operate in steadystate and gas generation is continuous.²/

In an open furnace, all the CO burns with induced air at the top of the charge, resulting in a large volume of gas. In a closed furnace most or all of the CO is withdrawn from the furnace without combustion with air.

Fune emission also occurs at furnace tap holes. Because most furnaces are tapped intermittently, tap hole funes occur only about 10 to 20% of the furnace operating time. Another source of fume occurs in handling the metal after the tapping step. Conveying the ladle, pouring, and casting give rise to fumes on an intermittent basis. $\frac{2}{3}$

Some processes conduct additional reactions in the ladle, such as chlorination, oxidation, and slag-metal reactions. In these cases, there may be actual gas generation in addition to the treatment gas, and possibly gross ejection of a portion of the ladle contents. These are batch processes with intermittent fume generation. $\frac{2}{2}$

Melting operations may be conducted in an open arc furnace in some plants. While no major quantities of gas are generated in this operation, thermally induced air flow may result in fume emission. $\frac{2}{}$

A minor source of particulate pollution on furnaces with selfbaking electrodes is the fume resulting from the electrode paste during heating and baking. This fume is usually directly vented. $\frac{2}{2}$ Emissions and emission rates will vary with (1) type of alloy produced, (2) process (i.e., continuous or batch), (3) choice of raw materials, (4) operating techniques, and (5) maintenance practices.

With silicon alloys, as the percentage of silicon in the alloy increases, the loss of SiC₂ increases, so that a silicon metal furnace produces substantially more fume than a 50% FeSi furnace at the same load.²/ In addition, the higher ferrosilicon operations (75% Si and above) are known as "hot" operations; i.e., the gas exiting from the mix is at a high temperature and the furnace is subject to blows (frequently jets of gas issue at high velocity directly from the high temperature reaction zone). Higher silicon operations are also subject to hearth build-ups of silicon carbide. Under these conditions, electrodes operate in a higher position and more fume can result.²/

Because manganese ores contain a significant amount of water, as well as higher manganese oxides which release oxygen upon heating at temperatures below 1000°C, a manganese furnace can be subject to "rough" operation. Sudden release of gas can result in substantial mix ejection from the furnace. In furnaces with self-baking electrodes, the relatively oxidizing atmosphere can result in "fluting" of the electrodes, furnishing a direct gas passage from the high temperature zone of the furnace, with increased fume emission. $\frac{2}{}$ Silicomanganese furnaces are subject to "slag boils," where slag rises up to cover the top surface of the charge, impeding mix delivery and uniform gas ascent.

Emissions from batch-operated furnaces are periodic. As a result of sudden addition of mix containing volatile constituents (coal volatiles, moisture, aluminum) to a hot furnace container, substantial violent gas eruptions can occur. This is best exemplified by the manganese ore-lime melt furnace where momentary gas flow following mix addition can be five times the average flow (as contrasted with variation of 20% or less in a well-running submerged-arc furnace). Temperature and dust loading peaks also correspond to the gas flow peak.

In contrast, chromium ore-lime melt furnaces, to which little or no gas releasing constituents are fed, are not subject to this violent behavior. In some circumstances, solids or molten material ejected from the furnace continue to burn in the air, giving rise to collection problems.

Some of the special alloys are also produced by aluminothermic reactions without the addition of electrical energy. These reactions, if unconfined, give rise to momentary peaks of gas flow. $\frac{2}{2}$

Volatile materials in the furnace charge give rise to rough operation. Another significant contributor to rough operation is the presence of fines or dense material in the feed. These materials promote bridging and nonuniform descent of the charge, resulting in gas channeling and bypassing. Sudden collapse of a bridge then gives rise to a momentary gas burst. A porous charge will give good gas distributions and use of good quality scrap will also reduce emissions. On some products, economics dictate the use of raw materials with more fines, or with more volatile matter. Each of these has an adverse effect on the smooth operation of the furnace, and consequently pollution may increase.

Differences in operating techniques can have a significant effect on fume generation. The average rate of furnace gas production is roughly proportional to electrical input, so that a higher load on a given furnace generally results in at least a proportional increase in fume emission. In some circumstances, fume emission increases at a rate greater than the load increase, as a result of rougher operation and inadequate gas withdrawal capacity.

At a fixed load, even though the gas generation is almost constant, fume concentration and, hence, the weight per hour emitted can vary by a factor of 5 to 1. Operation with insufficient electrode submergence promotes increased fume emission. There is also some evidence that higher voltage operation, in addition to promoting a higher electrode position, alters the mode of energy release beneath the electrodes, increasing locally the energy supplied per unit volume, promoting higher local temperatures, and increasing the fume concentration. $\frac{4}{2}$

On some operations, silicon metal production in particular, where stoking of the charge is necessary to break up crusts and partially agglomerated material and to cover up areas of blows, fume emission can be a function of how well and how often the furnace is stoked.

On other operations, where a mix seal and cover are used to allow collection of most or all of the furnace gas, direct venting and increased fume emission can occur if lack of mix prevents making a seal either because of poor mix placement or insufficient mix delivery. Direct venting can also take place during startup, shutdown, and "burndown" to remove undercover accumulations. $\frac{2}{}$

Loads on existing furnaces have been progressively increased as operating techniques improved and as more knowledge of transformer capacity became available. This tendency has taxed the furnace gas collection systems and, in the case of open furnaces, has certainly presented a more concentrated source of fume. $\frac{2}{}$

Maintenance practices significantly affect fume emission on covered furnaces, where accumulation of material under the cover and in gas offtakes and ducts reduces gas withdrawal capacity. Plugging of gas or water passages in cleaning apparatus results in reduced efficiency of gas cleaning.

Water leaks from electrode suspension equipment and other components above the furnace can result in some increase in gas flow (as steam or hydrogen).

17.3.1 Summary of Emission Rates

Table 17-1 presents a summary of emission rates from ferroalloy production. Particulate emissions currently total 160,300 tons/year. Electricarc furnaces account for over 90% of this total (150,000 tons), and electricarc furnaces producing ferrosilicon emit over 40% of the particulates (71,000 tons).

17.4 EFFLUENT CHARACTERISTICS

The chemical and physical properties of effluents from ferroalloy production processes are presented in Table 17-2. Properties of the emitted particulates depend upon the alloy being produced and furnace type. Particle size of the metallic fume emitted from the furnace ranges from 0.1-1.0 μ with a geometric mean of 0.3 μ . Grain loadings and flowrates are dependent upon furnace type. Open electric furnaces have high flowrates and moderate grain loadings while closed furnaces have moderate flowrates and generally high grain loadings.

With silicon alloys the fume produced is gray and contains a high percentage of SiO_2 . Some tars and carbon are also present arising from the coal, coke, or wood chips used in the charge. Chromium furnaces produce a SiO_2 fume similar to a ferrosilicon operation with some additional chromium oxides. Manganese operations produce a brown fume. Analyses indicate the fume to be largely a mixture of SiO_2 and manganese oxides.

17.5 CONTROL PRACTICES

Limited sources of information have been found which describe control practices for ferroalloys. However, one very complete writeup by R. A. Person $\frac{1}{has}$ been reviewed and excerpts used in the following description of control techniques and practices.

TABLE 17-1

PARTICULATE EMISSIONS PRODUCTION OF FERROALLOYS

| Source | Quantity of Material | Emission Factor | Efficiency of Control Cc | Application of Control Ct | Net Control Cc ^{.C} t | Emissions (tons/yr) |
|--------------------------|--|------------------------|--------------------------------|---------------------------------|--------------------------------------|------------------------|
| I. Furnaces | | | | | | |
| A. Blast Furnaces | 591,000 tons, ferromanganese | 410 lb/ton product* | 0.99 | 1.0 | 0.99 | 1,200 |
| B. Electric-Arc Furnaces | 317,000 tons, ferromanganese | 44 lb/ton | 0.80 | 0.50 | 0.40 | 4,200 |
| | 285,000 tons, silicomanganese | 195 1b/ton | 0.80 | 0.50 | 0.40 | 16,500 |
| | 665,000 tons, ferrosilicon | 357 lb/ton | 0.80 | 0.50 | 0.40 | 71,200 |
| | 96,000 tons, silicon metal | 583 lb/ton | 0.80 | 0.50 | 0.40 | 16,800 |
| | 166,000 tons, silvery iron 590,000 tons, ferrochrome, | 120 1b/ton | 0.80 | 0.50 | 0.40 | 6,000 |
| | ferrophosphorus | 200 1b/ton | 0.80 | 0.50 | 0.40 | 35,400 |
| II. Materials Handling | 2,710,000 tons of metal pro- | | | | | |
| | duced | 10 lb/ton of metal | | | | |
| | | produced | 0.90 | 0.35 | 0.32 | 9,000 |
| | | Total from Ferroalloys | 3 | | | 160,300 |

* All emission factors are "per ton of product."

369

TABLE 17-2

A. Particulate Chemical Particle Moisture Source Particle Size Solids Loading Composition Electrical Resistivity Content Toxicity Density I. Blast (a) Dust (20% of emitted 4.5-17 Mn: 15-25 See Table 17-3 for Manganese compounds Furnace particulate) Fe: 0.3-0.5 detailed data are poisonous 100 > 20Na₂0 + K₂0: 8-15 (b) Fume (80% of emitted Si02: 9-19 particulate) Al203: 3-11 Ca0: 8-15 Range: 0.1-1 Avg. 0.3 MgO: 4-6 S: 5-7 C: 1-2 II. Electric Furnace (a) Ferrosili-Optical Count Range during Hydrated silica: See Table 17-3 for con (50%) Range: 0.01-4 cycle 0.2detailed data 92.8 (open fur-Geometric mean: 0.3 2.7 X-Ray diffraction nace) Standard deviation: Mean: 1.5 showed presence 2-4 of: Si, Fe, Al, Ca, Mg, Mn, Cu and Ti (b) Miscellane- See Table 17-4 for See Table 17-3 for 0.4-30 See Table 17-4 for ous alloys detailed data detailed data detailed data A. Particulates (Concluded) Hygroscopic Flammability or Optical Source Solubility Wettability Explosive Limits Characteristics Handling Characteristics Properties 0 dorI. Blast Furnace Fume is pyro-Light, floury (fume com-Gray (ferrophoric ponent) ferromanganese manganese) fume forms a hard, cement-like deposit when wetted II. Electric Furnace

EFFLUENT CHARACTERISTICS - FERROALLOY MANUFACTURE

* See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

(a) Ferrosilicon 1.5-4% in. H₂0

(50%)

370

TABLE 17-2 (Concluded)

B. Carrier Gas

| Source | Flowrate | Temperature | Moisture Content | Chemical Composition | Toxicity | Corrosivity | <u>(dor</u> | llarnatility or Explosive Limits | Optical Properties |
|---|---|-------------|---------------------------------|--|----------|-------------|-------------|---|-----------------------|
| l. Blast Furnace | <pre>(a) 135 (one furnace) (b) 270* (one furnace)</pre> | 350-750 | Variable over eycle: 2-30 | ου, ου _ρ , Ν ₂ Η ₂ , ου _ρ | | | | Explosive be- cause of C. content | |
| II. Electric Furnace (a) Ferrosilicon (50%, open furnace) | | 95-176 | | | | | | | |
| (b) Ferroman- ganese (closed fur nace) | (a) -(b) 25.6-30.4 | 662 | | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | |
| (c) FeCr Alloy (closed furnace) | (a) (b) 28.8-33.6 | 662 | | CO: 72 CO ₂ : 11 H ₂ : 6 N ₂ : 10 CH ₄ : 1 | | | | | |
| (d) FeSi(75% Si, closed fur- nace) | (a) (b) 54.4-57.6 | 1832 | | | | | | | |
| (e) Miscellane- ous alloys (l) Open furnace | (a) 180-630* (b) | 250-550 | | | | | | | |
| (2) Semi- closed furnace | (a) 100* (b) | 400-1200 | | | | | | | |
| (3) Closed furnace | (a) 11-56 | | | | | | | | |

TABLE 17-3

FERROALLOY FUME RESISTIVITY / (ohm-cm, 200-300°F Temperature Range)

.

| Product | Without Conditioning | With Conditioning of Gas to 20% Moisture |
|----------|-------------------------|--|
| SMZ * | 8.7 x 10^{13} | 8.5 x 10 ¹¹ |
| 50% FeSi | 1.2×10^{13} | 9.3 x 10 ¹¹ |
| FeMn | 4.7 x 10 ¹¹ | 3.2 x 10 ⁸ |
| FeCr | 9.4 x 10 ¹⁰ | 2.1 x 10 ¹⁰ |
| SiMn | 1.3 x 10 ¹⁰ | 2.4 x 10 ⁸ |

* Si - 60-65% Mn - 5-7% Zr - 5-7%

372

TABLE 17-4

TYPICAL FERROALLOY FURNACE FUME CHARACTERIZATIONS

| Furnace Product: | 50% FeSi | SMZ* | SiMn** | SiMn** | FeMn | H.C.FeCr | Chrome Ore- Lime Melt | Mn Ore**- Lime Melt |
|---|--------------------------------------|---|---|--------------------------|---|-------------------------|---------------------------------|---------------------------------|
| Furnace Type | Open | 0 pen | Covered | Covered | Open | Covered | Open | Open |
| Fume Shape | Spherical, sometimes in chains | Spherical, sometimes in chains | Spherical | Spherical | Spherical | Spherical | Spherical and irreg- ular | Spherical and irreg- ular |
| Fume Size Char- acteristics (µ) Maximum Most Particles | 0.75 0. 05 ~0.3 | 0.8 0.05-0.3 | 0.75 0.2-0.4 | 0.75 0.2-0.4 | 0.75 0.05-0.4 | 1.0 0.1 - 0.4 | 0.50 0.05-0.2 | 2.0 0.2-0.5 |
| X-Ray Diffraction Primary | • | <u></u> | All fumes w | ere primaril; | y amorphous | <u></u> | | > |
| stituents | FeSi FeSi ₂ | Fe ₃ 0 ₄ Fe ₂ 03 Quartz SiC | Mn ₃ 0 ₄ MnO Quartz | Quartz SiMn Spinel | Mn ₃ 0 ₄ MnO Quartz | Spinel Quartz | Spinel | CaO |
| Chemical Analysis 4 | 8 - | | | | | | | |
| Si0o | 63-88 | 61.12 | 15.68 | 24.60 | 25.48 | 20.96 | 10.86 | . 3.28 |
| FeO | | 14.08 | 6.75 | 4.60 | 5,96 | 10.92 | 7.48 | 1.22 |
| MgO | | 1.08 | 1.12 | 3.78 | 1.03 | 15.41 | 7.43 | 0.96 |
| CaO | | 1.01 | | 1.58 | 2.24 | | 15.06 | 34.24 |
| MnO | | 6.12 | 31.35 | 31.92 | 33.60 | 2.84 | | 12.34 |
| A1203 | | 2.10 | 5.55 | 4.48 | 8.38 | 7.12 | 4.88 | 1.36 |
| LOI | | | 23.25 | 12.04 | | | 13.86 | 11.92 |
| TCr as Cr ₂ 03 | | | | | | 29.27 | 14.69 | |
| SiC | | 1.82 | | | | | | |
| Zr0 ₂ | | 1.26 | | | | | | |
| Pb 0 | | | 0.47 | | | | | 0.98 |
| Na ₂ 0 | | | | 2.12 | | | 1.70 | 2.05 |
| BaO | | | | | | •- | | 1.13 |
| K20 | | | | | | | | 13.08 |

* Si - 60-65%; Mn - 5-7%; Zr - 5-7%.

** Manganese fume analyses in particular are subject to wide variations, depending on the ores used.

The controls used are affected by the two types of electric furnaces. In the open furnace, all the CO produced burns with induced air at the top of the charge, resulting in a large volume of high temperature gas. In a closed furnace most or all of the CO is withdrawn from the furnace without combustion with air. When the furnace gas burns with air, as with an open furnace, a significant volume increase occurs. Depending on the amount of induced air, the volume to be treated for dust collection may increase by a factor of 50. Table 17-5 shows furnace gas generated without combustion while Table 17-6 gives a comparison of gas flows for open and closed furnaces. $\underline{1}/$

Semicovered furnaces have also been used. The gas is usually cleaned in a multistage centrifugal fan with water spray nozzles. However, existing units are restricted to a capacity of about 2,000 acfm and are higher power and water consumers than a Venturi scrubber.

17.5.1 Control Equipment

17.5.1.1 Open Furnaces: Modern open furnaces require a hood to protect the superstructure and the electrode column components. A hood at least the diameter of the furnace shell, with the minimum opening between the hood and operating or charging floor, and an air inlet velocity of at least 3 ft/sec have been the criteria for recent installations. Sufficient hood depth must also be provided to assure that combustion is substantially complete within the hood.

Installed cost of fume collectors depends on the particular installation and the degree to which utility services are available. Estimated costs for units recently installed or planned on open furnaces, excluding furnace hood and interior ductwork and liquid waste disposal systems, are shown in Table 17-7.1. These installed costs are 200-300% higher than would be estimated on the basis of general cost curves given in Appendix A.

17.5.1.1.1 Wet scrubbers: The only currently feasible type of wet collector for cleaning the large gas volumes from open furnaces is the Venturi type scrubber. With required pressure drops on the order of 60 in. w.g. the power consumption approaches 10% of the furnace rating (for a low hood design). Most Venturi designs allow recirculation of scrubbing liquor so that water consumption is reduced to that evaporated into the gas plus that exiting with the concentrated solids stream. The Venturi has the advantage of being able to absorb gas temperature peaks by evaporating more water. For a ferrosilicon or ferrochrome-silicon operation substantially all of the sulfur in the reducing agent appears in the gas phase, and a corrosion problem occurs in any liquid recycle system unless neutralizing agents or special materials of construction are used.

TABLE 17-5

<u>APPROXIMATE FURNACE GAS GENERATION</u>/ (Without Combustion)

| Product | (SCFM/MW) |
|-------------------------|-----------|
| Silicon Metal | 140-150 |
| 50% Ferrosilicon | 130-140 |
| Standard Ferromanganese | 160-170 |
| Silicomanganese | 120-130 |
| Ferrochrome-Silicon | 110-120 |
| H.C. Ferrochrome | 80- 90 |
| Calcium Carbide | 70- 80 |

(Based on gas saturated at 100°F, scf at 30 in. Hg, 60°F)

TABLE 17-6

COMPARISON OF FURNACE GAS VOLUMES 1/

| | Closed Furnace | Cpen Furnace (Low Hood) |
|-----------------|------------------|----------------------------|
| FeCrSi, 25 MW | | |
| ACFM at Temp. | 8700 at 1100°F | 230,000 at 430°H |
| scim | 2900 | 135,000 |
| 50% FeSi, 50 MW | | |
| ACFM at Temp. | 20,000 at 1100°F | 410,000 at 760°E |
| scfm | 6,600 | 175,000 |
| | | |

TABLE 17-7

ESTIMATED COST OF FURNACE CONTROLS1/

| | Estimated Installed Cost |
|--|--------------------------------|
| | (1969) \$/ACFM at Furnace Hood |
| | |
| Venturi Scrubber | 2 .40 - 3.6 0 |
| Bag Filter | 2.90 - 3.60 |
| Electrostatic Precipitator (with conditioning) | 3.80 - 4.20 |

Recent wet scrubber installations are summarized in Table 17.8.1/

17.5.1.1.2 <u>Baghouses</u>: Cloth-type filters do an effective job of cleaning the combustion gases from open furnaces so long as the filter media remain intact. Baghouse installations often utilize the pressure-type baghouse, with the fan on the dirty-gas side, to simplify the collector housing construction and to allow access into the collector during operation. To prevent carryover of burning mix particles, a mechanical collector ahead of the baghouse is desirable.¹/

Because of temperature limitations on the cloth (500°F for treated fiberglass), the gas must often be cooled by passing through heat transfer surfaces or by dilution. Cooling by water spray injection is possible, but can lead to control complications and possible blinding of the bags.

The amount of gas a cloth filter can handle when operating on silica fume without bag blinding is a maximum of about 2 acfm/sq ft of filter area. This limit results in a large number of bags, up into the thousands, in order to treat the combustion gas from an open furnace.

A significant problem associated with the use of fiberglass bags on silica fume collection is the buildup of electrostatic charge, which in turn leads to a high residual pressure drop across the bags.

17.5.1.1.3 <u>Electrostatic precipitators</u>: Electrostatic precipitators have been installed on open furnaces producing silicon, ferrosilicon, ferrochrome-silicon, and silicomanganese.

Unfortunately, most ferroalloy fumes at temperatures below 500 °F have too high an electrical resistivity, i.e., greater than 1×10^{10} ohm-cm. The resistivity is in an acceptable range only if the gas temperature is maintained above 500-600 °F. Water conditioning would lower the resistivity, but a large spray tower is required for proper humidification. Stainless steel construction would be a necessity for ferrosilicon or ferrochrome-silicon operations. The alternate use of steam is feasible only if low-cost steam is available.

The resistivity problem could be overcome by using a wet precipitator, but water usage appears to be greater than that for a wet scrubber without recycle.¹/ Wet electrostatic precipitators have been used at one installation in Europe. However, all parts of the precipitators exposed to the dirty water and to the wet gas were reconstructed of stainless steel.⁶/ An electrostatic precipitator is being installed on a ferroalloy furnace by AIRCO at Charleston, South Carolina.

TABLE 17-8

EXAMPLES OF FURNACE WET SCRUBBERS1/

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| | Open Furnace - Low Hood | | | Semi-Closed Furnace | | |
|----------------------------------|-------------------------|------------------|-----------------|---------------------|--|--|
| Collector | | Ī | <u>II</u> | III | IV | |
| Original Completion Date | | 1967 | 1968 | 1968 | 1965 | |
| Furnace Rating for Collector De: | sign | 25 MW | 30 MW | 30 MW | 45 MW | |
| Furnace Product | | FeCrSi | SiMn | H.C. FeCr | 50% FeSi | |
| Measured Collection Efficiency, | Avg | . 92.6% | 98.6% | 98.2% | 98.4% (particulates) 79% (organics) | |
| Inlet Loading, grains/scf | | 1.43 | 1.31 | 1.07 | 4.93 | |
| Outlet Loading, grains/scf | | 0.106 | 0.017 | 0.019 | 0.08 | |
| Design Volume at Furnace Hood | | 230,000 ACFM | 255,000 ACFM | 210,000 ACFM | | |
| Design Temperature | | 430°F | 620°F | 590°F | | |
| Actual Duct or Offtake Temperate | ure | 500 to 570°F | 490 to 550°F | 480°F | 1100 to 1200°F | |
| Design Volume Handled by Fans of | r | | | | | |
| Blowers | | 194,000 ACFM | 196,000 ACFM | 196,000 ACFM | 6,500 scfm | |
| Operating Pressure Drop across | | | | | | |
| Collector, inches water | | 55 | 57 | 57 | 72 to 80 | |
| Installed H.P Fans | | 2,600 | 2,800 | 2,800 | 600 | |
| - Auxiliaries | | 50 | 50 | 50 | | |
| Tons/Day Collected Dust | | 11 to 13 | 14 to 17 | 11 to 17 | 5 to 8 | |
| Tons/Day Uncollected Emission | | 0.75 to 1 | 0.20 | 0.26 | None | |
| Water Circulation | | 1,800 gpm | 1,800 gpm | 1,800 gpm | 75-100 gpm | |
| Water Usage | | 310 gpm | 350 gpm | 350 gpm | 75-100 gpm | |
| Problems: | (1) | System falls 25% | (l) High fan (1 | l) High fan (I | L) Continuous kerosene | |
| | | short of design | outage. | outage. | injection necessary | |
| | | flow. | | | for blowers. | |
| | (2) | High fan outage. | | | | |
| | (3) | Necessity to add | | | | |
| | | lime to neutra- | | | | |
| | | lize scrubbing | | | | |
| | | liquid. | | | | |

17.5.1.2 <u>Covered Furnaces</u>: Semicovered furnaces, while collecting a majority of the fume, may not in many cases be satisfactory for current or pending regulation.

The sealed furnace, which has a cover including sliding seals around the electrodes and mix spouts, is primarily a European development. It has thus far been applied only to calcium carbide, pig iron, standard ferromanganese and silicomanganese. Sealed covers are difficult to adapt to an existing furnace because of the extensive revisions that are usually required.

A modified cover, incorporating electrode seals, but covering only the "reaction zones" around the electrodes and leaving the outer rim of the furnace open, has been developed. This approach, called gas collection sleeves or smoke rings, has the advantages of collecting the gas in the observed region of maximum generation, of allowing partial stoking of the mix, and of being cheaper than a complete cover. Initial installations were made on ferromanganese furnaces and subsequently on calcium carbide and silicomanganese furnaces.1/

17.5.1.2.1 <u>Wet scrubbers</u>: The disintegrator type of scrubber does a good cleaning job when properly maintained and has the additional advantage of producing a slight pressure head (about 2 in. w.g.). However, the capacity limitation and high water and power consumption make it uneconomical for most new furnace installations.

The Venturi type scrubber has been installed on CO gas cleaning installations but the required pressure drops are high. The characteristics of a typical installation are included in Table 17-8.1/

17.5.1.2.2 <u>Electrostatic precipitator</u>: The electrostatic precipitator is a possible CO gas cleaning device, but has found limited ferroalloy application.

17.5.1.2.3 <u>Baghouses</u>: It would be possible to use a bag collector to clean CO gas, but no applications on ferroalloy furnaces are known.

17.5.1.3 <u>Blast Furnaces</u>: Blast furnaces are also used for ferroalloy production including ferromanganese. Wet scrubbers are used in cleaning the emitted gases. High maintenance costs may attend such an operation because of the cementing properties of the fume. It also requires a largescale water-treating plant to avoid stream pollution.

For these reasons, one producer conducted pilot testing of an electrostatic precipitator preceded by a spray cooler. The collected dust

from the precipitator, being pyrophoric, was burned in a rotary kiln and the product was then briquetted.3.7.8/

One Venturi scrubber installation in England reportedly cleaned the gases from a ferromanganese blast furnace to less than 0.02 grain/cf. This unit required a pressure drop of 24 in. w.g. and a water flow of 5 gal/ 1,000 cf of gas. $\frac{10}{}$

Sonic agglomeration of fume from a ferromanganese blast furnace was investigated in 1950 but was not economically attractive. $\frac{9}{2}$

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CHAPIER 18

IRON FOUNDRIES

18.1 INTRODUCTION

Gray iron foundries range from primitive, unmechanized hand operations to highly mechanized plants in which operators are assisted by electrical, mechanical, and hydraulic equipment. Cupola, electric-arc, electricinduction, and reverberatory air furnaces are used to obtain molten metal for production of castings.

The iron melting process in foundries is the principal source of emissions. Secondary sources include materials handling, casting shakeout systems, buffing and grinding operations, and core ovens. The production process, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

18.2 FOUNDRY PROCESSES

The gray iron cupola in its simplest form is a vertical, hollow shaft having a steel shell either lined with refractory or backed by a water curtain for temperature control. A charging door located above the bottom of the cupola admits the charge which consists of alternate layers of coke, iron materials, and flux. Tuyeres, located near the bottom of the cupola, admit air for combustion. Provision is made for removing slag and molten iron from openings below the tuyeres, the iron being tapped from the bottom level and slag tapped or skimmed from above the iron.

Electric-arc and induction furnaces are mostly used to produce specially alloyed irons. Fuels are not used in the heating process in these furnaces.

18.3 EMISSION RATES FROM IRON FOUNDRIES

Physical processes, chemical reactions, and the quality of scrap affect the emissions of dust and fumes from cupolas. Physical processes include entrainment of coke, lime and oil or grease particles. Non-uniform combustion results in variations in emissions. An oily charge can evolve huge volumes of black smoke and fine chips can significantly increase metal fuming rates. Because of the wide divergence of ratios of charge materials utilized, and the varying quality of the scrap, no simple accurate estimate can be made of the nature and quantity of pollutants emitted from foundry cupplas.

Quality and composition of emissions vary between cupolas and even at intervals in the same cupola. This variation is caused by changes in iron-to-coke ratios, air volume/ton melted, and quality of scrap. A charge containing limestone with a low degree of hardness and a large portion of fines will produce a relatively high dust content in the waste gases. The abrasion resistance and ash content of the coke also has an effect on the dust emission level. Emissions from hot-blast cupolas are generally higher than from cold-blast cupolas. This is probably due to larger quantities of small steel scrap being charged into the hot-blast cupolas, and is not a direct function of the combustion air temperature, blast volume, or other operating parameters.

Emissions of sulfur compounds are usually low because sulfur content of coke is generally 0.6% or less. SO_2 concentrations have been observed to vary between 25 and 250 ppm.9/ These concentrations, when combined with moisture, can form enough sulfuric acid to corrode surrounding equipment. Fluorine and/or HF from fluorspar may be emitted, probably in small quantitities.1/

Electric-arc furnace emissions are less of a problem than cupola emissions. Since these furnaces are mostly used to produce special alloy irons, the quality of material charged is better and freer from dirt and oils. Emissions are primarily metallic fumes; the quantity emitted varies from 5 to 10 lb/ton of metal charged. $\frac{2}{2}$

Emissions from electric-induction furnaces are even less of a problem than those from the electric-arc furnaces. Use of clean scrap, minimum exposure of the metal to air while in the furnace, and uniform operation of the furnace usually result in negligible quantities of emissions. The quantity of emissions, primarily metal oxides, is about 2 lb/ton of metal charged.²/

Apart from the cupola, other sources of iron foundry emissions are casting shakeout systems, buffing and grinding, and core ovens. The magnitude of these emissions is low compared to cupolas.

Table 18-1 summarizes emissions from operations associated with gray iron foundries. Cupola emissions are dominant, and currently total about 105,000 tons/yr. No estimate of emissions from casting shakecut systems, buffing and grinding operations, and core ovens was made due to lack of emission data from these secondary sources.

TABLE 18-1

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PARTICULATE EMISSIONS

IRON FOUNDRIES

| | Source | Quantity of Material | Emission Factor | Efficiency of Control | Application of Control Ct | Net Control C _c •C _t | Emissions tons/yr |
|------|---|------------------------------|------------------------|--------------------------|---------------------------------|--|----------------------|
| I. | Furnaces | 18,000,000 tons of hot metal | 16 lb/ton of hot metal | 0.80 | 0.33 | 0.27 | 105,000 |
| | A. Cupola | · · | | | | | |
| | 1. Hot blast | | 15 lb/ton of hot metal | | | | |
| | a. externally fired | | | | | | |
| | b. recuperative | | | | | | |
| | 2. Cold blast | | 23 lb/ton of hot metal | | | | |
| | B. Electric | | | | | | |
| | 1. Arc | | 5-10 lb/ton | | | | |
| | 2. Induction | | | · | | | |
| | C. Reverberatory | | | | | | |
| п. | Materials Handling | | *5 lb/ton of hot metal | ¥0.80 | *0_2 5 | •0.20 | 37,000 |
| | A. Freight Unloading Coke and Limestone | | | | | | |
| | B. Conveyors | | | | | | |
| | 1. Transfer points | | | | | | |
| | Discharge to storage bins, silos stockpiles | | | | | | |
| | C. Elevators | | | | | | |
| | 1. Boots | | | | | | |
| | 2. Heads | | | | | | |
| | D. Sand Handling | 10,500,000 tons of sand | 0.3 lb/ton of sand | | •- | | 1,000 |
| 111. | Core Ovens | | 0.3 lb/gal of core oil | | | | |
| IV. | Shell Core Machines | | 0.35 lb/ton of cores | | | | |
| v. | Casting Shake-out System | | | | | | |
| VI. | Grinding and Buffing | | | | | | 143,000 |

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* Assumed.

383

18.4 CHARACTERISTICS OF EFFLUENTS FROM IRON FOUNDRIES

The chemical and physical properties of effluents from iron foundries are summarized in Table 18-2. Cupola dust is a very heterogeneous mixture. Particulates contain coke and flux particles, various metals, their oxides, and some sulfates. Silica content is high, particularly in the 0-10 μ fraction. Of the metals portion, 60% are oxides of Si and Fe. Significant zinc and lead oxides are also found. Other elements found in the particulates include manganese, chromium, tin, titanium, molybdenum, zirconium, nickel, copper, cobalt, and silver. $\frac{3}{4}$ About 25-30 wt. % of the particulates are less than 10 μ . The particle size distribution ranges between wide limits, depending on melt rate, coke usage, scrap formulation, and furnace operating variables. Under some conditions, over 50% of the dust may be less than 1 μ in diameter, whereas in other cases less than 5% by weight of the total particulate may be under 2 u in diameter. Older data indicate no more than 10% of the particles by weight are in the size range below 10 μ . However, later studies indicate that particle sizes under 1 μ may constitute 40% and more of the total weight. Some of the scatter between the various investigations may be a result of differences in sampling equipment and techniques and of sampling at different locations in the ductwork.

18.5 CONTROL PRACTICES AND EQUIPMENT FOR IRON FOUNDRIES

18.5.1 Electric Melting Furnaces

The extremely fine particle size and large surface area of electric-furnace fume result in discharge to the atmosphere of a plume that may not meet the visibility restrictions in some air pollution codes, even when weight requirements are met. The concentration of particulate in the effluent air from an electric-furnace fume control system may have to be less than 0.05 grain/cu ft of air if an emission is to satisfy an equivalent opacity restriction.5/

There have been several electrostatic precipitator installations to control particulates from larger furnaces and there are about 50 installations imploying fabric filter collectors. Fabric filter collectors generally result in an effluent nearly free from visible particulates. $\frac{5}{}$

The collection of fumes from the electric furnace has been done by using canopy hoods to gather the expanding, rising gas column, by local exhaust around electrodes and charging doors, and by direct evacuation of the furnace itself. $\frac{4}{2}$

TABLE 18-2

EFFLUENT CHATACTERICTICS - TROUTE TALES

| | Partin | ulate | | | | El antes de l | Motore | |
|------|---------------------|---|---|---|-----------------------------|--|--|-----------------|
| So | urce | Particle Size | Solids Loading | Chemical Composition | Particle Density | Relictivity | Content_ | <u>Toxinity</u> |
| Iron | Foundry | | | | | | | |
| Cray | Iron Cupola | : | | | | | | |
| 1. | Light-off period | | 0.001-0.36 | | | | | |
| 2. | Melting period | | 0.3-1.0 | | | | | |
| 3. | Complete heat | 2-30 < 5, 2-35 < 10, 10-40 < 20, 20-60 < 50 Average distribution: 10 < 5, 22 < 10, 25 < 20, 35 < 50 Bahco analysis: (two tes 20-54 < 5, 37-63 < 10, 52-72 < 20, 66-77 < 40 Also see Figure 18-1 | Extreme range: 0.3-15 Usual range: 1-3 Average: 1.2 sts) | Mean range: SiO ₂ : 20-40 Ca0: 3-6 Al2O ₃ : 2-4 MgO: 1-3 FeO(Fe2O ₃ ,Fe): 12-16 MnO: 1-2 Ignition loss (C,S): 20-50 Other components may be present depending on charge composition | Mcan value: 2.5- 3.1 | See Figures 18-2 and 18-3 for detailed data | | |
| 5 | ource | Solubility Wetta | Hygro bility Charact | scopic Flammability or eristics Explosive Limit | s <u>Handling Characte</u> | eristics Optics | al Properties | <u>Odor</u> |
| G | ray Iron Cupola | CaO- s. H ₂ O Difficul CaO, SiO ₂ , Al ₂ O ₃ - s. 10% HC1 | t to wet | | Abrasive, cohesiv rosive | ve, cor-Variat dent comp | ble, depen- t on charge position | |

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

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385

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TheLE 18+2 (Concluded)

| S | ource | Flo | w Rate | Temperature | Moisture Content | Chemical Composition | <u>Tozicity</u> | <u>Corroslaity</u> | <u>Odor</u> | . waamaali ty ar Lasiaalye Limita | Ontical properties |
|------------|---------------------|------------|--|-----------------|-----------------------------|---|--|--|-------------|--------------------------------------|--------------------|
| Iron | Foundry | | | | | | | | | | |
| Cray Cu | Iron pela | | | | | | | | | | |
| 1. | Light-off period | (a) | 3-16 | | | CO ₂ : 0.3-10.3 O ₂ : 10.1-20.5 N ₂ : balance | | | | | |
| 2. | Melting point | (a) | 5-27.5 | | | CO ₂ : 2-13.4 O ₂ : 6.5-19.2 SO ₂ : 0.002-0.013 | | | | | |
| 3. | Complete heat | (a) (b) | 3-30.5 Avg. 10.5 60-135 Avg. 92 | 210-1410 2 8 | Cop gas dew point, 60 | CO ₂ : 2.8-12.3 O ₂ : 11.8-12.7 CO: 0-0.1 SO ₂ : 0.002-0.013 Fluorides may also be emitted depending on flux material | SO ₂ - 5, irritant CO-100 | Potentially corrosive due to SO ₂ | | | |

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Carrier Gas



Figure 18-1. Particle Size Ranges for Dusts from Coldand Hot-Blast Cupolas.3/



• Figure shows percent water vapor by volume."

Figure 18-2 - Apparent Resistivity of Dust and Fume in Plant A.





Figure 18-3 - Apparent Resistivity of Dust and Fume in Plant B.

388

18.5.2 Cupola Furnace

Only electrostatic precipitators, high-energy scrubbers, and fabric filters are capable of removing the fine particles from cupola gases. Regardless of whether electrostatic precipitators or baghouses are used as the means of gas cleaning, it is necessary to maintain efficient secondary combustion in the cupola stacks (recuperative preheater). Otherwise, the operation of the gas-cleaning equipment is adversely affected. Maintaining a reducing atmosphere in the cupola stack will allow unburned oil vapor and tarry matter, as well as coke fines and other combustibles, to be carried over into the gas-cleaning equipment. The secondary combustion process does, however, cause an increase in the volume of the gases to be treated. $\frac{5}{2}$

General collector selections and efficiency for the various foundry operations are shown in Tables 18-3, -4, and -5 taken from "Foundry Pollution Control Manual." $\underline{1}/$

Relative cost comparisons of the various types of dust collectors applied to hot-blast cupola waste gases are presented in Table 18-6. This table gives costs with respect to a Venturi type collector which has been assigned an index value of 1.00 and does not show absolute dollar costs. $\frac{3}{4}$ Another cost comparison for different types of collectors for a 12 ton/hr cupola is given in Table 18-7. $\frac{4}{4}$ Collector characteristics for a 15 ton/hr cold-blast cupola are shown in Table 18-8. $\frac{5}{4}$ The approximate cost of cupola collector systems is shown in Table 18-9. $\frac{6}{4}$

TABLE 18-3

IRON FOUNDRY DUST COLLECTOR EFFICIENCY1/

| | | | Typical Outlet Loading (gr/sef) | | | | | | | |
|--------------------------------|---------------------|---------------------|---------------------------------|-----------------------|----------------------------|---------------------|--------------------|---|--|--|
| Application | Particle Size | Loading (gr/scf) | Wet Cap | 6 in. ΔP Scrubbers | 30-70 in. ΔP* Scrubbers | Low Eff. Cyclone | Fabric Arrester | Comments | | |
| Sh ake out | Fine to medium | 1/2-1 | x | 0.01 | x | x | x | Wet scrubbers are used because of moisture. | | |
| Sand cooler | Mediuma | 1-20 | | 0.01-0.05 | x | x | x | Wet scrubbers are used because of moisture. | | |
| Airless abrasive cleaning | Fine to coarse | 1/2-5 | x | 0.01-0.05 | x | x | 0 .0 1 | Fabric filters and wet scrubbers most common. | | |
| Grinders | Coarse to medium | 1/2-2 | x | 0.01 | x | 0.1 | 0.01 | Cyclones used when fines are not present. | | |
| Dry sand reclaimer | Coarse to fine | 10-40 | x | 0.1 | 0.02-0.05 | x | 0.01 | Disposal problems generally influence choice of equipment. | | |
| Screens and transfer points | Medium | 1/2-3 | x | 0.005-0.01 | x | x | 0.01 | | | |
| Electric-arc furnace | Fine | 1/2-2 | x | 0.2 | 0.02 | x | 0.01 | Fabric filters more frequently used than others. | | |
| Gray Iron Cupola | Coarse to fine | 1/2-10 | 0.4 | 0.3 | 0.05 | 0.4 | 0.01 | All types in use. | | |

Notes: Coarse +20 µ; Medium 2.20 µ; Fine -2 µ. * Or equivalent energy input.

X Not applicable or rarely used on this application.

TABLE 18-6

USUAL COLLECTOR SELECTIONS FOR FOUNDRY OPERATIONS1/

| | | | | Col1 | lector Types U | sed in Foundry | Industry | | |
|--------------------|----------------|------------------|----------|------------|----------------|----------------|---------------|-----------|---------|
| | Dust D | tission | Common | High Eff. | | | | Catalytic | |
| Operation . | Concentration* | Particle Size** | Cyclore | Cyclone | <u>Vet</u> | Fabric | Electrostatic | Combus. | Remarks |
| Shakeout | | | | | | | | | |
| (Mechanical) | | | | | | | | | |
| Enc. Hoad | Moderate | Fine to medium | Rare | Occasional | Usual | Occasional | Nic | No | 1 |
| Side ∺cod | Light | Fine | No | Bare | Usual | Occasional | No | No | 1 |
| Sand Handling | | | | | | | | | |
| Molding send from | | | | | | | | | |
| Shakenut | Moderate | Fine to medium | Rare | Occasional | Usual | Rare | No | Ne | 2 |
| New sand | Noderate | Fine to medium | Rare | Occasional | Usual | CccasionAl | No | No | 3 |
| Core cand | Light | Medium | Rare | Cocasional | Usual | Occasional | No | No | 4 |
| Casting Cleaning | | | | | | | | | |
| Airless abrasive | Heavy | Fine to coarse | Nc | Rare | Occasional | Usual | Hare | No | 5 |
| Blast Bomes | Moderate | Fine to medium | No | Hare | Usual | Usual | No | No | 5 |
| Tumbling mills | lieavy | Fine to coarse | No | Rare | Usual | Uşual | No | No | 6 |
| Sprie mills | Moderate | Fine to ccarse | No | Cccasional | Usuel | Usual | No | No | ε |
| Grinding | | | | | | | | | |
| Sangeing | Moderate | Medium to coarse | Frequent | Frequent | Frequent | Frequent | No | No | • |
| Swing frame | Light | Fine | Rare | Frequent | Frequent | Frequent | No | 1ko | |
| Pretable | Light | Fine to medium | Rare | Frequent | Usual | Usuel | No | No | |
| Core | Heavy | Medium to coarse | Rare | Decasional | Usual | laual | No | No | 7 |
| Melting | | | | | | | | | |
| Cupola (ferrous) | Moderate | Pine to coarse | Rare | Occasional | Frequent | Occasional | Occasional | No | e |
| Electric (ferrous) | Light | Fine | No | No | Cecasional | Frequent | Rare | No | 9 |
| Brass melting | Light | Fine | No | No | Occasional | Frequent | Rare | No | 10 |
| Pattern Shop | | | | | | | | | |
| Weedworking | Mcderate | Medium to coarse | Usual | Rare | Bare | Occasional | No | No | 11 |
| Boiler Fly Ash | | | | | | | | | |
| Chain grate | Light | Medium | 30 | Occasional | No | No | No | No | 12 |
| Spreader stoker | Medium | Medium to coarse | No | Usual | No | No | No | No | 12 |
| Pulverizer | Heavy | Medium | No | Usuel | No | No | Frequent | Nc | 12 |
| Core ovens | Comb. fumes | Comb. fumes | No | No | Rare | No | No | Frequent | |
| Paint ovens | Comb. fumes | Comb. fumes | No | No | | No | Nc | Frequent | |
| Oil burn-off | | | | | | | | | |
| Furnaces | Comb. fumes | Comb. funes | No | X0 | Rare | No | No | Frequent | |
| | | | | | | | | | |

Contentration: Light - up to 1 gr/cu ft; Hoderate - 1 to 3 gr/cu ft: Heavy - over 3 gr/cu ft
 Particle Bize: Pine - under 2 u; Medium - 2 to 20 u; Coarse - over 20 u.

Notes:

(1) Loadings increase with metal to sand ratio and with lower moisture content of sand at time of shakeout. Smoke from burning seacoal and core binders often involved as well as steam.

(2) Concentration of dust is a function of moisture remaining in sand following the shakeout operation. Traps or dry centrifugal collectors sometimes used to return coarser particles to sand system. Water from wet collectors sometimes used at mixer to permit salvage of seacoal and bond as well as retard slurry formations in recirculated water.

(3) Collection equipment for molding sand hendling system can often be used for dust collection during the shorter period of new sand handling.

(6) Dust problems very similar to those for molding sand system.
(5) Dust problems from abrasive cleaning operations was one of the earliest in the foundry industry for which high efficiency collectors were universally. applied. Airless blasting produces beaviest loads due to abrading speed. Blast rooms where shot or grit is employed exhaust much larger air volumes for the dust released.

(6) The turbling action employed has tendency to grind or pulverize sand and scale particles, producing a substantial fraction of dust loading in low micron sizes.

(7) Collectors are indicated wherever production core grinders are used.

(6) Wet primary collectors on top of curola stack used where damage to roof or excessive cost of removal of cinder accumulation is main consideration. Fabric arresters or electrostatic precipitators selected in most critical air pollution areas where visible effluent must be minimized.

(9) While wet collectors have been usual selection in past, the fabric arrester appears the more usual selection for future installations due to its ability to provide a clear discharge. Relatively low temperatures make cost of such installations reasonable.
 (10) Collection of zino owide is receiving increasing attention where high zinc brass alloys are melted. Pabric arresters provide high efficiency at

ressonable cost where gas temperatures are moderate as from crucible, electric, and induction melting furnaces. High stack temperatures of reverberatory furnaces make problem more complex and collection equipment expensive.

(11) Cyclone or dry centrifugal usual selection. Can be followed by fabric collectors where recirculation of cleaned air is indicated.

(12) Fly ash from boiler stacks is often overlooked by the foundry industry but can be source of nuisance attributed to other stack discharges. High efficiency dry centrifugals provide degree of collection generally acceptable by present-day standards. High temperature and corrosive gases make better collection very empensive.

TABLE 18-51/

EFFICIENCY TESTS OF DRY MULTIPLE CYCLONES FOR FIVE DIFFERENT INSTALLATIONS

| | Dust La | Dading | |
|-----------------------------|--------------------------------------|---------------------------------------|------------------------------|
| Melting Rate (ton/hr) | Collector Inlet (1b/1,000 1b)* | Collector Outlet (1b/1,000 lb)* | Overall Efficiency (%) |
| 14.4 | 1.053 | 0.335 | 69 |
| 21.6 | 1.324 | 0.515 | 61 |
| 15.5 | 1.040 | 0.300 | 71 |
| 22.5 | 0.855 | 0.288 | 66 |
| 14.7 | 1.061 | 0.262 | 75 |

1

* Pounds of particulate matter per 1,000 lb. of flue gas.

TABLE 18-53/

COST COMPARISON FOR VARIOUS DUST COLLECTORS FOR CLEANING WASTE GASSS OF A HOT-HLAST CUPOLA

(Index value 1 for Venturi tube dust separation) Waste gas quantity to be cleaned: 7,350 soft Depreciation: 20% per annum

| Plar | <u>nt</u> | Venturi Tube Dust Collector | Wet Dust Collector, Simple Design | Dry Electr Offer 1 | o-Precipitator Offer 2 | Wet Electro- precipitator | <u>Fabric Du</u> Offar 1 | st Collector Offer 2 |
|--------------------------------|---------------|--------------------------------|---|-----------------------|---------------------------|------------------------------|-----------------------------|-------------------------|
| Guaranteed cle | a.p. | | | | | | | |
| dust content: | 15/nr | 7.70 | 7.70 | 3.85 | 5.70 | 3.85 | 5.25 | 3.30 |
| | gr/scf | 0.122 | 0.122 | 0.051 | 0.09 | 0.061 | 0.064 | 0.052 |
| Initial invest | ment costs | | | | | | | |
| (index value |) | 1.03# | 1.04* | 3.24 | 1,60 | 1.59* | 1.45 | 2.36 |
| Depreciation a | nd interest | 1.025 | 1 04# | | 1 65 | . 50* |) <i>45</i> | 0.70 |
| (Index value | , | 1.00* | 1.04- | 3.24 | 1.00 | 1.59* | 1.45 | 2.30 |
| Power consumpt (index value | ion) | 1.00 | 0.62 | 0.23 | 0.36 | 0.24 | 0.65 | 0.43 |
| Maintenance, s | ervicing, | | | | | | | |
| tralization | (index value) | 1.00 | 1.05 | 0.62 | 0.530 | 0.83 | 0.55 | 0.54 |
| Costs per oper | ation hour | | | | | | | |
| (index value | } | 1.00* | 0.88 * | 1.67 | 1.01 | C.96* | 1.14 | 1.50 |

Without facilities for water supply and settling tank.
 Table does not include erection costs.

TABLE 18-74/

APPROXIMATE COST OF CONTROL EQUIPMENT (12 ton/hr cupola)

| Weather Cap | \$ 30,000 |
|-------------------------|-----------|
| Dry Centrifugal | 60,000 |
| Medium Pressure Wet | 90,000 |
| High-Temperature Fabric | 150,000 |
| High-Energy Wet | 170,000 |

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TABLE 18-85/

| COLLECTOR | CHARACTERISTICS | FOR 15 | TONS/HR | COLD-BLACT | CUPOLA |
|-----------|-----------------|--------|----------|------------|--------|
| | OPERATED | ON ALT | ERNATE D | AYS | |

| | | | 9 | | | | | | | | |
|---|---|--|---|---|---|---|---|----------------------------|---------------------------------------|------------------------------------|--|
| Assume Blast Volume Charging Door 4:) sq Total Gas Volume | . ft. at 300 f | = 8,000 cfm pm = 12,000 cfm = 20,000 cfm = 62,500 cfm | at 70°F at 70°F at 70°F at 1,200°F | | | | Assume Emissions 15 Consisting of Cinders 8 = Dust 4 - Fumes 3 = | | | | |
| Collector Type | Discharge Gas Temperature (°F) | H ₂ O Vapor at Exit Temp. Added for Cooling (cfm) | Total Vol. at Exit Temp. | Lower Effective Collection Range (µ) | Collector Pressure Drop W.G. (in.) | Probable H.P. Note 1 Exit Temp. | <u>70</u> | Water Required (gpm) | Probabl Note 2 (grains/ scf) | e Emission Grains/cfm at 500 | Approx. Instal. Cost on Existing Cupolas |
| Wet ćap | 4 00- 700 | 9,850 | 47,850 cfm at 550°F | 44 | 0.25 | | | 200 | 0. 4 5 | 0.25 | \$ 35,000 |
| Low pressure drop centrifugal with cooling tower | 350-500 | 10,200 | 43,600 cfm at 425°F | 30 | 1.5 | 24 | 40 | 34.3 | 0.36 | 0.20 | 50 ,00 0 |
| With heat exchanger | 600-700 | None | 41,800 cfm at 650°F | 30 | 1.5 | 34 | 71 | 0 | 0.45 | 0.25 | 150,000 |
| High eff. dry centrifugal | 350-500 | 10,200 | 43,600 cfm at 425°F | 7 | 3.0 | 34.3 | 57 | 34.3 | 0.27 | 0.15 | 55,000 |
| Wet collectors | 125-190 | 9,750 | 33,750 cfm at 175°F | 1 | 5.0 | 52.5 | 63 | 48-100 | 0.11 | 0.062 | 75 ,000 |
| Electric precipitator | 250-300 | 10,200 | 38,000 cfm at 275°F | 0.1 | 0.5 | 18 | 25 | 41 .2 | 0.039 | 0.021 | 100,000 |
| Fabric arresters Synthetic faoric | 250-275 | 9,600 | 36,800 cfm at 260°F | 0.1 | 4.0 | 4 2.5 | 57.5 | 41.8 | 0.0096 | 0.0053 | 75,000 |
| Glass fabric | 400-500 | 10,200 | 44,200 cfm at 450°F | 0.1 | 4.0 | 40.5 | 69.5 | 33.2 | 0.0206 | 0.0114 | 75,000 |

Note 1: Horsepower calculations assume pressure loss through ducts and cooling tower of 2 in. added to stated collector loss except for wet cap (5 in. with heat exchanger).

Note 2: Lower than the usual boiler stack acceptable emission regulations of 0.257 grain/cu ft at 500°F (0.465 grain/scf).

TABLE 18-9

COMPARISON OF CUPOLA DUST CONTROL SYSTEMS⁶/

| Equipment | Initial Cost Installed In \$1,000's ^a / | M & O Cost/Year In \$1,000's ^{b/} | Outlet Emission, <u>Grain/scf^{C/}</u> | Connected Horsepowerd/ |
|----------------------------|--|---|--|---------------------------|
| Wet cap | 50 | 3 | 0.5 | 20 |
| Multitube cyclone | 150 | 10 | 0.3 | 100 |
| 6 in. ∆ P scrubber | 150 | 10 | 0.2 | 100 |
| 70 in. ∆ P scrubber | 225 | 25 | 0.05 | 325 |
| Fabric filter | 250 | Wide variations | < 0.02 | 100 |

(Two No. 8 Cupolas -- 7,800 cfm blast air alternate usage -- 1 grain/scf dust load)

a/ With water clarification system and ductwork, electrical, etc.

- b/ Maintenance and operating cost per year, including power costs for 16 hr/day operation, but not depreciation.
- c/ Outlet emission also dependent on particle size distribution, which in turn is dependent on scrap quality, etc.
- d/ Connected horsepower, including pump for wet units.

18.5.3 Electrostatic Precipitators

Electrostatic precipitators have failed to attain consistently high collection efficiencies due to wide variation of gas stream conditions. To satisfactorily apply electrostatic precipitation to foundry-cupola-fume collection, it is essential to determine the temperature at which the peak resistivity of the fume occurs, and to design the gas conditioning system to provide a gas temperature well away from that at which the resistivity reaches its maximum. Electrostatic precipitators have been employed in Europe to a greater degree for cupola operations and utilize both wet and dry electrode cleaning techniques. Data on some of these units are given in Table 18-10.3/

18.5.4 Fabric Filters

There are several installations employing completely automatic, tubular dust collectors using synthetic filter bags in conjunction with cooling of the hot gases prior to filtration. The primary difficulty in their use arises from poor control of inlet gas temperature. When it is too high, the bags burn out; when it is too low, the fabric blinds from condensation of water vapor.5/ The fabric collector temperature is generally limited to the capability of the fabric media and, at present, glass is operable up to 550° F.

Fabric filters are being used increasingly for cleaning cupola gases whenever high collection efficiencies are desired. Operating characteristics for three installations are given in Table 18-11. $\frac{3}{2}$

The temperature of the gas stream from the top of a cupola may be as high as 2200°F. Therefore, the gases must be cooled, prior to entering the baghouse. Cooling can be effected by evaporative water or other means of heat exchange or by dilution with ambient air.

It should be remembered that if fluorspar is used as a fluxing agent in the cupola, this can be damaging to glass-fiber bags.

General cost data for fabric filters given in Appendix A indicate that an installed cost of 3.50/acfm would apply to a unit handling about 10,000 acfm. This decreases to less than 2.00/acfm for 50,000 - 100,000 acfm.

Installed cost of baghouses ranges from 0.93 to 3.50/acfm. Installation expense ranges from 12-43% of the FOB price with the average being 25%. Annual operating and maintenance expense ranges from 5-16% of the installed cost with an average of 11.6%.

TABLE 18-10

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CUPOLA PLANTS WITH ELECTRO-PRECIPITATORS³/ (European Installations)

| <u>No</u> . | Furnace | Melting Rate (T/hr) | Filter | Type of Gas_ | <u>Cas</u> Before Cooler (°F) | Temperatu Before Filter (°F) | ure After Filter _(°F)_ | Clean Gas Volume scfm Dry | Dust_Co Raw Gas Grain/scf Dry | Clean Gas Grain/scf Dry | Collection Efficiency (%) | Dust Emission in the Atmosphere (Lb/Hr) | Pressure Loss of the Unit (In. W.G.) | Water Requirement (Circulation and Make-Up Water) (gpm) |
|-------------|---|---------------------------|--------|----------------------|--|---------------------------------------|----------------------------------|---------------------------------------|---|----------------------------------|---------------------------------|---|---|--|
| 1 | Hot Bl a st | 13.2 | Dry | Тор | | Up to 750 | App. 570 | 6,500 | 7-9.2 | 0.05 - 0. 0 7 | 98.5- 99.7 | 3.26 | 1 | |
| 2 | Hot Blast | 16.5 | Dry | Тор | 930- 1,110 | 570 | * | 6,800 | Up to 4.3 | 0.065 | 98.5 | 3,79 | * | |
| 3 | Hot Bl as t | 6.6 | Dry | Waste | * | 149 | * | 8,2 0 0 | * | * | 97.6 | * | • | |
| 4 | Hot Bl a st | 6.6 | Wet | Top Plus Waste | * | 140 | ¥ | 4,800 | 1.22 | 0.021 | 98.3 | 0.845 | * | * . |
| 5 | Hot Blast | 8.8 | Wet | Waste | 390 | * | 104 | 19,000 | 0.70 | 0.033 | 9 5.0 | 5.30 | 6.3** | 264 |
| 6 | 2 Hot Blast Units | 20.0 | Wet | Waste | 750-840 | * | * | 29,000 | 5.5 | 0.043 | 9 8.0 | 11.00 | * | * |
| 7 | Hot Blast Exter- nally heated | 19.0 | Wet | Тор | 680 | * | 155 | 7,200 | 3.09 | 0.037 | 98 .8 5 | 2.26 | 6.5 | 200 |
| 8 | Hot Blast | 13.4 | Wet | Top Plus Waste | 500 e | * | 131 | 9,200 | 4.65 | 0.062 | 97.0 | 6.17 | 3.5 | 138 |

* No data available.

** Pressure loss inclusive connecting pipelines.

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- TABLE 18-11 .

CUPOLA DUST REMOVAL INSTALLATIONS WITH FABRIC FILTER3/

| | | | | | | | | | | | Dust Content | t | - | | |
|-------------|---------------|---------------------------|--|--|--------------------------------------|--------------------------------------|-------------------------------|--------------------------------------|--|-------------------------------------|--|---|---------------------------------|---|--|
| <u>No</u> . | Furnace | Melting Rate (T/hr) | Dust Removal Plant | Pressure Drop In. W.G. | <u>Gas</u> Cupola Exit (°F) | Temperato Filter Inlet (°F) | ure Filter Exit (°F) | Gas Q <u>Befor</u> <u>scfm</u> | uantity <u>e Filter</u> scfm <u>Dry</u> | After Cupola Grain/scf Dry | Before Fabric Filter Grain/scf Dry | After Fabric Filter Grain/scf Dry | Collection Efficiency (%) | Dust Discharge in Atmosphere (1b/hr) | |
| 1 | Cold Blast | 5.0 | Waste gas cleaning closed glass fabric filte | 4 r | 1,380 | 44 6 | 2 3 0 ^{**} | 8,400 | 4,500 | * | 1.19 | 0.0015 | 99.83 | 0.073** | |
| 2 | Hot Blæst | 33.0 | Top gas cleaning (part of gas quanti- ty) closed glass fabric filter | About 14 in. W.G. filter plus pipeline | 930 | 3 9 0 | 248 | Approx. 13,000 | 7,300 | 3.52 | 2 .84 | 0.041 | 99. 75 | 0.530 | |
| 3 | Hot Blast | 17.6 | Waste gas cleaning, open glass fabric filte | 3-6 r | 1,830 | 480 | ¥ | €5,000 | 38,000 | * | 0.35 | * | 99.0 | | |

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* No data available.

** Before cleaned gas measuring point after fabric cleaner, approximately 1,200 ccfm false air was drawn in.

18.5.5 Wet Scrubbers

Various types of wet scrubbers are widely used for control of cupola emissions.⁹/ The SO_2 content of the cupola waste gases must be considered in designing a wet scrubber system. It is often overlooked that it is not sufficient to neutralize the scrubbing water to a pH value of 7 so that it enters the scrubber in a neutral state. An acidic reaction occurs after it contacts the cupola waste gases and a serious corrosion danger exists. The wash water thus should be adjusted to a pH of 9 so that in the gas washer itself the acidic range is not reached.

Although the wet-scrubber systems absorb some of the SO_2 from the waste gases, the odor of SO_2 may be more perceptible than with other collection systems because wet scrubbing lowers the temperature of the gases which causes a decrease in plume rise.³/ The carbon content of the dust makes wetting more difficult and thus puts higher requirements on wet scrubbers.

Wet scrubbers pose the problem of sludge removal and potential water pollution which must be taken into account in computing the cost of this type of collector.

Wet caps have been in common use on cupola gases but these only remove the coarser particles and are usually not adequate for compliance with local codes.

18.5.6 Dry Cyclones

Centrifugal dust collectors are used in many ways in the foundry industry. They can function satisfactorily up to temperatures over 800° F. They are used for cupola waste gases provided the fine grain proportion in the cupola dust is not too high. The collection efficiency may run 80-90%. However, the raw gas dust content and its particle size distribution should be determined by measurement to ascertain the efficiency that can be expected for any specific application.³/ The results of five tests on different installations using dry multiple cyclones are given in Table 18-5.¹/

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CHAPTER 19

SECONDARY NONFERROUS METALS INDUSTRY

19.1 INTRODUCTION

The secondary nonferrous smelting and refining industry comprises establishments primarily engaged in recovering nonferrous metals and alloys from scrap and dross. The secondary nonferrous industry, as used here, will include copper, lead, zinc, and aluminum recovery. Copper, including brass and bronze alloys, and lead production from secondary smelters account for about 50% of the yearly total production of these metals in the United States. $\frac{5}{7}$

The nature of furnace operations in this industry is such that emissions vary widely during the cycle from charging the scrap to pouring the melt. Peak emission surges occur in nearly all the furnace operations. The principal emission from the secondary copper, lead, zinc, and aluminum industries is particulates--smoke, dust, and metallic fumes. Small amounts of sulfur oxide may also be evolved. Table 19-1 summarizes particulate emissions from the secondary nonferrous metals industry.

The production processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for the secondary copper, lead, zinc, and aluminum industries are discussed in the following sections.

19.2 SECONDARY COPPER SMELTING AND REFINING

Obsolete domestic and industrial copper-bearing scrap are the basic raw materials for the secondary copper industry. The overall industry is composed of many groups, including dealers, collectors, foundries, ingot makers, and smelters. Scrap as received is frequently not clean and may contain any number of metallic and nonmetallic impurities. These impurities can be removed by mechanical methods, heat methods, or gravity separation. $\frac{1}{2}$

A number of types of furnaces are used for the melting, smelting, refining, and alloying of the processed scrap metal. Reverberatory, rotary, or crucible furnaces are used, depending on the size of the melt and the desired alloy. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller, whether electric or nonelectric, and are used principally for small quantities of special-purpose alloys. $\underline{l}/$

19.2.1 Emission Sources and Rates

Emissions that may contribute to atmospheric pollution are released from various operations in secondary copper smelting and refining. Included are the handling and concentrating of raw materials (i.e., scoop processing); the burning of oil, grease and insulating materials; the refining and concentrating of low-grade scrap and metallurgical wastes in a blast furnace; plus the firing up, charging, alloying, and pouring operations connected with the furnace. The types and ranges of emissions depend on factors such as fuel, composition, and melting temperature of the alloys, types of furnaces, and operating factors such as methods of charging, melting, refining, removing slag, adding alloy metals, and pouring.

Individual emission sources in the various operations mentioned in the preceding paragraph are discussed in more detail in the following sections.

19.2.1.1 <u>Scrap Processing</u>: The mechanical methods of processing scrap cause few or no pollutant problems, while pyrometallurgical processes all create air pollutants to some degree.

Sweating is carried out at medium temperatures to remove lowmelting-point metals such as lead, solder, and babbit metal from radiators and other scrap. Metal fume losses are very low, but fume and combustion products of antifreeze residues, soldering salts, and hose connections may be released.2/

Burning also removes insulation that was not mechanically stripped from wire or cable. Source tests indicate that uncontrolled emissions can be a dense black smoke containing particulate matter in concentrations as large as 29 grains/scf at 12% CC₂. $\frac{3}{2}/$

A heated rotary kiln is often used to vaporize excess cutting fluids from machine shop chips or borings. This drying operation creates considerable amounts of hydrocarbons. The nature of the combustion process that eliminates these hydrocarbons will determine whether fumes and soot escape or whether emissions are clean and fully oxidized. The vaporized fumes must be burned in afterburners to oxidize the hydrocarbons and prevent air pollution.

The blast furnace (or cupola) produces a concentrated product called "black copper" or "cupola melt" from low-grade materials such as slag and skimmings. The product actually has variable proportions of copper, tin, lead, zinc, nickel, and other metals. The charge is introduced at the top of a vertical furnace, along with coke for fuel and a reducing agent, plus limestone or other materials for fluxing. Slag and concentrated alloy are tapped near the bottom of the furnace. Slag is often tapped continuously while metal is obtained at intervals. A large volume of air is introduced through tuyeres spaced around the periphery of the furnace. Temperatures in the smelting zone are sufficient to reduce oxides to molten metal. These temperatures drop rapidly while the gas rises through the charge material to the top of the furnace. The particulate matter and gases emitted from the blast furnace are likely to be rather variable because of the large variety of scrap, slag, skimmings, and spills that are processed. $\frac{1}{2}$

19.2.1.2 <u>Smelting and Refining</u>: Direct-fired (or open-flame) furnaces such as reverberatory and rotary types will produce larger concentrations of zinc oxide fume than will indirect-fired furnaces such as crucibles and electric-induction furnaces.

Since the hot, high-velocity combustion gases come into direct contact with the metals in the charge, metal losses are high when there is an appreciable proportion of zinc in the alloy. The direct-fired type of furnace is often more difficult to hood effectively. Except for the physical arrangements, however, the actual smelting and refining that produce high-quality ingots are similar in both direct-fired and indirectfired furnaces.

A number of factors in furnace operation can affect the type and quantity of emissions. Among these are the type of fuel used, control of air-fuel ratios, control of temperatures, the order of adding metals to the furnace, provision of proper slag cover, and good housekeeping in the furnace area. 1/

19.2.1.2.1 <u>Heating</u>: Fuel used in the various furnaces can have important effects on the types of emissions from the plants. Electric furnaces do not add any objectionable emissions and, what is more important, they do not have the effects of hot gases sweeping across the surface of the melt. Indirectly heated furnaces also avoid this sweeping effect.

The choice of oil or gas as a fuel is usually made on the basis of lowest cost for a given heat content, but gas is often more trouble-free, both in minimizing pollution and in maintaining proper combustion conditions. When oil is used, very careful control of the air-fuel ratio is necessary to reduce pollutants such as soot, smoke, and unburned fuel particles to a minimum.

19.2.1.2.2 <u>Charging</u>: The type and condition of the scrap raw material are factors that may affect the amount and character of each emission. Scrap that is cily, greasy, or dirty may have these contaminants removed by preliminary treatment, or the operations may be done directly in the main furnaces. In either case considerable smoke emissions are apt to occur. With combustion there will be emissions of the normal products of combustion plus unburned hydrocarbons, fly ash, and dust in the stack gases. When the scrap material being used has relatively large proportions of lowvolatility constituents such as zinc, metallic oxide fume will be in the stack gases of the furnaces.

During the charging cycle, emissions are also dependent upon factors such as location of the charging doors, the percentage of volatile alloy constituents (principally zinc), and upon whether the entire charge is made at the beginning of the heat or at intervals during the melting stage. Overhead charging doors in reverberatory furnaces will permit large losses of hot gases, fly ash, and fume into the plant when charges are loaded at intervals during the heat. Effective hooding of overhead charge doors poses difficult problems because of the necessity of providing access for loading equipment into the space between the charge door and the hood. End and side doors are not as vulnerable to the loss of furnace gases, especially end doors that load the charge in the direction of the induced flow of the furnace gases.

Some of the greatest air pollution problems occur during charging. It is physically difficult to place the entire charge into the furnace at one time. Later charges are, therefore, added to molten metal, and the combustible materials (and plain dirt) are emitted in tremendous bursts that are almost impossible to burn completely or even to contain within the capacity of the collection system. $\underline{l}/$

19.2.1.2.3 <u>Melting</u>: After material is charged, all doors and openings of the furnace are closed. Burners are set to maximum efficiency for fastest melt-down and superheating of the molten metal. Supplemental oxygen may be used at this time. Excessive fuming may occur whenever zinc is present or combustible contaminants are present in the charge. The latter may include items such as grease, oils, and rubber. Much of the combustible emissions may be controlled by proper draft regulation and burner setting. The lack of uniformity in scrap, however, makes this control difficult.

19.2.1.2.4 <u>Refining</u>: Refining, a chemical process of purification, is that cycle of the heat in which impurities and other constituents of the charge, present in excess of specifications, are reduced or removed. Many different processes are employed to bring the composition of the melted scrap within permissible limits. Refining methods vary with the type of furnace, the type of alloy being produced, the condition or availability of different types of scrap in the charge, and the experience and opinions of the personnel involved. The chemicals used in refining, commonly termed fluxes, may be gaseous, liquid, or solid. By far the most extensively used gas for refining is compressed air (oxygen). Blowing air into the molten bath of metal causes a selective oxidation of metals in accordance with their position in the electromotive series. Iron, manganese, silicon, and aluminum are high in the series and are, therefore, oxidized in preference to copper, tin, and other metals. Part of the zinc is oxidized, but this is an unavoidable loss. Below certain concentrations, the undesirable metals are oxidized simultaneously. Solid fluxes as a whole do not contribute to air pollution, except in releasing impurities that must be removed from the alloy in one way or another. Flux covers, which are eventually skimmed off, have a generally beneficial effect on the quality of stack emissions by preventing excessive volatilization losses. Some of the more common fluxes are broken glass, charcoal, borax, sand, limestone, iron scale, soda ash, and caustic soda. $\frac{1}{}$

19.2.1.2.5 Alloying: Modification of the alloy during the heat by addition of virgin metal or specialized scrap may lead to an increase in fume emission. Excessive formation of fume becomes greater as the percentage of volatile constituents increases. Owing to its very low boiling point, zinc is the most serious problem.

19.2.1.2.6 Pouring: Physical methods of pouring the molten alloy into molds vary. The furnaces may be tapped directly to a moving, automatically controlled mold line, the alloy sometimes filling one or more molds at once and then being shut off while a new set of molds moves into position on the endless conveyor. In other variations, the metal is tapped from the furnace into a ladle, which should have a slag cover, especially for highzinc alloys. The molten alloy is then moved to a mold line, which may be movable or staticnary.

Metal-oxide fumes are produced as the hot molten metal is poured through the air, even over these short distances. Other dusts may be produced, depending upon the type of linings or coverings associated with the mold as it is filled with hot molten metal.

19.2.1.3 Summary of Emission Rates: Table 19-1 summarizes emission rate data for the various sources in the secondary copper-production cycle. Materials-preparation processes account for about 70% of the particulate emissions. The wire-burning step of the materials preparation emits about 41,000 tons/year. Emissions from smelting and refining furnaces total about 17,000 tons/year.

PARTICULATE EMISSIONS SECONDARY NONFERROUS METALS

| | | Source | | Quentity of Meterial | Emission Factor | Efficiency of Control Se | Application of Control Ct | Net Control C _c .C _t | Emission tons/yr |
|-----|------|--|-----------|-------------------------|----------------------------------|--------------------------------|---------------------------------|--|-----------------------|
| _ | _ | | | <u></u> | | | | | |
| 1. | Cop | çer | | | | | | | |
| | A. | Materials Preparation | | | | | | | |
| | | 1. Wire burning | 300,000 | tons insulated wire | 275 1b/ton | | | | 41,000 |
| | | 2. Swenting furnaces | 64,000 | tons, auto radiators | 15 . 50 lb/ton comp | 0.95 | 0.20 | 0.19 | 2002 3 307 |
| | | 3. Dist. Idrnmers | 287,000 | tons, scrup and residu | e So 16/ Son Strap | 0.50 | 0.78 | 0.69 | 2,000 |
| | Э. | Smelting and Refining 1. In secondary smelters, etc. | 1,170,000 | tons Scrap | | | | | |
| | | (a) coarge (b) refine | | | 30 IE/Con charge | | | | • |
| | | (c) pour | | | 0.6 | | | | |
| | | • • | | | 70 | 0.05 | 0,60 | J.57 | 17,000 |
| | | | | | Total from S | econdary Cop | oper | | E0,700 |
| II. | λŪ | minum | | | | | | | |
| | A. | Sweeting Furnaces | 500,000 | tons of scrap | 32 lb/ton scrap | 0.95 | 0.20 | 0.19 | 6,000 |
| | _ | | | | | | | | |
| | ₽. | Sefining Firnsees | 1,015,000 | tons screp | 4 It/ron corm | 0.55 | 0.60 | 0.57 | 905 |
| | | 2. Pot (crucible) | | | 2 lb/ton scrap | | | | |
| | | 3. Induction | | | | -+ | | | |
| | c. | Fluxing | 136,000 | tons Cl used | 1,000 lb/ton Cl used | | | 0.25 | 51,000 |
| | £. | Dross Processing 1. Hot process | | | | | | | |
| | | e. Milling process | | | Total from S | econdary AL | minum | | 57,900 |
| | | | | | | | | | |
| ш. | Le s | d Purraces | | | | | | | |
| | Α. | Br. | 53.000 | tons screp | 0.8 lb/ton screp | 0.95 | 0.95 | 0.90 | < 100 |
| | 5. | Blast Firnace | 119,000 | tons scrap | 190 " | 0.35 | 0.95 | 0,90 | 1,000 |
| | с. | Reverteratory | | | 130 " " | | | | |
| | D. | Rotary Reverberatory | | | 70 " | | | | |
| | | Average, reverberatory | 554,00C | tons scrap | 100 lb/ton screp Total from S | 0.95 econdary les | 0.95 Id | 0,9C | <u>3,000</u> 4,000 |
| | | | | | | | | | 1,000 |
| rv. | Zir | ic . | | | | | | | |
| | Α. | Sweating | | | | | | | |
| | | 1. Metallic scrap | 52,000 | tons scrap | 12 lb/ton charge | 0.95 | 0.20 | 0.19 | 300 |
| | | Residual scrap | 210,000 | tons scrap | 30 | C.95 | 0.20 | 0,19 | 2,600 |
| | В. | Distillation Furnace | 233,000 | tons Zn recovered | 47 lb/ton Zn | | | | |
| | | 2. Miffle | | | 45 lb/ton Zn | | | | |
| | | Average, distillation | furnaces | | 45 15/ton 2n | 0.95 | C.60 | 0.57 | 2,200 |
| | | | | | Total from S | econdary Zir | 10 | | 5,100 |
| | | | | | Total from S | econdary Nor | nferrous Meta | als | 127,/00 |

19.2.2 Characteristics of Effluents

The chemical and physical properties of effluents from secondary copper production are summarized in Table 19-2. The metallic fumes emitted from the smelting and refining furnace are submicron in size. The fumes also readily agglomerate, and the exhaust plume is usually opaque.

19.2.3 Control Practices and Equipment

19.2.3.1 General Control Practice: Air pollution control practices for the secondary nonferrous metals industry were investigated in a 1969 study done by the U. S. Department of Commerce. $\frac{6}{}$ While the study did not pertain solely to secondary copper, the results will be summarized in this section for convenience.

19.2.3.1.1 <u>Baghouses</u>: Most smelters observed had completely dry collection systems. Water quenching was not used; instead, outside air was mixed with the hot flue gases.⁶/ This latter procedure has the drawback of requiring a design to accommodate not only the furnace flue gas, but also the volume of outside air injected into the system. In addition, there is considerable fire hazard. The hot flue gases are often deficient in free oxygen, and if the furnace charges contain oily scrap or other combustible materials, admission of oxygen-rich outside air can cause low-order explosions and fire.⁶/

Of the 23 plants considered in the Commerce Department study, eight had efficiently functioning dry baghouse systems. One had an equivalent system but used some water as a gas cooling spray before the baghouse. Most of these plants were brass or bronze ingot producers and lead smelters. In addition to baghouse systems, and at other plants, small modular baghouses of simple design are used to filter gases and in-plant air from ducted hoods over kettles, furnace charging doors, open hearths, and slag melt draw points. $\frac{6}{7}$

19.2.3.1.2 Electrostatic precipitators: Electrostatic precipitators are used to clean furnace flue gases. This system of gas cleaning is efficient when properly designed and engineered for the individual plant. Collection efficiency drops when residence time is insufficient. Surges in furnace flue gas volume can easily cause too short a residence time unless equipment is designed for capacity to accommodate peak volumes and peak loading of flue gases. Efficiency is also temperature sensitive owing to the relation of temperature to resistivity. $\frac{6}{}$

| TABLE 1 | 9-2 |
|---------|-----|
|---------|-----|

EFFICENT "MARACTERISTICS - SECONDARY NONFERROUS METALS"

A. <u>certiculate</u> (fart 7)

| <u>Star</u> ee | Pa | rticle Size | Solids Loading | Chemical Composition | Particle Density | Electrical Resistivity | Moisture Content | Toxicity |
|-------------------------------|------------------------------------|---|--|--|------------------|---|------------------|--|
| Secondary Nor Game is Mite | 1- | | | | | | | |
| L. Certer | | | | | • | | | |
| λ. Fue | iirida Me C | tallic fume .03-0.5 (unag- lumerated) | 2-4 | Typical constituents: 2n0, Pb0, C, fly ash, and a variety of sec- ondary constituents representing charge composition. For spe- cific alloys the follow- ing are representative. 2n0 and Pb0 distribu- tions: <u>Copper-Brass Alloy</u> Zn0: 14-95 Avg 59 Pb0: 5-29 Avg 10.5 <u>Copper-Nickel Alloys</u> Zn0: 54-87 Avg 57 <u>Copper-Lead Alloys</u> Zn0: 5-5 Pb0: 51-52 Avg 57 Secondary Constituents: Tin, cadmium, copper, silice, and carbon | | See Table 19-3 for fuller statement of interrelated variables | | 2n - 15 Pb - 0,15 |
| 3. Ing. Pr. tis | nt Me Diac- C Dh E | tallic fume 103-0.5 (unag- lomeratet) | 1-20 (nigh values when compressed air is injected into bath) | Cypical composition range of baghouse catch: Zn: 45-77; Pb: 1-12; Sn: 0.3-9; Ju: 0.05-1.0; S: 0.1-0.7. | | | | |
| 11. (A A) | Ver ra Mea (u | y fine; typical nge: 0.07-0.4 n size; 0.3 naggimerated) | 2-12 (bløst furnace) 1-6 (rever- terstory furnace) | Po0, SnO, 2nO, tar, fly ach, coke dust, sul- fates, sulfideg | | | | Zn0 - 15 |
| 111 . %ins | | | | | | | | |
| २८ ७४ हो इ हा हा | 55 6300 44 54 55 55 | | | | | See Figures 19-1 and 19- for details | -2 | |
| 1. | Notfie furnace | 0.03-0.5 (unegglomer- ated) | 0.A-: | Zn, Cl ₂ , ZnO NH ₂ Cl, Al ₇ O ₅ Oxides of NG, Sn, H, St, Cc, Na (dependent on charge composi- tion and quantity of flux) | | | | |
| ċ. | Brverbor- slory fungace | No detailed data; probably about 1 g | 0.8-1 | Similar to Rattle furnace | | | | |
| IV. Alumir | nus. | <pre>100 < C (cryplite fluxing, electron photomicrograph) 100 < 1 (chlorinat process)</pre> | 0.1-2.0 ting | Highly variable, may con tain AlpCy, AlCly, ReC fluorides, caldes of alkali metals |]- ., | | | Toxic due to flucrides a chlorides |

• See Ciding Rey, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

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TABLE 19-2 (Continued)

A. <u>Electicalate</u> (Fart II)

| <u>Source</u> Secondary Non- ferrous Mutals | <u> Solubility</u> | Wettability | <u>Hygroscopic Characteristics</u> | Flammability cr Explosive Limits | Handling Characteristics | Optical Properties | <u>Odor</u> |
|---|--------------------|------------------|---|-------------------------------------|--------------------------|--------------------|-------------|
| 1. Copper - | s. el. alk. | | Absorbs water, tends to lump and/or mass | · | Agglomerates, cohesive | | |
| 2. Lead | • | Difficult to wet | | | 80 11 | | |
| 5. 2150 | н | | | | 97 PL | | |
| 4. Aluminum | | | | | Abraalve, corrosive | | • |

B. Centier Jas

| Scurce | Flow Rate | Temperature | Content | Chemical Composition | Toxicity | Corresivity | Otor | Explosive limits | Optical Properties |
|----------------------------------|------------------------------------|---|---------|---|----------------------------------|-------------|------|------------------|-----------------------|
| Secondary Non- Serrous Metals | | | | | | | | | |
| 1. Copper | | | | | | | | | |
| A. Foundries Alley Type | | | | | | | | | |
| 1. byasa | | | | | | | | | |
| n. üscil- lating burrel | (m) 3.1. (p) 0.450. | 270-330 | | Typical composition (similar for all furnace types) | 80 ₂ - 5, irritant | | | | |
| furnace t. Hotating barrel | (@)7.6♥ (5)0,390♥ | 560 | | Firmace Cutlet Cl2: 10.6-14 C2: 1.1-4.9 | | | | | |
| furnace c. Tilting- kettle | (*) 18.7-22.2* (%) 0.996-1.344* | 360-400 | | CC: 0-3.3 N ₂ : t alan ce SC ₂ : trice | | | | | |
| furnece d. Cruci- ble | (a) 3-3.1* (b) 0.34-0.4* | 400-450 | | <u>Stack</u> CC ₂ : 0.4-2.4 C ₂ : 16.8-19.8 | | | | | |
| | | | | CC: C M ₂ : balance SG ₂ : trace | | | | | |
| 2. Websi | | | | - | | | | | |
| a. Pit cruci- | (а) 2-3.4* (Ъ) С.5-0,0* | 197-225 | | | | | | | |
| t. Elec- tric erc | (a) 0.725* (b) 0.134* | 107 | | | | | | | |
| 7 (and | | | | | | | | | |
| a. Tilt-)ng fur- nace | (a) 2.1-2.5" (b) 0.38-0.5" | 315-362 | | | | | | | |
| | | | | | | | | | |
| Production | | | | | | | | | |
| l. Hever- beratory furnace | (=) 5.6-17.6 | 450-550; 20C- 220 at baghouse inlet | 3.1-24 | Stack CO ₂ : 0.34-1.4 Avg.: 0.67 O ₂ : 17.8-19.1 Avg.: 18 % | | | | | |
| | | | | Ng: balance CO: 7.7-42.2 ppm Avg.: 22.7 ppm | | | | | |
| | | | | SC ₂ : < 1 ppm Hydrocarbons: | | | | | |
| | | | | 0.02-C.C5 ppm Halogens: < 1 ppm NO _K : < 1 ppm | | | | | |

· Actual cubic feet.

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TABLE 19-2 (Concluded)

2. <u>Currier Gis</u> (Concluded)

| 5 | ourc | ± | | Flow Rate | Temperature | Moisture Content | Chemical Composition | Texicity | Corresivity | Odor | Flammability or Explosive limits | Optical Properties |
|------|------|-----------------------------------|----------------|---|--|---------------------|--|--|-------------|------|-------------------------------------|-----------------------|
| | è | . Rotary furnace | (-) | 11.4+36.7 | | 1.7-2.3 | Stack CO2: 0.14-1.11 Avg.: C.51 O2: 10.2.2.5 Avg.: 10.2 H_2: balance C3: 6.8-10.8 ppc Avg.: 8.4 SO2: 10 ppc Hydrocarbons: 0.16-0.37 ppc Halagena: 1 ppc MO2: 1 ppc HopS: 1 ppc | | | | | |
| | 3 | . Cupoin | (;) | 13.7-37 | 145-200 at bag- houre inlet | 1.1-2.7 | Stack CQ:: 0.5-1.4 Avg:: 0.8 Og: 18.9-19.4 Avg:: 19.2 Ng:: 19.2 Ng:: 10.2-1575 ppm Avg:: 1200 ppm SOg: 1 ppm Ng:: 2.200 ppm Ng:: 2.1 ppm Ng:: 1 ppm Halogens: < 1 ppm | | | | | |
| 11. | Les | đ | (e) | 2.1 (one blast furnace) 3.1 (one reverberstory furnace) 2.1-2.5 (two crucible furnace) | 500 (blust) 950 (rever- beratory) 315-362 s) | | ເຜຼ, ເວ, ບູ, N ₂ , ເບຼ, ະ ₂ ວ | 50 ₂ - 5, irritant 20 - 160 | | | · | |
| 111. | 215 | 12 | | | | | | | | | | |
| | A. | Sweat Porrace Flux Phese | | | | | | | | | | |
| | | 1. Kettle furnece | (*) 2 (b) 1 | -10 45-722 | 105-195 | | Approximate Oz:21 N ₂ :76 | | | | | |
| | | 2. Reverber- atory furnace | (n) / (b) 4 | -8 two furnaces) 100-800 | 190 | 4.5 | Νγτical CC ₂ :2.4 Η ₂ C:4.5 Ν ₂ :76.6 C ₂ :15.8 | | | | | |
| ۲v. | Alu | mipue | | | | | | | | | | |
| | | 1. Reverber- atory furnace | (*) 1 (b) 3 | -9 .1 | 200-1430 | | Typical Orsat CO ₂ :6.8 O ₂ :8.6 CC:0.02 H ₂ :77.3 H ₂ 0:7.3 Crace SO ₂ | SO ₂ - 5 irritani CO - 100 | | | | |

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| TABLE | 19-3 |
|-------|------|
|-------|------|

| | ELECTRICAL RESISTIVITY OF COLLECTED BRONZE 1 | <u>-UME</u> 12/ |
|---------------------|--|-------------------------|
| | (Laboratory Measurements) | |
| Water Conten (%) | t Temperature (°F) | Resistivity (ohm-cm) |
| 6 | 280 | 4×10^{13} |
| 6 | 330 | 1.8 x 10 ¹³ |
| 6 | 380 | 5 x 10 ¹² |
| 6 | 430 | 1.8 x 10 ¹² |
| 6 | 4 80 | 5 x 10 |

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Figure 19-1 - Apparent Resistivity of Zinc Fume $\underline{11}/$ from Slag Fuming Plant

As function of temperature at 1.3% moisture content by volume

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As function of temperature at 1.3% moisture content by volume

412

19.2.3.1.3 <u>Wet scrubbers</u>: Five of the 23 plants considered in the Commerce Department study had a wet scrubber as the major component of their flue gas cleaning system. Three were aluminum alloy ingot producers, one a zinc remelt alloy shop, and one a producer of brass and bronze ingots. The wet scrubbers are best applicable to cleaning furnace gases with low particulate grain loading but high loading of soluble gases and mists such as hydrochloric and sulfuric acids.⁶/

The packed tower is a popular wet-scrubber design in use in the secondary nonferrous metals industry, particularly in aluminum plants where chlorine is used to purge magnesium from the furnace melt. The scrubber towers may be constructed by using a steel shell suitably lined with rubber or acid-resistant brick to isolate the shell from the highly corrosive gases.

19.2.3.1.4 Incinerators and afterburners: Most grades of scrap metal require incineration of attached foreign nonmetallic constituents before smelting and refining. Insulation on wire is a major contaminant which is usually removed by incineration. Generally, the incinerator operating temperature must be maintained high enough to either burn or volatilize the contaminant and low enough to prevent excessive oxidation of the metal. $\frac{6}{7}$

Copper wire scrap, with its various kinds of insulation, sometimes presents incineration problems. Mechanical stripping of fine gauge wire is being done at some plants, thereby obviating the need for incineration.

Burning of copper wire to free the copper from insulation sheaths of plastic, rubber or paper is most efficiently done in a two-stage incinerator. In the primary chamber the temperature is maintained hot enough to support combustion of the insulation but low enough to prevent excessive oxidation of copper. The only partly burned hydrocarbons escape in a sooty gas stream into a secondary chamber equipped with an afterburner. Very hot temperatures and an excess of oxygen convert the hydrocarbons to CO_2 and E_2O .

Polyvinyl chloride-coated wire presents an incineration problem. The PVC is fire resistant and it resists normal incineration methods. Furthermore, combustion of PVC liberates chlorine which combines either with water vapor to form hydrochloric acid or with metallic elements in the scrap to form harmful metal chlorides. Phthalic anhydride is also generated by burning polyvinyl chloride. To prevent the escape of noxious components through the flue, combustion gases must be passed from the afterburner chamber through an additional packed wet scrubber. The resulting effluent is neutralized with sodium hydroxide or other chemical base. Obviously, disposition of the scrubber effluent could cause water pollution problems. $\frac{6}{}$ Some other coatings on scrap metal have compositions that require special caution during incineration. Teflon contains fluorine, and unregulated burning of Teflon-coated scrap releases toxic gaseous fluorides. A source of white smoke is silicon rubber, which burns with release of SiO_2 .

One of the deficiencies of air pollution control equipment in secondary nonferrous metals plants is in the afterburner units on incinerators. Many do not have the precise temperature control needed for complete combustion, and it seems doubtful that the design features insure adequate mixing of the hot gases with proper quantities of oxygen from the air. Another possible fault in many afterburner designs is the failure to provide sufficient retention time of the hot gases for combustion in the area of appropriate temperature and oxygen availability.⁶

Experimental testing of a Peabody scrubber operating at a total gas pressure drop of 43 in. w.g. showed dust collection efficiency of 94.5% for an incinerator burning insulated copper wire (equipped with an afterburner).^{7/}

19.2.3.2 <u>Specific Control Practices for Secondary Copper</u>: The principal source of atmospheric emissions in the brass- and bronze-ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, etc. Because zinc is a sajor low-boiling-point constituent, appreciable amounts of zinc oxide are normally present in the exit gases also.

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Funes and dust from the blast furnace or cupola are similar to those from ingot furnaces. A common practice is to direct these fumes to the same collection device used for ingot furnace emissions. A dry inertial collector frequently precedes a baghouse in order to remove the large abrasive particles, but high-efficiency particulate collection equipment is necessary to remove the fine particulate. $\underline{1}$

Hooding a rotary-tilting-type reverberatory furnace for complete capture of fumes is difficult, and complete collection is seldom achieved. These furnaces are undoubtedly the most difficult type of brass furnace to control.

Capturing the dust-laden gases generated during charging and pouring operations is particularly difficult. One reverberatory furnace installation, using top charging, is covered by a 12 ft. x 24 ft. hood with an air intake capacity of nearly 40,000 cfm. This size is still sometimes insufficient to capture all the emissions. $\underline{l}/$ The only air pollution control equipment to receive general acceptance in the brass- and bronze-ingot industry is the baghouse collector. Recent NAPCA data indicate that the concentration of particulate matter escaping baghouses ranges from 0.006 to 0.036 grain/scf, and operating efficiencies were generally between 95 and 99.6%. Filter ratios of 2.0 to 2.7 cfm/sq ft and pressure drops of 2 to 6 in. of water are usually encountered. $\frac{1}{2}$

The cooling of gases prior to filtration is a major engineering design consideration to prevent burning of the bags and to maintain the gas above the condensation temperature. If The gases leaving a reverberatory furnace may be 100° to 200°F hotter than the molten metal and must be cooled before reaching the filter cloth. Direct cooling, by spraying water into the hot combustion gases, is not generally practiced because (1) corrosion of ductwork and equipment increases; (2) vaporized water increases exhaust gas volumes; and (3) temperature of the gases in the baghouse must be kept above the dewpoint. Water-jacketed coolers and radiation convection coolers are used to cool the gases without water-injected sprays.

The baghouse designs must take into account the variations in temperature, gas volume and emissions during the entire refining cycle so that plant operations may be continued at full capacity under any conditions. The baghouse should have a sufficient number of compartments so that one compartment can be bypassed while the others continue to operate and thus permit replacement of broken bags or allow for unusual cleaning requirements. The use of four compartments normally satisfies this requirement.¹/ Maintaining duct velocities of 2,500 - 3,000 ft/min is desirable to minimize buildup of dusts in the duct.

Table 19-4 shows the results of tests performed on baghouses venting brass furnaces. Larger baghouses are necessary for crucible gas-fired furnaces because of the heat and volume of the products of combustion from the gas burners.⁸/ A summary of information on baghouses for brass and bronze furnaces is given in Table 19-5.¹/

While baghouses have been found to be the most successful device for collecting large quantities of zinc oxide, there has been no universal acceptance of a particular filter fabric. These fabrics must be able to withstand fairly high temperatures in spite of the dilution and precooling of gases. They must also withstand considerable physical abuse and vibration. The use of glass fabric in baghouses allows higher temperature operation (550°F continuous) than the use of synthetic organic fabrics. However, the inherently low mechanical strength of glass fabric requires cleaning methods of a lower intensity than the mechanical shaking methods used with the synthetics. $\underline{l}/$

| TABLE | 19-4 | |
|-------|------|--|
| TABLE | 19-4 | |

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|---------------|---------|-----|----------|-----------|-------|
| BRASS-MELTING | FURNACE | AND | BAGHOUSE | COLLECTOR | DATAS |

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| Case | <u>A</u> | B | <u>c</u> | | |
|----------------------------------|--------------|-----------|-------------------------|--|--|
| Furnace data | | | | | |
| Type of furnace | Crucible | Crucible | Low-frequency induction | | |
| Fuel used | Gas | Gas | Electric | | |
| Metal melted | Yellow brass | Red brass | Red brass | | |
| Composition of metal melted, % | | | | | |
| Copper | 70.6 | 85.9 | 82.9 | | |
| Zinc | 24.8 | 3.8 | 3.5 | | |
| Tin | 0.5 | 4.6 | 4.6 | | |
| Lead | 3.3 | 4.4 | 8.4 | | |
| Other | 0.8 | 1.3 | 0.6 | | |
| Melting rate, lb/hr | 388 | 343 | 1,600 | | |
| Pouring temperature, °F | 2,160 | 2,350 | 2,300 | | |
| Slag cover thickness, in. | 1/2 | 1/2 | 3/4 | | |
| Slag cover material | Glass | Glass | Charcoal | | |
| Baghouse collector data | | | | | |
| Volume of gases,cfm | 9,500 | 9,700 | 1,140 | | |
| Type of baghouse | Sectional | Sectional | Sectional | | |
| | tubular | tubular | tubular | | |
| Filter material | Orlon | Orlon | Orlon | | |
| Filter area, sq. ft. | 3,836 | 3,836 | 400 | | |
| Filter velocity, ft/min | 2.47 | 2.53 | 2.85 | | |
| Inlet fume emission rate, lb/hr | 2.55 | 1.08 | 2.2ª/ | | |
| Outlet fume emission rate, lb/hr | 0.16 | 0.04 | 0.086 | | |
| Collection efficiency, % | 93.7 | 96.2 | 96.0 | | |

a/ Includes pouring and charging operations.

BACHOUSE INFORMATION SUMMARY - BRASS AND BRONZE INGOT INSTITUTE

| | | | זעד א איז איז איז איז איז איז איז איז איז א | Muter | ial Collecte | d in Bag | houses | Frequency |
|---|--|------------------------|---|-------------------|--------------------|---------------|--------------|-----------------------|
| Size of Baghouse, cim | No. of Bags - <u>Diamacter, In.</u> | Bag <u>Material</u> | Furnaces Vented to the Baghouse | Lb/Ton Charged | Lb/Ton Produced | <u>\$ 2n0</u> | \$ Pb0 | of Bug Replacement |
| 2 units - 24,000 each (design) 18,000 (actual) | 1,944 - 6 | Orton and dacron | 2 Rev-60 tons/ht each 2 Rot-2 tons/ht each 4 Elec-1 at 4 tons/ht 3 at 1/2 ton/ht | 58 | 67 | 63 | 8 | 18 months |
| 3 units - 13,000 each (design) | 2,268 - 6 | Datron | 2 Rev-60 tons/ht each 2 Rot-4 tons/ht each 1 Cupola | 60 | 68 . | 78 | 7.5 | 10 to 15 months |
| 10,000 cfm (design) | 100 - 15 | Glass | 1 Radiator sweater | | | | | |
| 27,500 (design) 18,000 (actual) | 324 - 8 | Orlon and decron | 4 Rev-60 tons/ht each | | | | | 4 months |
| 30,000 (design 29,000 (actual) | 528 - 8 | Orlon and Jacron | 3 Rot-4 tons/ht each | 60 9 / | ദ്രമ / | <u>اود،</u> | 8 <u>9</u> / | 6 months |
| | 320 - 5 | Orlon | No flow diagram pro- vided; equipment layout not ascertainable | | | | | 12 months |
| | 900 - 8 | Orlon | 3 Rev-30-75 tons/ht each 1 Rot-10 tons/ht | 55 | NR | 58 | 3 | 12 months |
| Square-filter type 26,000 (design) | 400 - 10 | Or lon | Cupole 2 Rev-80 tons/ht each 5 Rot-7-1/2-35 tons/ht each | NR | NR | 65 | 5 to 6 | 6 months |
| Multiple-bag type | 1,500 - 6 | Orion | No flow diagram pro- vided; layout of equipment not oscertainable | | | | | |
| (lustom-designed 12,500 cfm/chamber (No. of chambers not reported) | 416 - 18 | ΨοσΊ | 3 Rev-2-75 tons/ht each 3 Rot-2.7 tons/ht each 3 Crucible-0.25 tons/ht each 1 Elec-3 tons/ht 1 Cupola-no tonnage reported | NR | NR | 55 | NR | 51 months |
| 30,000 (design and actual) | 1,200 - 5 | Orlon | 3 Rev-2-30 tons/ht each 1 - 12 tons/ht each | | | | | |
| 50,000 (design and actual) | 800 - 8 | Orlon | 4 Slug-15-25 tons/ht each | NR | NR | NR | NR | 12 months |

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 \underline{a} Not stipulated if these figures are total figures for the three units.

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Electrostatic precipitators and wet scrubbers have not proved entirely satisfactory on lead and zinc fumes from brass and bronze furnaces. Lead oxide in particular is difficult to collect by electrostatic precipitators because of its relatively high resistivity. In addition, high-voltage precipitators have not been available in small units suitable for small nonferrous foundry use and the first cost may, moreover, be prohibitive. $\frac{\beta}{2}$

A number of dynamic and static scrubbers have been tested on brass furnaces and all have been found unsatisfactory. The scrubbers failed to reduce the particulate matters sufficiently and opacity was excessive. These scrubbers were replaced by baghouses. $\frac{8}{2}$

The Commerce Department study also reported cost data for air pollution control in the secondary nonferrous metals industry. The average operating cost, for three dissimilar systems, was about 0.60/year per cfm of capacity and ranged from 0.36 to 1.07/year per cfm. Since some larger plants have air-cleaning equipment with a capacity to treat 150,000 cfm, their associated costs of servicing and maintaining this equipment could be as much as 120,000/year.6/

The cost of air pollution control as computed in the Commerce Department study of baghouse systems, shown in Table 19-6, averaged about 3/4% of the value of annual shipments. The study indicated that these installations and operating costs may have the effect of reducing net after-tax profits by 8 to 10%. A breakdown of cost findings is shown in Tables 19-7, 19-8 and 19-9.6/

The costs reported in the Commerce Department $study^{6}/$ are much higher than the general cost figures presented in Appendix A. For example, the installed cost for a baghouse ranges from \$2.66 to \$8.33/acfm as given in Table 19-8. However, Appendix A indicates that the average installed cost of a baghouse should be about \$2.00/acfm and the highest expected cost should not exceed \$3.00/acfm. Also, the operating (and maintenance) costs shown in Table 19-9 range from \$0.36 to \$1.07/acfm which is three to ten times higher than would be expected on the basis of cost equations in Appendix A.

Other data available on air pollution costs at brass and bronze smelters indicate a broad range for installed costs. It is reported that a cost of \$5.00 per cfm might be "typical" for an installed system, the baghouse itself representing about 40% of the total cost. $\frac{1}{}$ This installed cost agrees with cost data shown in Table 19-8 but, as previously discussed, this is considerably higher than the general cost figures in Appendix A.

ANNUAL COST OF AIR POLLUTION CONTROL SYSTEMS6/ (Secondary Nonferrous Metals Industry)

| | 5-Year Deprecistion Basis | 7-Year Depreciation Basis |
|--|---------------------------------|---------------------------------|
| Annual cost as percentage of annual value of shipments | % | % |
| Mean Installed equipment Operating and maintenance TOTAL | 0.46 0.44 0.90 | $0.33 \\ 0.44 \\ 0.77$ |
| Median Installed equipment Operating and maintenance TOTAL | 0.52 <u>0.43</u> 0.95 | 0.37 <u>0.43</u> C.80 |
| Annual per cubic-foot-per-minute (cfm) of gas-cleaning capacity (dollars) | \$ | \$ |
| Mean Installed equipment Operating and maintenance TOTAL | 0.86 <u>0.76</u> 1.62 | 0.61 <u>0.76</u> 1.37 |
| Median Installed equipment Operating and maintenance TOTAL | 0.80 0.88 1.68 | 0.60 <u>C.88</u> 1.48 |

Source: 1968 BDSA survey interview of six plants with installed dry baghouse systems.

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INSTALLED COSTS OF GAS-CLEANING EQUIPMENT SYSTEMS, BY TYPE OF SMELTER⁶/

| Capacity to | | |
|--------------------------|--|--|
| | | |
| Treat Smelter Flue Gases | | |
| w <u>Average</u> | | |
| | | |
| | | |
| 0 4.66 | | |
| | | |
| | | |
| | | |
| 9 6.23 | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| 4 3.52 | | |
| | | |
| 2.50 | | |
| | | |

-- Not available, not compiled separately, or not applicable.

a/ Excludes 2 highest and 1 lowest of 11 plants.

| | Cents/Pound of Annual Metal Production | | | Cents/Dollar of Annual Metal Shipments | | | Dollars/Cubic-Foot-Per- Minute of Capacity to Treat Smelter Flue Gases | | |
|--|---|------|---------|---|------|---------|--|----------------|---------|
| | High | Low | Average | High | Low | Average | High | Low | Average |
| Baghouses: | | | | | | | | | |
| 8 plants | 2.03 | 0.50 | 1.07 | | | | | | |
| 7 plants | | | | 5.08 | 1.25 | 2.68 | | | |
| 6 plants | | | | | | | 8.33 | 2.66 | 5.09 |
| Wet scrubbers: | | | | | | | | | |
| 2 plants | 1.35 | 0.67 | 1.01 | | | | | | |
| l plant | | | | | | | | | 2.50 |
| Combined baghouse and wet packed scrubber: | | | | | | | | | |
| l plant | | | | | | | | - - | 4.84 |
| Electrostatic precipitators: | | | | | | | | | |
| 2 plants | 0.75 | 0.33 | 0.54 | | | 1.29 | | | |
| l plant | | | | | | | | - - | 4.09 |

INSTALLED COSTS OF GAS-CLEANING EQUIPMENT SYSTEMS, BY TYPE OF EQUIPMENT6/

-- Not available, not compiled separately, or not applicable.
TABLE 19-9

ANNUAL OPERATING COSTS OF GAS-CLEANING EQUIPMENT SYSTEMS, BY TYPE OF SMELTER 6/

| | Cents/Pound of | | | Dollars/Cubic-Foot-Per- | | |
|-------------------------------|--------------------|----------|---------|-------------------------|----------|------------|
| | <u>Met</u> High | al Produ | Average | <u>Minute</u> High | Cleanin | g Capacity |
| | <u>mrgn</u> | LOW | Average | <u>mrgn</u> | TOM | Average |
| All nonferrous smelters: | | | | | | |
| 4 plants | 0.28 | 0.05 | 0.12 | | | |
| 3 plants | | | | 1.07 | 0.36 | 0.82 |
| Brass and bronze ingot maker: | | | | | | |
| l plant | | | 0.06 | | | 1.07 |
| Lead smelter: | | | | | | |
| l plant | | | 0.08 | | <u> </u> | |
| Multi-product smelters: | | | | | | |
| 2 plants | 0.28 | 0.05 | 0.16 | 1.03 | 0.36 | 0.69 |

-- Not available, not compiled separately, or not applicable.

The costs of maintenance and operation of an air pollution control system have been reported by four smelters at \$2.00, \$0.90, \$1.50, \$1.73/ton of ingots produced. These costs include credits for value of byproduct material but the amortization of the capital cost of the system is not included.¹/ These operating and maintenance costs are consistent with data in Table 19-8.⁶/ Again, this is much higher than would be expected based on general cost equations in Appendix A.

19.3 SECONDARY LEAD SMELTING AND REFINING

Reverberatory, blast, and pot furnaces are the three furnace types most commonly used in secondary lead smelting and refining. In addition to refining lead, most of the secondary refineries also produce lead oxide by the Barton process.

Various grades of lead metal along with the oxides are produced by the lead industry. The grade of product desired determines the type of equipment selected for its manufacture. The most common grades of lead produced are soft, semisoft, and hard. By starting with one of these grades and using accepted refining and alloying techniques, any special grade of lead or lead alloy can be made.

Soft lead may be designated as corroding, chemical, acid copper, or common desilverized lead. These four types are high-purity leads and are the products of the pot furnace after a considerable amount of refining has been done.

Semisoft lead is the product of the reverberatory-type furnace and usually contains from 0.3 to 0.4% antimony and up to 0.05% copper.

Hard lead is made in the blast furnace. A typical composition for hard lead is 5 to 12% antimony, 0.2 to 0.6% arsenic, 0.5 to 1.2% tin, 0.05 to 0.15% copper, and 0.001 to 0.01% nickel. $\frac{3}{2}$

19.3.1 Emission Sources and Rates

The emission sources in secondary lead processing are similar to those discussed for secondary copper in Section 19.2.1. The main emission sources are the furnaces. The types and ranges of emissions from the furnaces will depend upon factors such as fuel, composition and melting temperature of the alloys, furnace type and operating factors. Individual emission sources in the various operations comprising the production cycle for secondary lead are discussed in more detail in the following sections. 19.3.1.1 Scrap Processing: The sweating of lead from scrap and dross is widely practiced. Junk automobile storage batteries supply most of the lead. In addition, lead-sheathed cable and wire, aircraft tooling dies, type-metal drosses, and lead dross and skims are also sweated. The rotary furnace, or sweating tube, is usually used when the material processed has a low percent of metal to be recovered. The reverberatory box-type furnace is usually used when the percent of metal recovered is high.

The discharge from a lead-sweating furnace may contain dust, fumes, smoke, sulfur compounds, and fly ash. This is particularly true when junk batteries are sweated. The battery groups and plates removed from the cases contain bits of asphaltic case, oil and grease around the terminals, sulfuric acid, lead sulfate, lead oxide, and wooden or glassfiber plate separators. The organic contaminants burn poorly and the sulfur compounds release SO_2 and SO_3 . The sulfur trioxide is particularly troublesome; when hydrolized to sulfuric acid, the acid mist is difficult to collect and is extremely corrosive.

Uncontrolled rotary lead-sweat furnaces emit excessively high quantities of air contaminants. Although the other types of scrap lead and drosses sweated in a reverberatory furnace are normally much less contaminated with organic matter and acid, high emission rates occur periodically.

Blast furnaces are used quite extensively in secondary smelting of lead storage batteries. The lead blast furnace or cupola is constructed similarly to those used in the ferrous industry. The materials forming the usual charge for the blast furnace, and a typical percentage composition, are 4.5% rerun slag, 4.5% scrap cast iron, 3% limestone, 5.5% coke, and 82.5% drosses, oxides, and reverberatory slags. Hard lead is charged into the cupola at the start of the operation to provide molten metal to fill the crucible. Normal charges are then added as the material melts down. The limestone and iron flux that floats on top of the molten lead retard its oxidation.3/

19.3.1.2 <u>Remelting</u>, Alloying, and Refining Processes: Pot-type furnaces are used for remelting, alloying and refining processes. Remelting is usually done in small pot furnaces, and the materials charged are usually alloys in the ingot form, which do not require any further processing. The quantity of air contaminants discharged from pot furnaces as a result of remelting, alloying, and refining is much less than that from reverberatory or blast furnaces.

A rather specialized phase of the industry is the production of lead oxide. Battery lead oxide, containing about 20% finely divided free lead, is usually produced by the Barton process. Molten lead is run by gravity from a melting pot into a kettle equipped with paddles. The paddles are rotated at about 150 rpm, rapidly agitating the molten lead, which is at a temperature of 700° to 900°F. Air is drawn through the kettles by fans located on the air outlet side of a baghouse. The lead oxide thus formed is conveyed pneumatically to the baghouse where it is collected and delivered by screw conveyor to storage.

Other lead oxides requiring additional processing but commonly made are red lead oxide (minimum, Pb_3O_4), used in the paint industry, and . yellow lead oxide (litharage or massicot, PbO), used in the paint and ink industries.

Since the process requires the use of a baghouse to collect the product, and no other contaminants are discharged, no air pollution control system as such is needed.3/

19.3.1.3 <u>Summary of Emission Rates</u>: Table 19-1 summarizes emission rate data for the various sources in the secondary lead production cycle. Reverberatory furnaces account for nearly 75% (3,000 tons/year) of the particulate emissions in secondary lead production.

19.3.2 Effluent Characteristics

The chemical and physical properties of effluents from secondary lead production are summarized in Table 19-2. Metallic fumes emitted from the furnaces are submicron in size. Mean diameter is about 0.3 μ for unagglomerated material.

19.3.3 Control Practices and Equipment

In general, plants which are engaged in secondary lead smelting with either a blast furnace or a reverberatory furnace require an extensive system for air pollution control. The baghouse has long been considered as the most acceptable device for collecting lead fumes. The gas stream from the smelting furnaces is first passed through a series of water- or air-cooled tubes and then sent to a baghouse. The temperature of the baghouse must be kept fairly high to prevent the tar volatiles from condensing and blinding the bags. Lime is also added as the gas stream enters the baghouse to help prevent this blinding action. On leaving the baghouse the gas stream is discharged to the stack or in some instances further treated in an electrostatic precipitator in order to meet local ordinance requirements. $\frac{5}{2}$

Reverberatory furnaces are used in lead-smelting operation. All the smoke and fume produced by this type of furnace must be collected and, since they are combined with the products of combustion, the entire volume emitted from the furnace must pass through the collector. Baghouses have been found to operate satisfactorily in this service. Provisions should be made to prevent sparks from contacting the filter cloth and temperature must be controlled by preceding the baghouse with radiant cooling ducts, water-jacketed cooling ducts or other suitable devices. Dacron bags are being used successfully in this service. Test results of secondary leadsmelting furnaces venting to a baghouse are shown in Table 19-10. $\underline{8}$ /

One of the largest secondary lead smelters in the U.S. uses fiberglass bags for fume collection, at higher than 400°F, of combined effluent from a reverberatory furnace and a lead blast furnace. The 400°F filtering temperature was desired to eliminate deposition of organic tars on the bags. $\frac{9}{2}$

The control system for a lead blast furnace is similar to that employed for gray-iron cupola furnaces. Electrostatic precipitators are not used for economic reasons. Moreover, difficulties can be encountered in conditioning the particles to give them resistivity characteristics in the range that will allow efficient collection. $\underline{8}/$

In the refining and alloying of secondary lead the air pollution problems are not as complex as those arising from the smelting of lead scrap. The fumes produced can be effectively treated by collecting them from the kettle hoods with a flow of around 200 cfm and passing them through a baghouse $\frac{10}{}$

Available data on control equipment costs are presented along with the data for secondary copper in Section 19.2.3.2.

| | ويتعتب المراجع والترية تيزينا تترجع فبالبرد فعطيته | | | |
|--|--|--|--|--|
| Test Number | <u>1</u> | 2 | | |
| Furnace data | | | | |
| type of furnace | Reverberatory | Blast | | |
| Puel used | Natural gas | Coke | | |
| Meterial charged | Battery groups | Battery groups, dross, slag | | |
| Process weight, 1b/br | 2,500 | 2,670 | | |
| Control equipment dats | | | | |
| lype of control equipment Tilter material | Sectioned tubular beghouse ^B / | Sectioned tubular baghouse ^{B/} | | |
| Filter eres sa. ft. | 16.000 | 16,000 | | |
| Filter velocity, ft/min at 327°F | 0,98 | 0.98 | | |
| Dust and fume data | | | | |
| Gas flow rate, sofm | | | | |
| Furnace outlet | 3,060 | 2,170 | | |
| Baghouse cutlet | 10,400 ^b / | 13,000b/ | | |
| Gas temporature, °F | | - | | |
| Furnece cutlet | 951 | 500 | | |
| Baghouse outlet | 327 | 175 | | |
| Concentration, grains/scf | | | | |
| Furnace outlet | 4.98 | 12.3 | | |
| Beghouse outlet | 0.013 | 0.035 | | |
| Dust and fume emission, 1b/hr | | | | |
| Furnace outlet | 130.5 | 229 | | |
| Baghouse outlet | 1.2 | 3.9 | | |
| Baghouse efficiency, 🖇 | 99.1 | 98.3 | | |
| Baghouse catch, wt. 🕉 | | | | |
| Particle size O to l µ | 13.3 | 13.3 | | |
| 1 to 2 | 45.2 | 45.2 | | |
| 2 to 3 | 19.1 | 19.1 | | |
| 3 to 4 | 14.0 | 14.0 | | |
| 4 to 16 | ô.4 | 8.4 | | |
| Sulfur compounds as SO2, vol. 🐔 | | | | |
| Eaghouse outlet | 0,104 | C.03 | | |

TABLE 19-10

DUST AND FUML EMISSIONS FROM A SECONDARY LEAD-SMELTING FURNACE

B/ The same baghouse alternately serves the reverberatory furnace and the blast furnace.
 b/ Dilution air aimitted to cool gas stream.

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19.4 SECONDARY ZINC SMELTING AND REFINING

Zine is melted in crucible, pot, kettle, reverberatory, or electric-induction furnaces for use in alloying, casting, and galvanizing and is reclaimed from higher melting point metals in sweat furnaces. Secondary refining of zine is conducted in retort furnaces, which can also be used to manufacture zine oxide by vaporizing and burning zine in air.

19.4.1 Emission Sources and Rates

The emission sources in zinc recovery parallel those in the previous secondary processes, and the emissions are influenced by the fuel, composition and melting temperature of the alloys, furnace type, and operating factors. Individual emission sources in the various operations comprising the production cycle for secondary zinc are discussed in more detail in the following sections.

19.4.1.1 <u>Scrap Processing</u>: Zinc can be recovered by sweating in a rotary, reverberatory, or muffle furnace. Zinc-bearing materials fed to a sweating furnace usually consist of scrap die-cast products such as automobile grilles, license plate frames, and zinc skims and drosses.

Air contaminants released from a zinc-sweating furnace consist mainly of smoke and fumes. The smoke is generated by the incomplete combustion of the grease, rubber, plastics, and so forth contained in the material. Zinc fumes are negligible at low furnace temperatures, because zinc has a low vapor pressure even at 900°F. With elevated furnace temperatures, however, heavy fuming can result. $\frac{3}{2}$

19.4.1.2 Zinc Melting: The melting operation is essentially the same in all the different types of furnaces. Zinc to be melted may be in the form of ingots, castings, flashing, or scrap. Ingots, rejects, and heavy scrap are generally melted first to provide a molten bath to which light scrap and flashing are added. After sufficient metal has been melted, the bath is heated to the desired pouring temperature, which may vary from 800° to 1100°F. Before pouring, a flux is added and the batch agitated to separate the dross accumulated during the melting operation.

The discharge of air contaminants from melting furnaces is generally caused by excessive temperatures and by the melting of metal contaminated with organic material. Fluxing can also create excessive emissions, but fluxes that clean the metal without fuming are available.3/

The first visible discharge noted from a furnace is from organic material. Before the melt is hot enough to vaporize any zinc, accompanying organic material is either partially oxidized or vaporized, causing smoke or oily mists to be discharged. This portion of the emissions can be controlled either by removing the organic material before the charging to the furnace or by completely burning the effluent in a suitable incinerator or afterburner.

Normally, zinc is sufficiently fluid for pouring at temperatures below 1100°F. At that temperature, its vapor pressure is 15.2 mm. of mercury, low enough that the amount of fumes formed cannot be seen. If the metal is heated above 1100°F, excessive vaporization can occur. Zinc can vaporize and condense as metallic zinc if existing temperatures and atmospheric conditions do not promote oxidation. Finely divided zinc so formed is a definite fire hazard, and fires have occurred in baghouses collecting this material. $\frac{3}{}$

19.4.1.3 Zinc Vaporization: Retort furnaces are used for operations involving the vaporization of zinc including (1) reclaiming zinc from alloys, (2) refining by distillation, (3) recovering zinc from its oxide, (4) manufacturing zinc oxide, and (5) manufacturing powdered zinc.

Belgian retorts, distillation retorts, and muffle furnaces are used as retort furnaces.³/ Belgian retorts are used to reduce zinc oxide to metallic zinc. Distillation retorts, used for batch distillations, reclaim zinc from alloys, refine zinc, make powdered zinc, and zinc oxide. Muffle furnaces, used for continuous distillation, reclaim zinc from alloys, refine zinc, and make zinc oxide.

The Belgian retort furnace is one of several horizontal retort furnaces that for many years have been the most common device for the reduction of zinc. The horizontal retort process is now being replaced by other methods capable of handling larger volumes of metal per retort and by the electrolytic process for the reduction of zinc ore.3/

Figure 19-3 illustrates a typical Belgian retort. One end is closed and a conical-shaped clay condenser from 18 to 24 in. long is attached to the open end. The retorts are arranged in banks with rows four to seven high and as many retorts in a row as are needed to obtain the desired production. The retorts are generally gas-fired. The air contaminants emitted vary in composition and concentration during the operating cycle. During charging operation very low concentrations are emitted. The feed is moist, and, therefore, not dusty. As the retorts are heated, steam is emitted. After zinc begins to form, both carbon monoxide and zinc vapors are discharged. These emissions burn to form gaseous carbon dioxide and solid zinc oxide. During the heating cycle, zinc is poured from the condensers about three times at 6- to 7-hr. intervals. The amount of zinc vapors discharged increases during the tapping operation. Before the spent charge is removed from the retorts, the temperature of the retorts is lowered, but zinc fumes and dust from the spent charge are discharged to the atmosphere $\frac{3}{2}$ In addition, the retorts sometimes break and the zinc charge is emitted to the atmosphere in the combustion gases.



Figure 19-3 - Diagram Showing One Bank of a Belgian Retort Furnace $\frac{3}{2}$

The distillation retort furnace (shown in Figure 19-4) consists of a pear-shaped, graphite retort, which may be 5 ft. long by 2 ft. in diameter at the open end and 3 ft. in diameter at its widest cross-section. Normally, the retort is encased in a brick furnace with only the open end protruding and it is heated externally with gas- or oil-fired burners. The retorts are charged with molten, impure zinc through the open end, and a condenser is attached to the opening to receive and condense the zinc vapors. After the distillation has been completed, the condenser is moved away, the residue is removed from the retort, and a new batch is started.

During the 24-hr. cycle of the distillation retorts, zinc vapors escape from the retort (1) when the residue from the preceding batch is removed from the retort and a new batch is charged and (2) when the second charge is added to the retort. As the zinc vapors mix with air, they oxidize and form a dense cloud of zinc-oxide fumes. Air contaminants are discharged for about 1 hr. each time the charging hole is open. When the zinc is actually being distilled, no fumes escape from the retort; however, a small amount of zinc oxide escapes from the speise hole in the condenser. Although the emission rate is low, air contaminants are discharged for about 20 hr. per day.

Muffle furnaces (similar to that shown in Figure 19-5) are continuously fed retort furnaces. They generally have a much greater vaporizing capacity than either Belgian retorts or bottle retorts, and they are operated continuously for several days at a time. Heat for vaporization is supplied by gas- or oil-fired burners by conduction and radiation through a silicon carbide arch that separates the zinc vapors and the products of combustion. Molten zinc from either a melting pot or sweat furnace is charged through a feed well that also acts as an air lock. The zinc vapors are conducted to a condenser where purified liquid zinc is collected, or the condenser is bypassed and the vapors are discharged through an orifice into a stream of air where zinc oxide is formed.

Any discharge of zinc vapor from the condenser forms zinc oxide of product purity; therefore, the condenser vents into the intake hood of a product-collecting exhaust system. Since some zinc oxide is always produced, even when the condenser is set to produce a maximum of liquid zinc, the product-collecting exhaust system is always in operation to prevent air contaminants from escaping from the condenser to the atmosphere.³/

19.4.1.4 <u>Summary of Emission Rates</u>: Table 19-1 summarizes emissionrate data for the various sources in secondary zinc processing. Zinc sweating furnaces account for about 60% of the total quantity of particulates emitted in secondary zinc production.



Figure 19-4 - Diagram of a Distillation-Type Retort Furnace $\frac{3}{2}$



Figure 19-5 - Diagram of a Muffle Furnace and Condenser

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19.4.2 Effluent Characteristics

The chemical and physical properties of effluents from secondary zine production are summarized in Table 19-2. Metallic fumes emitted from the furnaces are submicron in size, and range from 0.03 to 1μ (unagglomerated material).

19.4.3 Control Practices and Equipment

An afterburner should be provided to incinerate the combustible matter discharged from a low-temperature sweating furnace. A baghouse should be used with the afterburner to capture the dust and fumes. Table 19-11 shows test results for a zinc die-cast sweating operation controlled by a baghouse .3/

Air pollution control for retort furnaces is achieved with a baghouse. Glass bags have been found adequate when gas temperatures exceed the limits of cotton or orlon. Filtering velocities of 3 ft/min are generally employed. $\frac{8}{7}$

Available data on control equipment costs are presented along with the data for secondary copper in Section 19.2.3.2.

19.5 SECONDARY ALUMINUM SMELTING AND REFINING

Secondary aluminum smelting is essentially the process of remelting aluminum, but encompasses the following additional practices: (1) fluxing, (2) alloying, (3) degassing, and (4) demagging.

Aluminum for secondary smelting comes from three main sources:

1. Aluminum pigs. These may be primary metal but may also be secondary aluminum produced by a large secondary smelter to meet standard alloy specifications.

2. Foundry returns. These include gates, risers, runners, sprues, and rejected castings. In foundries producing sand-mold casting, foundry returns may amount to 40 to 60% of the metal poured.

3. Scrap. This category includes aluminum contaminated with oil, grease, paint, rubber, plastics, and other metals such as iron, magnesium, zinc, and brass.

The melting of clean aluminum pigs and foundry returns without the use of fluxes does not result in the discharge of significant quantities of air contaminants. The melting of aluminum scrap, however, frequently requires air pollution control equipment to prevent the discharge of excessive air contaminants.

TABLE 19-11

AND A ZINC-SWEATING FURNACE CONTROLLED BY A BAGHOUSE3/

| Test | Number |
|------|--------|
|------|--------|

<u>1</u>

2

| Furnace data | | |
|-------------------------------|--------------------------|--------------------------|
| Type of furnace | Reverberatory | Reverberatory |
| Size of furnace | 5 ft. 9 in. wide x 6 ft. | 5 ft. 9 in. wide x 6 ft. |
| | 4 in. long x 4 ft. high | 4 in. long x 4 ft. high |
| Process weight, lb/hr | 760 | 2,080 |
| Material sweated | Aluminum skims | Zinc castings |
| . · · · · | | |
| Baghouse data | | |
| Type of baghouse | Sectioned tubular | Sectioned tubular |
| Filter material | Orlon | Orlon |
| Filter area, sq. ft. | 5,184 | 5,184 |
| Filter velocity, ft/min | 1.9 | 1.85 |
| Precleaner | None | None |
| Dust and fume data | | |
| Gas flow rate, scfm | | |
| Baghouse inlet | 8,620 | 7,680 |
| Baghouse outlet | 9,580 | 7,420 |
| Average gas temperature, °F | | • |
| Baghouse inlet | 137 | 190 |
| Baghouse outlet | 104 | 173 |
| Concentration, grains/scf | | |
| Baghouse inlet | 0.124 | 0.205 |
| Baghouse outlet | 0.0138 | 0.0078 |
| Dust and fume emission, 1b/hr | | |
| Baghouse inlet | 9.16 | 13.5 |
| Baghouse outlet | 1.138/ | 0.5 |
| Control efficiency, 🗲 | 87 . 7 <u>8</u> / | 96.3 |

a/ Visible emissions released from the baghouse indicated that a bag had broken during the latter part of the test.

Crucible and reverberatory furnaces are commonly used for melting aluminum. Both gas- and oil-fired units are common. Electric-induction furnaces are becoming common. Most electric furnaces are relatively small. $\underline{3}$ /

19.5.1 Emission Sources and Rates from Secondary Aluminum Smelting

All the pyrometallurgical processes associated with aluminum smelting create air pollutants to some degree. Individual emission sources in the various operations comprising the production cycle for secondary aluminum are discussed in more detail in the following sections.

19.5.1.1 <u>Scrap Processing</u>: Open-flame, reverberatory-type furnaces are used by secondary smelters to produce aluminum pigs for remelting. These furnaces are constructed with the hearths sloping downward toward the rear of the furnace. All types of scrap aluminum are charged into one of these furnaces, which operate at temperatures of 1250° to 1400°F. In this temperature range, the aluminum melts, trickles down the hearth, and flows from the furnace into a mold. The higher melting materials such as iron, brass, and dross oxidation products formed during melting remain within the furnace. This residual material is periodically raked from the furnace hearth. Some large secondary aluminum smelters separate the aluminum suspended in the dross by processing the hot dross immediately after its removal from the metal in the refining furnace. The aluminum globules suspended in the dross can also be separated and reclaimed by a cold, drymilling process. This process is used primarily to process drosses having a low aluminum content.

In theory, an aluminum-sweating furnace can be operated with minor emissions of air contaminants if clean, carefully hand-picked metal free of organic material is processed. In practice, this selective operation does not occur and excessive emissions periodically result from uncontrolled furnaces. Stray magnesium pieces scattered throughout the aluminum scrap are not readily identified, and charging a small amount of magnesium into a sweating furnace causes large quantities of fumes to be emitted. Emissions also result from the other materials charged, such as skims, drosses, scrap aluminum sheet, pots and pans, aircraft engines, and wrecked airplanes.

Smoke is caused by the incomplete combustion of the organic constituents of rubber, oil and grease, plastics, paint, cardboard, and paper. The sweating of dross and skims is responsible for the high rates of emission of dust and fumes. Residual aluminum chloride flux in the dross is especially troublesome because it sublimes at 352°F and is very hygroscopic. In addition, it hydrolyzes and forms very corrosive hydrogen chloride. In the dry-milling process, dust is generated at the crusher, in the mill, at the shaker screens, and at points of transfer. These locations must be hooded to prevent the escape of fine dust to the atmosphere.

When aluminum is reclaimed by the hot dross process, some fumes are emitted from the flux action; however, the main air pollution problem is the collection of the mechanically generated dust created by the rotation of the dross barrel.

19.5.1.2 <u>Aluminum Melting</u>: For melting small quantities of aluminum, up to 1,000 lb., crucible or pot-type furnaces are used extensively. Almost all crucibles are made of silicon carbide or similar refractory material. Small crucibles are lifted out of the furnace and used as ladles to pour into molds. The larger crucibles are usually used with tiltingtype furnaces. For die-casting, molten metal is ladled out with a small hand ladle, or it can be fed automatically to the die-casting machine.

The reverberatory furnace is commonly used for medium- and largecapacity heats. Small reverberatory furnaces of up to approximately 3,000 lb. capacity may be of the tilting type. Sometimes a double-hearth construction is employed in furnaces of 1,000 to 3,000 lb. holding.

Small crucible furnaces are usually charged by hand with pigs and foundry returns. Many reverberatory furnaces are also charged with the same type of materials, but mechanical means are used because of the larger quantity of materials involved.

Frequently, a large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clear, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems.

The extent of visible emissions discharged from degassing aluminum with chlorine gas depends on metal temperature, chlorine flow rate, and magnesium content of the alloy. Other factors affecting the emissions to a lesser degree are the depth at which the chlorine is released and the thickness and composition of the dross on the metal surface .3/

When chlorine is used for demagging, it is added so rapidly that large quantities of both aluminum chloride and magnesium chloride are formed, the molten bath is vigorously agitated, and not all of the chlorine reacts with the metals. As a result, a large quantity of aluminum chloride is discharged along with the chlorine gas and some entrained magnesium chloride. The aluminum chloride is extremely hygroscopic and absorbs moisture from the air, with which it reacts to form hydrogen chloride. These air contaminants are toxic, corrosive, and irritating. 19.5.1.3 <u>Summary of Emission Rates</u>: Table 19-1 summarizes emission-rate data for the various sources in secondary aluminum processing. Chlorine fluxing operations for degassing and demagging steps account for 51,000 tons/year out of a total of approximately 58,000 tons/year of emitted particulates.

19.5.2 Characteristics of Effluents

The chemical and physical properties of effluents from secondary aluminum production are summarized in Table 19-2. Emitted particulates are less than 2 μ in size. The particulates may be toxic because of the fluorides and chlorides that are emitted.

19.5.3 Control Practices and Equipment

In aluminum-sweating operations, raking the residual metal and dross from the furnace is a critical operation from an air pollution standpoint, and hoods should be installed to capture emissions at these locations.

An afterburner followed by a baghouse is recommended as control equipment for an aluminum-sweating furnace. Baghouse filtering velocities should not exceed 3 ft/min. The afterburner must be so designed that the carbonaccous material is intimately mixed with the exhaust air and held at 1200° to $1400^{\circ}F$ for a retention time of about 0.3 sec. Secondary air may have to be admitted to the afterburner to ensure complete combustion.

The hot gases must be cooled before entering a baghouse, and radiant cooling or dilution with cold air is recommended in preference to evaporative cooling with water. If hot furnace gases are cooled with water, the aluminum chloride hydrolyzes, producing hydrochloric acid that attacks the ductwork and bags. Even the condensation from night air during shut-down provides sufficient moisture to corrode the equipment in the presence of these chemicals. Tables 19-11 and 19-12 show test results on control systems for aluminum-sweating furnaces. $\frac{3}{2}$

The wet scrubber is particularly suitable for the aluminum smelter. Spray quenching of the hot furnace gases creates steam which reacts with aluminum chloride gas to form soluble hydrated aluminum oxide and hydrochloric acid; both of these are relatively easy to remove in an appropriately designed and operated scrubber. In order to obtain adequate collection efficiency, the use of high-efficiency wet scrubbers, with a caustic solution as the scrubbing medium, has been found necessary. Table 19-13 shows typical test date on collection efficiency for various wet scrubbers. $\underline{8}/$

To adequately control emissions from chlorinating eluminum, the wet scrubber may be followed by a baghouse or electrical precipitator. At present the trend in control equipment for aluminum-fluxing emissions appears to be away from electrical precipitators and toward the scrubber-baghouse combination. $\frac{\theta}{2}$

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TABLE 19-12

DUST AND FUME EMISSIONS FROM AN ALUMINUM-SWEATING FURNACE CONTROLLED BY AN AFTERBURNER AND BAGHOUSE

| Furnace data | | | | | | | |
|-------------------------------|----------|--------------------------------------|-------------------|------------------|--|--|--|
| Type of furnace | | Reverberatory w | with integral aft | erburner | | | |
| Furnace hearth area | | 4 ft. 7 in. wide x 8 ft. 10 in. long | | | | | |
| Process weight, 1b/hr | | | 2,870 | - | | | |
| Material sweated | | Screp aluminum | • | | | | |
| | | _ | | | | | |
| Baghouse data | | | | | | | |
| Type of bags | | Tubular | | | | | |
| Filter material | | Decron | | | | | |
| Filter area, sq. ft. | | | 4,800 | | | | |
| Filter velocity, ft/min | | | 2.16 | | | | |
| Precleaner | | Settling chambe | er | | | | |
| Dist and fume data | | Settling | Furnace Charge | Bachouse | | | |
| | | Chember Inlet | Door Hood | Outlet | | | |
| | | Undiality inites | | | | | |
| Gas flow rate, sofm | | 1,360 | 5,580 | s,s50 <u></u> ∎∕ | | | |
| Average gas temperature, °F | | 350 | 204 | 150 | | | |
| Concentration, grains/scf | | 0.505 | C.C81 | 0.0077 | | | |
| Dust and fume emission, 1b/h | r | 5.89 | 3.88 | 0.58 | | | |
| Particulate control efficien | cy, % | | | 94.1 | | | |
| | | | | | | | |
| Orsat analysis at settling | | | | | | | |
| chamber inlet, volume 🖇 | | | | | | | |
| CO ₂ 6.8 | | | | | | | |
| o ₂ 8.6 | | | | | | | |
| cō 0.02 | | | | | | | |
| N ₂ 77.33 | | | | | | | |
| E₂0 7.25 | | | | | | | |
| Pontiolo cizo prolucio et ba | 5 | | | | | | |
| outlet ut d | gnouse | | | | | | |
| Lef meet as a | | | | | | | |
| | | | | | | | |
| -00 mesn. 14.1 | | | | | | | |
| Particle size analysis of -60 | D | | | | | | |
| mesh portion, wt. % | | | | | | | |
| 0 to 2 µ 5.9 | | | | | | | |
| 2 to 5 µ 32.4 | | | | | | | |
| 5 to 10 u 30.9 | | | | | | | |
| 10 to 20 u 17.7 | | | | | | | |
| 20 to 40 😐 7.7 | | | | | | | |
| < 40 µ 4.4 | | | | | | | |
| Combustible carbon in particu | ilate | | | | | | |
| discharge, dry wt. % | | | | | | | |
| Settling chamber | | | | | | | |
| inlet 83.7 | | | | | | | |
| Furnace chamber | | | | | | | |
| door hood exit 67.3 | | | | | | | |

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a/ Volume is greater at the baghouse exit than at the inlet because of leakage.

TABLE 19-13

SCRUBBER COLLECTION EFFICIENCY FOR EMISSIONS . FROM CHLORINATING ALUMINUM®/ (Scrubber Collection Efficiencies, \$)²/

| | Slot | Scrubber | Packed-Column Scrubber | | | |
|--------------|-----------|-------------|------------------------|-------------|--|--|
| | | 10% Caustic | | 10% Caustic | | |
| Contaminants | Water | Solution | Water | Solution | | |
| HCL | ,90 to 95 | 95 to 99 | 95 to 98 | 99 to 100 | | |
| CL2 | 30 to 50 | 50 to 60 | 75 to 85 | 90 to 95 | | |
| Particulates | 30 to 50 | 50 to 60 | 70 to 80 | 80 to 90 | | |

a/ Collection efficiency depends mainly upon scrubbing ratio (gal/1,000 cu.ft.), velocity of gas in scrubber, and contact time and, to a lesser extent, on other aspects of the design. These values are typical efficiencies obtained by actual tests but do not reflect the entire range of results.

More precise controls need to be developed and methods need to be found to adapt the wet scrubber to the peak chlorine "burn-off" cycle when the temperature of the aluminum furnace is raised to volatilize all residual chlorine from the system. $\frac{6}{2}$

Available data on control equipment costs are presented along with the data for secondary copper in Section 19.2.3.2.

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CHAPTER 20

COAL PREPARATION PLANTS

20.1 INTRODUCTION

An expanding market demand for high-quality fine-mesh coal has necessitated improvement and enlargement of fine-coal preparation facilities. The primary purpose of a preparation plant is to crush the coal, remove impurities, and classify the product into standard sizes. The equipment and processes involved in coal preparation are similar to those used in the beneficiation of most mineral ores. These are generally wet processes which do not, in themselves, cause air pollution problems. However, when the wet product must be dried to prevent freezing due to cold weather or to satisfy customer specifications, significant air pollution problems can occur.

The major air pollution problems associated with coal-preparation procedures are gaseous emissions from ignited coal-refuse disposal areas, dust from refuse and coal-storage piles, and particulate matter from coal dryers and de-dusting operations. $\frac{1}{2}$ The coal-cleaning process, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are reviewed in the following paragraphs.

20.2 COAL-CLEANING PROCESS

The great increase in mechanization and full seam mining has resulted in substantial increases in the impurity content of the raw coal as well as in a finer size content. As a result, the percentage of coal cleaned by mechanical methods has increased from only 24% of the total production of bituminous and lignite coal in 1942 to 65% in 1965. The amount of refuse discarded during preparation for the same period increased from 13 to 21%. Changes in the equipment used in the cleaning process were as follows:

443 Preceding page blank

| MECHANICAL | CLEANING BY PROCESS, | PERCENT ¹⁵ / |
|--------------|----------------------|-------------------------|
| Process | <u>1942</u> ª/ | 1965 |
| Jig | 47 | 46 |
| Dense-medium | 9 | 29 |
| Table | 2 | 13 |
| Pneumatic | 14 | 8 |
| Classifier | 7 | 2 |
| Launder | 13 | 1 |
| Flotation | < 1 | 2 |

 a/ Unclassified nearly 8%. Data on the amount cleaned by flotation was not collected until 1960 when 1.8 million net tons was so treated. In 1965 this figure increased to 6.9 million tons.

The principal mechanical cleaning processes are discussed in more detail in the following paragraphs.

20.2.1 Hydraulic Separation and Concentration

20.2.1.1 Hydraulic Separation - Jigging: Jigging is a process of particle stratification in which the particle rearrangement results from an alternate expansion and compaction of a bed of particles by a pulsating fluid flow. The particle rearrangement results in layers of particles which are arranged by increasing density from top to bottom of the bed. This response, developed from the many and continuously varying forces acting upon the particles, is a solid-fluid separation more related to particle density and less to particle size than any other "hydraulic type" process. The stratification is usually carried out in a rectangular, open-top container, called a jig, in which the mass of particles (termed a "bed") is supported on a perforated base through which the water flows in alternating directions. Following the particle stratification, the particle bed is physically "cut" at any desired particle density plane thus creating the desired quality products. The jig includes means for continuously introducing the raw coal, for moving the water through the coal bed in a controllable manner as well as for separating and removing the stratified particles from the system as two or more product streams. In coal preparation, this highly versatile unit operation is more preferably applied to a wide size-range of particles with top sizes up to 3 in. than to a closely sized fraction. $\frac{15}{10}$

Single jig washers have capacities from 5 to > 700 tons/hr of feed coal. The separation results attainable by jigging have favored this unit operation as optimum for creating a clean coal product as required by steam coal specifications. Although the jig is used in preparing coals which

444

are difficult to separate, its limitations to achieve both quality products and high recovery are being recognized in comparison with heavy media-based processes which make sharper separations from feeds having high "neargravity" contents. Thus the accuracy of the densimetric stratification in the upper portions of the jig bed is less precise. In jigging, as in most mineral-preparation unit operations, high recovery and product quality are interdependent and inverse process characteristics.<u>15</u>/

20.2.1.2 <u>Hydraulic Concentration</u>: Hydraulic concentrating devices depend on the physical characteristics, size, shape, and density of particles suspended in a liquid medium to effect a concentration of desired quality.

The principal fine-coal washers utilized in the United States today are wet concentrating tables, cyclones, launders, feldspar jigs and hydrotators. Of these the concentrating table is the most popular, especially in the cleaning of bituminous coal. Cyclone types are becoming increasingly important in washing both anthracite and bituminous coal. The launders and feldspar jigs are utilized on a limited scale for cleaning bituminous coal and the hydrotator is used extensively for cleaning anthracite.

Fine-coal hydraulic concentrating devices generally include those devices which clean 3/8 in. top-size coal. This is an arbitrary size which seems most consistent with actual practice, although certainly these devices can effectively clean coarser or finer coal. $\frac{15}{5}$

20.2.2 Dense Medium Separation

Dense medium separations include those coal-preparation processes which clean raw coal by immersing it in a fluid having a density intermediate between clean coal and reject. As there is a general correlation between ash content and specific gravity, it is possible to achieve the required degree of removal of ash-forming impurities from a raw coal by regulating the specific gravity of the separating fluid.

Dense medium processes offer the following advantages over other coal cleaning processes:

1. Ability to make sharp separations at any specific gravity within the range normally required even in the presence of high percentages of the feed in the range of \pm 0.1 specific gravity units.

2. Ability to maintain a separating gravity that can be controlled with \pm 0.005 specific gravity units.

3. Ability to handle a wide range of sizes (up to 14 in.).

4. Relatively low capital and operating costs when considered in terms of high capacity and small space requirements.

5. Ability to change specific gravity of separation to meet varying market requirements.

6. Ability to handle fluctuations in feed both in terms of quantity and quality. $\frac{15}{}$

Commercial application of the dense medium process is a practical extension of the familiar laboratory float-and-sink test, which is used as a standard (100% efficiency) gravimetric separation. Commercial plants do not exactly duplicate laboratory float-and-sink separations for the following reasons: suspensions, rather than true liquids, usually are used as separating media; the introduction of feed and removal of the float and sink introduce disturbances in the separating medium; agitation, or upward currents in the vessel, normally are required to keep the separating medium in suspension; and the practical need for high throughput does not allow sufficient retention time for perfectly separating near-gravity material.

Theoretically, any size particle can be treated by dense median processes; practically, the sizes treated range from about 0.5 mm. (32 mesh) to about 6 in., although sizes ranging up to 14 in. occasionally are washed. Sizes coarser than about 1/4 in. normally are treated in static dense medium separators, while the size range 0.5 mm. to about 1/4 in. normally is washed in separators employing centrifugal force; for example, the dense medium cyclone washer.15/

20.2.3 Froth Flotation

Flotation is a chemical process that depends on the selective adhesion to air of some solids and the simultaneous adhesion to water of other solids. A separation of coal from coal waste then occurs as finely disseminated air bubbles are passed through a feed coal slurry. Air-adhering particles (usually the coal) are separated from nonadhering particles, floated to the surface of the slurry and then removed as a concentrate. This process involves the use of suitable reagents to establish a hydrophobic or air-adhering surface on the solids to be floated, and to render the other solids hydrophilic. As shown in Section 20.2, the flotation process accounted for about 2% of the coal cleaned by mechanical methods in 1965.15/

20.2.4 Dry Cleaning and Concentration

The particular field of application of machines utilizing air currents as the primary separating medium is in the cleaning of the fine sizes of bituminous coal. Approximately 25,400,000 tons of bituminous coal were cleaned by air machines during 1965. No application has been found for cleaning anthracite.

Seven successful pneumatic coal-cleaning machines have been developed and introduced to the American coal-mining industry:

- 1. Peale Davis: "Pneumo-Gravity" machine
- 2. Arms "Concentrator," oscillating table
- 3. Heyl and Patterson oscillating table
- 4. "Stump Air-Flow," pulsating air jig
- 5. "Super Airflow," pulsating air jig
- 6, Ridge air jig
- 7. Phillip air jig

While not all coals can be beneficiated by air washing, the air washing of coals that are easy to clean can be readily proved advantageous. Of all the preparation methods, pneumatic cleaning is the most acceptable from the standpoint of delivered Btu cost. This is based on the premise that a percent of moisture is just as detrimental as a percent of ash.

Historically most air-cleaning devices used a vertical upward current of air through the bed of material. They differed by the method of imparting mobility to the bed and the method of removing the refuse. In general terms, the air machines were divided into three types:

1. Pneumatic jigs where the air current was pulsated.

2. Pneumatic tables where the refuse was diverted from the direction of flow of the clean coal by a system of riffles fixed to the deck.

3. Pneumatic launders where the products flowed in the same direction, and the clear coal was skimmed off the top of the bed and/or the refuse was extracted from the bottom in successive stages.

In recent years, however, the latter two types of units have declined in popularity. In fact, a survey of the industry revealed that all of the air-cleaning machines in use in 1966 depended on pulsating air as the medium of concentration. Dry concentration of coal has come a long way in recent years. Today, there are numerous examples of successful plants treating 3/8 in. by 0 and 1/4 in. by 0 coal and coal as large as 2-1/2 in. in capacities up to 350 tons/hr. Although the rate of installations has tapered off, there were over 200 full-size units of airflow equipment in operation in 1965 processing over 20 million tons of coal annually. $\frac{15}{}$

These are indications that the downward trend in new air-cleaning installations may be reversed in the not too distant future. Governmental regulations are placing greater and greater emphasis on control of both stream and air pollution originating from preparation plants. Pneumatic cleaning has the inherent advantage in this regard in that it does not contribute to stream pollution at all, as may water cleaning techniques. Similarly, although air cleaning plants admittedly can be dusty, the majority of the dust is confined within the plant and particulate emission to the atmosphere away from the plant is minor if cloth filters are used. Also, dry concentration obviously will not cause thermal or chemical pollution of the air. These considerations may therefore weigh heavily in favor of air cleaning as regulations inevitably become more stringent through increased governmental action.

A second factor which may contribute heavily to increased use of dry cleaning techniques is the fact that recent evidence indicates that less extensive cleaning of some coals may tend to minimize corrosion of fire-side boiler tubes in power plants. With some coals, extensive cleaning to minimize the ash content in the washed coal contributes to beiler tube corrosion by removing ash constituents such as alkaline earth materials (e.g., CaO and MgO) which are corrosion inhibitors while removing lesser amounts of corrosion-promoting constituents such as alkalies (e.g., Na₂O and K₂O). Thus, by cleaning at lower specific gravities to reduce ash, the ratio of corrosion promoters to corrosion inhibitors in the ash increases when preparing some coals for market. Extensive cleaning and the resultant lower yield may therefore, in some instances, contribute to corrosion rather than reducing it as is desired. In fact, it has been shown that, some run-of-mine coals are more desirable from both a corrosion and a yield standpoint than they are after cleaning.

In addition to these factors, several other major advantages are inherent to dry concentration techniques. The largest advantage is the simple fact that dry concentration requires the lowest initial capital investment and has the lowest maintenance costs of all currently used methods of upgrading fine coal. There is also continuing realization on the part of operators and consumers of the necessity for providing a dry coal for freeze-free shipments. Air-washed coal is also more amenable to oil treatment for dust control and it flows freely and does not arch in bins and hoppers. In transit, dry-cleaned coal will shed rain and arrive with only the surface of the car wetted whereas wet-washed, thermally dried coal may act as a sponge and soak up water. The rigid enforcement of stream pollution laws gives a permament advantage to dry concentration as discussed above. Admittedly, wet fine coal cannot be cleaned with air and Federal regulations cause more and more coal to be wetted at the face. However, it is more economical to pre-dry the coal for dry concentration than to dry the washed coal after it is recovered from the water. A further factor influencing the choice of pneumatic equipment is the lack of sufficient water in arid regions, localities of high altitude or cold climates. <u>15</u>/

20.2.5 Thermal Drying

The continuing increase in the percentage of minus 1/4 in. coal produced as a result of the increased use of mechanical mining methods has, over the years, tended to shift considerable portions of the work of producing salable coal to the fine-coal cleaning section of the preparation plant. Because a given weight of fine coal will contain substantially greater surface area than an equivalent weight of coarse coal, it follows that, when subjected to wet-cleaning processes, the fines will absorb and retain considerable more moisture than coarser fractions. Increased moisture pickup in the finer size complicates fine coal cleaning since beneficiation may not be limited to the removal of ash and sulfur but often must be expanded to include the additional step of thermal drying to remove excessive moisture. Thus, water which provides the medium for cleaning fine coal is in itself detrimental and, like ash and sulfur, reduces coal quality.

Removal of surface moisture by drying is done for one or more of the following reasons: (1) to avoid freezing difficulties and to facilitate handling during shipment, storage and transfer to the points of use; (2) to maintain high pulverizer capacity; (3) to reduce heat loss due to evaporation of surface moisture from the coal in the burning process, thus increasing heating efficiency; (4) to improve the quality of coal used for special purposes, such as in the production of coke, briquettes, and chemicals; (5) to decrease transportation costs; and (6) to facilitate dry coal cleaning processes. $\frac{15}{}$

Coal dryers can be grouped into six basic types. The six basic dryer types are: (1) fluidized bed; (2) suspension or flash; (3) multi-louvre; (4) vertical tray and cascade; (5) continuous carrier; and (6) drum or rotary type.15/ Figures 20-1 to 20-4 illustrate various types of thermal dryers.

Recent coal industry trends in the application of the preceding types of drying facilities are indicated in Table 20-1. The expanding general application of coal drying (from 31.5 to 58.7 million tons between 1958 and 1964) and the expanding specific application of fluidized-bed coal drying (from 10.6 to 38.3% of all coal dryers between 1958 and 1964) are noteworthy.







Figure 20-2 - Exhausting-Type Fluidized-Bed Thermal Coal Dryer, Showing Component Parts and Flow of Coal and Drying Gases<u>3</u>/



Figure 20-3 - Schematic Drawing Showing Component Parts of Flash-Drying Unit4/



Figure 20-4 - Schematic Sketch of Screen-Type, Thermal Coal-Drying Unit $\frac{4}{}$

| TABLE 2 | 0-1 |
|---------|-----|
|---------|-----|

| | | | | | | | | 15/ | |
|-----------|-------|------|----|-------|----|--------|------------|-----------|--|
| THERMALLY | DRIED | COAL | ΒY | TYPES | OF | DRYING | EQUIPMENT. | 1958-1964 | |

| Year | Rotary | Continuous Carrier | Vertical Tray and <u>Cascade</u> | <u>Multi-Louvre</u> | Suspension _or Flash | Fluidized Bed | Total |
|---------------|-----------|-----------------------|--|---------------------|-------------------------|------------------|--------------------|
| | | | <u>]</u> | Number of Plants | | | |
| 1958 | 6 | 64 | 58 | 50 | 44 | 6 | 228 |
| 1959 | 9 | 66 | 57 | 55 | 48 | 12 | 247 |
| 1960 | 11 | 63 | 58 | 57 | 47 | 16 | 252 |
| 1961 | 11 | 66 | 64 | 56 | 40 | 23 | 260 |
| 1962 | 11 | 60 | 59 | 49 | 58 | 29 | 266 |
| 1963 | 11 | 57 | 54 | 44 | 49 | 38 | 253 |
| 1964 | 9 | 56 | 50 | 42 | 49 | 49 | 255 |
| | | | | Net Tons Dried | | | |
| 19 58 | 405,057 | 7,774,090 | 5,775,347 | 9,416,368 | 4,834,324 | 3,336,929 | 31,542,125 |
| 1959 | 717,948 | 8,381,332 | 5,682,861 | 9,734,894 | 6,625,409 | 4,622,292 | 35,764,736 |
| 1960 | 771,014 | 8,099,827 | 5,023,497 | 11,469,532 | 6,479,501 | 6,025,026 | 37,868,397 |
| 1961 | 1,007,814 | 8,989,457 | 5,574,594 | 10,611,069 | 5,681,477 | 7,768,609 | 39,633,040 |
| 1962 | 1,998,254 | 8,931,633 | 5,856,812 | 9,631,349 | 8,105,551 | 12,432,991 | 46,956,5 90 |
| 1963 | 2,549,294 | 9,499,674 | 6,048,360 | 9,469,847 | 8,131,081 | 14,857,074 | 50,555,330 |
| 1964 | 1,959,496 | 9,658,965 | 5,507,522 | 9,943,032 | 9,154,519 | 22,478,004 | 58,701,538 |
| | | |] | Percent of Total | | | |
| 1958 | 1.3 | 24.7 | 18.3 | 29.8 | 15.3 | 10.6 | 100.0 |
| 1959 | 2.0 | 23.5 | 15.9 | 27.2 | 18.5 | 12.9 | 100.0 |
| 1 9 60 | 2.0 | 21.4 | 13.3 | 30.3 | 17.1 | 15 .9 | 100.0 |
| 1961 | 2.5 | 22.7 | 14.1 | 26.8 | 14.3 | 19.6 | 100.0 |
| 1962 | 4.2 | 19.0 | 12.5 | 20.5 | 17.3 | 26.5 | 100.0 |
| 1963 | 5.0 | 18.8 | 12.0 | 18.7 | 16.1 | 29.4 | 100.0 |
| 1964 | 3.3 | 16.5 | 9.4 | 16.9 | 15.6 | 38.3 | 100.0 |

20.3 EMISSION RATES FROM COAL PREPARATION PLANTS

Because coal is relatively friable, the mining and subsequent handling operations break part of the coal into dust that can be readily carried by currents of air. In a coal preparation plant mechanical handling operations such as unloading, transferring from one belt to another, screening, cleaning, and crushing in a dry state result in the generation and release of varying amounts of additional dust. The dust problem, of course, is much less serious in plants employing entirely wet processing. In addition to dust from handling operations, thermal drying of the fine coal product frequently presents another dust collection problem.

All industrial coal dryers now in use are the continuous direct contact type which employ convection as the major principle of heat transfer. Thus, hot gases and wet coal are brought into intimate contact with each other on a continuous gas flow-coal feed basis. To achieve drying, hot gases are generated in a combustion chamber and brought into contact with wet coal by a fan or blower. The size consistency of the coal being dried and the velocity of the gases through the bed are major factors in determining the air pollution potential of the plant. Emissions include products of combustion and entrained coal fines.

The calculation of emissions from thermal dryers based on the use of an emission factor is not accurate since the emissions from each type of dryer vary over a wide range depending on operating methods. The flash dryer carries all of the product into a product separation cyclone, while the fluid-bed type may carry over from 5% to 50% of the product into the cyclone collection system. For these reasons, the emissions are best calculated on the basis of average cutlet grain loadings from control equipment, as was done in a recent internal NAPCA study. $\frac{5}{}$

The NAPCA study included a survey of thermal dryers operated at eight of the largest coal companies. The survey covered about 60% of the total coal dried yearly in the U.S. It determined a total air flow from these dryers of 1.16 x 1012 scf/year.3/

This survey also indicated that 50% of the dryers were equipped with cyclones, while the remaining 50% were equipped with cyclones plus some type of wet scrubber. Total emissions were then calculated to be in the order of 300,000 tons/year assuming an outlet grain loading of 4.0 grains/ scf from cyclones, 0.15 grain/scf from low-energy scrubbers, and 0.04 grain/ scf from high-energy scrubbers.

The assumed grain loadings have been found to correspond with data in the literature and data from the West Virginia Air Pollution Control Commission. However, the fact that 50% of the dryers are equipped with only cyclones seemed low in view of a 1967 West Virginia Air Pollution Control Commission survey which indicated that less than 15% of the dryers in that state had cyclones only $\frac{6}{}$

Further analysis of the NAPCA survey showed that 50% of the dryers did have cyclones only, but these represented only 13.8% of the total air flow. On this basis, the emissions are calculated in the following manner:

 $(1.16 \times 10^{12} \text{ scf/year})(13.8\%) (\frac{4 \text{ grains}}{\text{scf}}) (\frac{1 \text{ ton}}{14 \times 10^6 \text{ grains}}) = 45,700 \text{ tons/year}$

 $(1.16 \times 10^{12} \text{ scf/year})(86.2\%)(\frac{0.15 \text{ grains}}{\text{scf}})(\frac{1 \text{ ton}}{14 \times 10^6 \text{ grains}}) = 10,700 \text{ tons/year}$

Total 56,400 tons/year

If this represents about 60% of the coal dried, the total annual particulate emissions from thermal dryers are 94,000 tons/year.

A second method of calculating emissions, for comparison purposes, can be done on the basis of emission factors for the dryers. Data in Reference 17 show that the emission factor for the outlet of the dryer cyclone is 12 lb/ton for flash dryers and 13 lb/ton for fluid bed dryers. The emission factor for the other types of dryers is probably somewhat lower since their mode of operation should not carry out as much dust to the cyclone. This includes the rotary, continuous carrier, cascade, and multi-louvre dryers. $\underline{15}$ / However, it might be assumed that the average overall emission factor is 12 lb/ton, although this may be somewhat high. The calculation of the emissions also involves the question of what percent of the coal is dried in units that are equipped with wet scrubbers. The two calculations given below show the quantities emitted on the basis of two different assumptions. The efficiency of the wet scrubbers has been estimated at 95% for both cases.

a. It is assumed that 50% of the coal is dried in units equipped with wet scrubbers. This is similar to the NAPCA study which assumed that 50% of the total air flow for all dryers is cleaned in wet scrubbers. The NAPCA survey actually showed that 50% of the number of dryers were equipped with wet scrubbers and it was presumed that this also represents 50% of the total air flow. The emissions for this assumption are calculated as: $(73,000,000 \text{ tons/year})(\frac{2,000 \text{ lb/ton}}{12 \text{ lb/ton}})(1 - (0.50)(0.95)) = 230,000 \text{ tons/year}$

b. It is assumed that 85% of the coal is dried in units equipped with wet scrubbers. This assumption is based on our analysis of the data in the NAPCA survey and is supported by information from the West Virginia Air Pollution Control Commission. The emissions for this assumption are calculated as:

$$(73,000,000 \text{ tons/year})(\frac{12 \text{ lb/ton}}{2,000 \text{ lb/ton}})(1 - (0.85)(0.95)) = 83,000 \text{ tons/year}$$

These results support the previously discussed emission calculations but do not resolve the question of the extent to which thermal dryers are equipped with wet scrubbers. Based on the present information and calculations described in this section it is felt that the emission quantity of 94,000 tons/year is the more accurate figure.

Insufficient data were available to calculate particulate emission rates from the secondary sources. Also, data could not be found on particulate emissions from burning coal refuse banks. Reference 7 reports an emission level of 400,000 tons/year of particulate from coal refuse. This figure was calculated assuming that the emission factor for refuse piles corresponds to that for open burning. This is a questionable assumption, and the number of 400,000 tons/year is considered a gross estimate.

20.4 CHARACTERISTICS OF COAL-PREPARATION-PLANT EMISSIONS

The chemical and physical properties of coal-preparation-plant emissions are summarized in Table 20-2. Particulates generated during thermal drying present fire and explosion hazards both within drying chembers and cyclones, fans, and duct work beyond the drying chamber.

20.5 CONTROL PRACTICES AND EQUIPMENT FOR COAL-PREPARATION PLANTS

20.5.1 Thermal Drying Plant

In most thermal drying plants a system of control units is utilized with dry collectors serving as primary dust separators and wet collectors serving as secondary dust separators. $\frac{\theta}{2}$

TAFLE 20-2

EFFICENT CHARACTERISTICS - COAL PREPARATION PLANTS*

| A. <u>includate</u> | | | | | | | |
|-------------------------|---|----------------|----------------------|---------------------|----------------------------------|----------------------------|-----------------|
| <u>Agunae</u> | Farticle Size | Solids fonding | Chemical Composition | larticle Gensity | Electrical <u>Resistivity</u> | Moisture <u>Content</u> | <u>Texistry</u> |
| t. chermal Dryer | | | | | | | |
| a) Malti-louvre type | Cyclone Oxtlet 100 < 40, 58 < 5 10 < 1 (Joulter Counter) | 2-200* | Coal Dust, Fly Ash | | | | |
| o) fluid-Bed type | Cyclone Outlet 90 < 10, 80 < 5 40 < 2 (Whitby Centrifuge Analysis) Also see Figure 20-5 | | | | | | |

| Source | Sclubility | <u>Wettability</u> | Hygroscopic <u>Characteristics</u> | Flammability or Explosive limits | Handling <u>Characteristics</u> | Optical <u>Froperties</u> | <u>Gdor</u> |
|---------------------|------------|--------------------|---------------------------------------|--|------------------------------------|------------------------------|-------------|
| 1. Thermal Dryer | | Hydrophobic | | Fire or explosion hazards may exist both within drying chambers and cy- clones, fans, and duct work beyond drying chamber. | | | |

B. <u>Carrier Sas</u>

| Source | <u>Flowrate</u> | <u>Temperature</u> | Moisture <u>Content</u> | Chemical <u>Composition</u> | <u>Texicity</u> | <u>Corrosivity</u> | <u>Cdor</u> | Flammability or Explosive <u>limits</u> | Optionl Properties |
|----------------------|---------------------------------------|--------------------|----------------------------|---|-----------------|--------------------|-------------|---|-----------------------|
| 1. Thermal Dryer | | | | | | | | | |
| a) Flash type | a) 20-37 | | | CO ₂ ,N ₂ ,O ₂ , | | | | | |
| b) Conveyor type | a) 33-85 | | | 00, 202 | | | | | |
| c) Fluid-Bed type | a) 21-135 (22 plants) avg. 81.6 | 9C-400 | | | | | | | |

See Ocding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.
Grains/actual cubic foot.

2


Figure 20-5 - Typical Particle-Size-Analysis Curves for Material Going to Cyclones (Coal Thermal Dryers)<u>16</u>/

A recent NAPCA survey 5/ indicated that all thermal coal dryers are equipped at least with dry cyclones, and about 50% also have low-energy wet scrubbers while about 4% have high-energy scrubbers.

The cyclones used as primary collectors can produce an exit solids loading of 3 to 3.5 grains/cu ft.9/ However, this loading can exceed 12 grains/cu ft in some cases.10/ The cutlet grain loading from a low-energy wet scrubber (preceded by a cyclone) is usually about 0.15 grain/scf, although it may vary from 0.05 to 0.42 grain/scf.5/

One coal company described the use of impingement-screen liquid scrubbing units but they have never operated satisfactorily because the impingement screens were easily blocked. These units had to be bypassed because of uncontrollable fires in them and the danger of explosion. They were later replaced with a different type of wet scrubber with a water usage rate of 3 gal/1,000 cu ft giving an exit grain loading of 0.035 to 0.048 grain/cu ft.

The installation of Venturi-type scrubbers at another coal company for cleaning the exhaust from a fluid-bed dryer is described in Reference 2. Installation was preceded by investigation of a 1,000 cfm test unit. Grain loading of the gases leaving the dry collectors was 3 grains/ sof (see Figure 20-6). The outlet grain concentration loading from a Venturi scrubber as a function of pressure drop is shown in Figure 20-7. As a result of the tests, a commercial-size unit was installed for the 175 ton/hr dryer handling 95,000 cfm with a specified cutlet loading of 0.05 grain/sof. This loading required 1,200 hp. for the combined pressure drop of 42 to 44 in. of H_2O of which about 20 in. is required for the Venturi. The installed cost was about \$1.00/cfm of gases, although much existing equipment was utilized. If existing equipment had not been available, it was estimated that the cost would probably have been \$1.50/cu ft.2/ These costs compare closely with general cost figures given in Appendix A.

Another recent Venturi scrubber installation is reported to have been installed at a cost of 0.90/acfm. This 35-in. w.g. Venturi scrubber was installed downstream of the cyclones, which served a 400 ton/day fluidbed dryer, and handled approximately 200,000 acfm of gas. This installed cost of 0.90/acfm also compares very closely with the cost figures in Appendix A. However, this actual cost figure includes stainless steel construction for all surfaces in contact with water. $\frac{14}{2}$

Careful consideration should always be given toward elimination or reduction of dust at its source. In connection with thermal dryer installations, it has often been found necessary to evaporate all water to attain successful operation of the dryer itself. This requirement leads to very high dust loadings to the collectors. It may be found possible to redesign or modify the thermal dryer to permit successful operation at a level of evaporation whereby 0.5 to 1.0% surface moisture remains on each coal particle. The dust loading to secondary collection equipment can sometimes be substantially reduced, providing increased collector efficiency and more satisfactory final emission to the atmosphere as well as reduced recirculation of ultra-fine coal in a plant water circuit.⁸/

20.5.2 Coal Refuse

Coal refuse, which is discarded as a part of the coal preparation, forms large piles which often catch on fire. A survey in 1962 identified 488 burning mine waste piles. $\underline{11}$ / These are a source of particulate and gaseous pollution but no information has been located that would allow an assessment of the quantity of particulate emitted.

One of the methods used to control these coal refuse bank fires involves the use of high-pressure water nozzles followed by compaction. Overall cost has been estimated at 0.65/cu yard of material.12/



Figure 20-6 - Particle Size Distribution of Effluent2/ (Fluid-Bed Dryer, Grain Loading, 3 Grains/scf)



Figure 20-7 - Venturi Scrubber Performance on Coal Dryer²/ Effluent (Inlet Loading, 3 Grains/scf)

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CHAPTER 21

CARBON BLACK

21.1 INTRODUCTION

Carbon black is ultrafine soot manufactured by the burning of hydrocarbons in a limited supply of air. This finely divided material (10 to 400 μ in diameter) is of industrial importance as a reinforcing agent for rubber and as a colorant for printing ink, paint, paper, and plastics.

Three basic processes currently exist in the United States for producing this compound. They are: the furnace process, accounting for about 83% of production; the older channel process, which accounts for about 6% of production; and the thermal process (1970 figures). Atmospheric pollutants from the thermal process are negligible since the exit gases which are rich in hydrogen are used as fuel in the process. In contrast, the pollutants emitted from the channel process are excessive and characterized by copious amounts of highly visible black smoke. Emissions from the furnace process consist of carbon dioxide, nitrogen, carbon monoxide, hydrogen, hydrocarbons, particulate matter, and some sulfur compounds. For the furnace process, collection equipment is an integral part of the process for collection of the product.

The manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment are discussed in the following sections.

21.2 MANUFACTURING PROCESSES

The fundamental steps in carbon black (frequently referred to as black) manufacturing, regardless of the process used are:

- 1. Production of black from feed stock,
- 2. Separation of black from the gas stream, and
- 3. Final conversion of the black to a marketable product.

In the channel and furnace process, the black is produced by burning the feed stock. In the thermal process, the feed stock is thermally decomposed into black and hydrogen; there is no burning. $\frac{1}{2}$

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21.2.1 Furnace Process

The furnace process is subdivided into either the gas or oil process depending on the primary fuel used to produce the carbon black. In both cases, gas (gas process) or gas and oil (oil process) is injected into a reactor with a limited supply of combustion air.

21.2.1.1 Gas-Furnace Process: Figure 21-2 shows a schematic flow diagram of the gas-furnace process. The furnace or reactor is refractory lined and is designed with special inlets or ports for natural gas and for air. An annular mixing orifice formed of refractory material is located within the converter. The flue gases, largely carbon monoxide, hydrogen, nitrogen, and water vapor, carry the hot carbon from the furnace through a long horizontal brick-lined flue, to a cooling tower where water sprays reduce temperatures from 1800 to 500°F. Agglomeration of the fine black particles occurs either in an electrostatic field provided by an electrical precipitator or by centrifugal force in cyclone collectors. When the electrical precipitator is used, about 30%, depending on the grade of black produced, is shaken off the electrodes into the collecting hopper attached to the bottom of the precipitator. The remainder of the flocculated black is caught, to a very large extent, in the cyclone collectors and bag filters which generally follow the precipitator. The gases including the carbon monoxide and condensable vapors (steam) are discharged through the stack of the final collector directly to the atmosphere. The black is carried to the finishing area by screw or pneumatic conveyors. \underline{l}

21.2.1.2 <u>Oil-Furnace Process</u>: The oil-furnace process is similar to the gas-furnace process except that the raw material used is oil instead of natural gas and the furnace design is also different. Each producer has developed and patented furnace designs. The design of the furnaces and burners constitutes an important part of carbon black technology. A flow diagram of the oil furnace process used at a large modernized plant is shown in Figure 21-1.

21.2.2 Channel Process

A schematic flow diagram of the channel process is shown in Figure 21-3. A typical channel plant may cover many acres and may be composed of several hundred steel buildings (called "burner houses" or "hot houses") housing some 2,000 to 4,000 flames and the appropriate number of channel irons, upon which the flames impinge and deposit carbon black.



Figure 21-1 - Flow Diagram of Oil-Furnace Process1/



Figure 21-2 - Flow Diagram of Gas-Furnace Process1/



Figure 21-3 - Flow Diagram of Channel Process

Air is supplied through openings at the base of each building. The spent gases and products of combustion pass out of the hot house through openings and stacks in the roof. Gas rates are on the order of 45 to 80 cu ft/24-hr day/burner tip, and may range from 150,000 to as high as 260,000 cu ft/24-hr day/hot house. Combustion is controlled by natural draft openings in the top and bottom of each house. Draft control is visual and dependent upon the skill of the operators. A large excess of air holds the temperature of the house below 1000°F. However, this large excess of air does not completely burn the natural gas because the combustion time from the gas tip to the channel is very short, and complete mixing of air and gas in this interval does not occur. 1/2/

Screw conveyors pick the black up from the various houses and convey it to the processing area where an air separator removes particles of grit (hard calcined carbon). The fluffy black is then further processed through a high-speed harmer mill (micropulverizer) to break up lumps that form in the conveyors, and also to render any remaining grit particles extremely fine. It also pulverizes oversize product pellets that recycle from downstream screening. The black then passes to the pelletizing step and subsequent packaging.

21.2.3 Thermal Process

Thermal blacks are produced by the thermal decomposition of natural gas in the absence of air or flame. (1) The thermal process, Figure 21-4, comprises: (1) the cracking units (termed generators) consisting of checkerwork furnaces; (2) coolers; (3) carbon collectors; and (4) packing. The furnaces are 12 to 14 ft. in diameter and 25 to 35 ft. high, and consist of a riveted steel shell, insulated and lined with refractory brick and filled with checker brick similar to that of a blast-furnace stove. $\frac{3,4}{2}$



Figure 21-4 - Flow Diagram of Thermal Process 1/

Thermal black differs from other carbon black operations in that it is cyclic rather than continuous $\frac{5}{}$ The process is intermittent, the checkerwork being first heated to 2400 to 2800°F by the complete combustion of a blast of natural gas and air introduced at the bottom. When the bricks are brought up to the required temperature, the stack (vent to the atmosphere) is closed and natural gas is admitted from the top of the furnace for the decomposing part of the cycle. Thermal black is produced when the heat from the brickwork decomposes the gas into a smoke of thermal carbon plus quantities of hydrogen.⁶ When the bricks become cool, the natural gas flow is shut off and the remaining carbon smoke is flushed out into the cyclone separators. The complete cycle for a single generator requires approximately 10 min. Of this time, about half is required for heatup and half for the cracking process.⁵

The effluent gas from the generator, which is on the production cycle, consisting of about 90% hydrogen, 6% methane, and a remaining complex mixture of higher hydrocarbons, carries the suspended black.⁷/ The smoke from the furnace is passed by countercurrent flow through a watersprayed cooling tower to cool the smoke to about 125°C. This temperature allows it to be safely filtered through the cloth bags in the collectors and yet not wet either the bags or the carbon. Recovery is about 40 to 50% of the carbon in the fuels.

The collected black is transported by screw conveyors to the processing area where it is passed through a magnetic separator, screen, and hammer mill. It may then be packed through an auger packer as fluffy black in 25 or 50 lb. paper bags, or passed through pelletizing equipment, which transforms the fluffy black into a free-flowing product.

21.3 EMISSION SOURCES AND RATES

The most important factor affecting emissions is the basic manufacturing process and its inherent efficiency. Thus, emissions from the channel black process are excessive, while those from the thermal process are negligible. Particulate emissions from the furnace process are affected by the type of collection equipment used. Gaseous emissions are largely determined by the overall yield, type of fuel (that is, liquid or gas), the reaction time and temperature, the ratio of gas to oil in the feed, and the amount of combustion air. $\frac{8}{}$

Additional emissions may result from the conveying, grinding, screening, drying, and packaging operations at a carbon-black plant. Poorly designed or maintained equipment can result in leaks and spills. Spillages of the fluffy black before pelleting are the source of pollution. After pellets have ceased to form in the dry pelleting process the drum is emptied, and reloaded with fresh loose black, and reseeded, and then pelleting resumes. The emptying of the drum will naturally result in black spillage.

Maintenance operations will often result in carbon-black spillage. The cleaning of clogged screens, located either at the top of the storage tank into which the finished black is screened or at the pelleting section where oversized pellets are screened out, causes black to be discharged into the atmosphere. Whenever a production line is plugged, the remedial measures are either to pound the line or use a vibrator. If this proves ineffective, high-pressure air is used to dislodge the black. Carbon black is generally emitted to the atmosphere in this operation.

Carbon black is so finely divided that whenever a leak develops in plant equipment, such as in the conveyor system, or in the bins, or at the bagging equipment, black will seep out into the atmosphere.

Table 21-1 summarizes emission rates for carbon black manufacture. Emission factors for the channel black process are questionable because of a complete absence of emission data. $\frac{8}{}$ Emissions due to conveying, grinding, etc., were not estimated because of the variability of these emissions. $\frac{8}{}$ Particulate emissions currently total about 93,000 tons. The channel process, which accounts for only about 6% of the total production, emits nearly 90% (82,225 tons) of the particulates.

21.4 CHARACTERISTICS OF EFFLUENTS FROM CARBON-ELACK MANUFACTURE

Limited data were found on the chemical and physical properties of effluents from carbon-black plants. Available data are summarized in Table 21-2. The particle size of the emitted carbon black is extremely fine (i.e., of the order 0.1-0.5 μ). The carbon monoxide content of the offgas may be as high as 20% by volume.

21.5 CONTROL PRACTICES AND EQUIPMENT

The channel process emits large quantities of carbon because no way has yet been developed to separate the escaping black and avoid upsetting the burning conditions, which in turn would drastically affect yield and quality. $\frac{1}{2}$ Production by the channel process has declined over the years, and at present only 3 plants are known to be in operation. $\frac{9}{2}$ These three plants produce a total of approximately 71,500 tons/yr representing about 6.0% of the total carbon black produced in the U. S.

TABLE 21-1

PARTICULATE EMISSIONS FROM THE MANUFACTURE OF CARBON BLACK Application Efficiency Net Quantity of Emissions Emission of Control of Control Control Material C_c c_t $C_c \cdot C_t$ (tons/yr) Source Factor 2,300 lb/ton I. Channel process 71,500 tons, 0.0 0.0 0.0 82,000 product carbon black II. Furnace process 60 lb/ton156,000 tons, 5,000 A. Gas product* carbon black B. Oil 1,180,000 tons, $10 \ lb/ton$ 6,000 _ _ _ ---carbon black product* 93,000 Total

* Controlled emission factor. Cyclone followed by scrubber; 97% efficiency.

****** Controlled emission factor. Fabric filter; 99.5% efficiency.

472

TABLE 21-2

EFFLUENT CHARACTERISTICS - CARBON BLACK

| Sou | rce | Particle Size | Solids Loading | Chemic Composi | al tion | Particle Density | Electrical Resistivity | Mici Cor | sture itent <u>Toxici</u> | <u>ty</u> |
|-----|-----------------------------|------------------------------|------------------------------|----------------------|--|--------------------------------------|---------------------------|-------------|-------------------------------------|-----------------------|
| Ι. | Thermal Process | 0.1-0.5 | | Carbo | on 1- (B | 5 lb/ft ³ ulk Density) | | | | |
| 11. | Furnace Process (oil) | 0.02-0.4 | 10-50 (Reactor Outlet) | Carbo | >n | | | | | |
| В. | Carrier Gas | | | | | | | | | |
| Sou | rce | Flowrate | Temperature | Moisture Content_ | Chemical Composition | Toxicity | <u>Corrosivity</u> | <u>Odor</u> | Flammability or Explosive Limits | Optical Properties |
| Ι. | Furnace Process | | | | | | | | | |
| | a. Oil | a) 3- 5 b) 120-150 | | | Typical Compo CO2: 3.0 O2: 0.3 CO: 6.0 H2: 8.0 | sition | | | | |
| | b. Gas | a) 3 b) 360 | | | $C_2H_2: 0.5$ CH_4, C_2H_6 etc.: 0.2 $N_2: 41$ $H_2O: 40$ | | | | | |

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

A. Particulate

For the firmace process, collection equipment is an integral part of the process for collection of the product. The types of equipment commonly used for effectively separating and collecting finely divided black from a gas stream are agglomerators, electrostatic precipitators, cyclone separators, scrubbers, and baghouses. $\underline{1}/$

In old plants, the black-laden gases are first cooled to about 450 to 550°F, and then passed through a dry electrostatic precipitator which agglomerates the black. The increased diameter and density of the agglomerated black permits it to be removed effectively from the gas stream by using several cyclone separators. Together these have a recovery efficiency of 85 to 90%, leaving about 10% of the initial carbon in the off-gases. Collection or removal of nearly all the remaining 10% is accomplished when the off-gases are passed through either a bag filter to give 99% recovery or a wet-scrubber system with 37 to 98% collection overall. The scrubber system may comprise water scrubbing and wet electrostatic precipitation or washing in a slot scrubber followed by a wet cyclone scrubber. In order to recover the black, the slurry is circulated back to the reactors where it is used for quench. The black is thus re-entrained in the snoke and recovered.

The electrostatic precipitator is rapidly disappearing from use in the carbon-black industry. Even at some older plants they are no longer in operation, since they have been shut off to save operating and maintenance expenses. They are not energized, and no carbon black is removed from them. The current trend is to do without electrostatic precipitators in new furnace-black plants. The trend is to a mechanical agglomeration device (i.e., cyclones) placed ahead of bag filters. When the older plants were built, suitable filters had not yet been developed, and the use of cyclones by themselves was inadequate.

In recent years, the carbon-black industry turned to agglomeration apparatus of lower first cost and of equivalent or superior performance compared with the electrostatic precipitator. Accordingly, in most plants, the black-laden gases, cooled to about 550° F, enter a series of large diameter cyclones (usually four) which separate about 70% of the carbon. The gases with the remaining black may be cooled further to about 360° F. They are then passed to a bag filter which separates the remaining black from combustion gases for an overall recovery of 99+%.

In some plants, cyclones (as well as electrical precipitators) have been eliminated and the design for carbon-black separation calls for a system with an agglomerating device and a single bag filter connected in series. $\frac{1}{2}$

21.5.1 Control Equipment

21.5.1.1 Wet Scrubbers: Wet scrubbers, despite their high recovery efficiency, have very limited use in the United States for separating carbon black from a gas stream. Nor are wet electrostatic precipitators currently in use by the carbon black industry in this country.

21.5.1.2 Cyclone Separators: Two main types of cyclone separators are utilized in carbon-black collection: (1) medium-efficiency or high-capacity cyclones, generally of fairly large diameter and used singly; (2) modern high-efficiency, high-velocity cyclones, usually nested in groups of two, four, eight, or more. Primary cyclones are of various sizes. A typical cyclone used (old design) is 11 ft. in diameter and 35 ft. high. The cyclone based on the new design (high efficiency) is 6 ft. in diameter and 15 ft. high. Secondary cyclones are only 54 in. in diameter and 10 to 12 ft. high. Cyclones have an agglomerating effect on the black because of the centrifugal motion created within the equipment.

21.5.1.3 <u>Baghouses</u>: In bag filters, the black-laden gas stream enters the open bags at the bottom and passes through the cloth, depositing solids on the cloth, and the clean gas discharges to atmosphere. The bags are cleaned by reversing the flow of the gas and repressuring. The temperatures involved rule out the use of cheap reliable filter media, such as cotton, wool, and "orlon." The maximum working temperature of these materials is about 275°F. These filters faced a considerable corrosion problem until bags of woven glass fabric made from staple yarn were introduced. Filtration can thus be carried out at temperatures up to 550°F. However, the brittle fibers cannot stand up to the shaking required to free the black collected on the cloth, and the cloth wears out quickly. To solve this problem, cloth manufacturers coat the fibers with resins and silicone oils to help fibers slip over each other more easily.

In carbon-black manufacture, bag filters are eliminating the need of electrostatic precipitators, scrubber units, and even cyclone separators.

Filter-bag life varies greatly depending on several factors, such as gas-to-cloth ratio (or how heavily the cloth is loaded), the grade of black being produced, and the type of cloth used. Typical bag life is about 12 months.

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CHAPTER 22

PETROLEUM REFINING

22.1 INTRODUCTION

The petroleum industry can logically be divided into three major divisions: production, refining, and marketing. Production includes the operations involved in locating and drilling oil fields, removing oil from the ground, pretreatment at the well site, and transporting the crude to the refinery. Refining is limited to operations necessary to convert the crude into salable products. Marketing involves the distribution and sale of finished petroleum products. Only the refining operations will be considered in this discussion.

The emission of particulate matter from refineries may originate from catalyst regeneration, decoking operations, airblown asphalt stills, sludge burner, boilers, process heaters and incinerators.^{\pm} Flare systems may also produce particulate emissions because of formation of carbon particles but this is a result of the combustion process at the flare.

Production processes, particulate emission sources, particulate emission rates, effluent characteristics, end control practices and equipment for petroleum refining are discussed in the following sections.

22.2 EMISSION SOURCES

Refineries vary greatly in both the quantity and type of emissions. The most important factors affecting refinery emissions are crude oil capacity, air pollution control measures in effect, general level of maintenance and good housekeeping in the refinery, and the processing scheme employed. The emissions which may contribute to air pollution are sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and malodorous materials. Other emissions of lesser importance include particulates, aldehydes, ammonia, and organic acids. Table 22-1 indicates potential sources of the various contaminants from refineries and emphasizes the variety of equipment and operations which must be considered in a complete survey of refinery emissions. 15/

Many processes and operations in oil refineries necessitate the use of high-pressure steam, or require feedstock at an elevated temperature. A wide variety of boilers and process heaters are used to fill these needs. Heaters may be of unique design, although most units are the box, or cylindrical, vertical type. Boilers are generally of conventional design.

477

TABLE 22-1

POTENTIAL SOURCES OF SPECIFIC EMISSIONS FROM OIL REFINERIES

| Emission | Potential Sources |
|--------------------|---|
| Oxides of sulfur | Boilers, process heater, catalytic cracking unit regenerators, treating units, H ₂ S flares, decoking operations |
| Hydroc arbons | Loading facilities, turnarounds, sampling, storage tanks, waste-water separators, blow-down systems, catalyst regenerators, pumps, valves, blind changing, cooling towers, vacuum jets, barometric condensers, air-blowing, high-pressure equipment handling volatile hydrocarbons, process heaters, boilers, compressor engines |
| Oxides of nitrogen | Process heaters, boilers, compressor engines, catalyst regenerators, flares |
| Particulate matter | Catalyst regenerators, boilers, process heaters, decoking operations, incinerators |
| Aldehydes | Catalyst regenerators |
| Ammonia | Catalyst regenerators |
| Odors | Treating units (air-blowing, steam-blowing), drains, tank vents, barometric condenser sumps, waste-water separators |
| Carbon monoxide | Catalyst regeneration, decoking, compressor engines, incinerators |

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The fuel may be refinery gas, natural gas, heavy fuel oil, coke, or combinations, depending on economics and operating conditions. Particulate emissions from boilers and process heaters are included in the stationary combustion sources discussed in Chapter 6.

During catalytic cracking, reforming, and hydrogenation, coke formed on the surface of the catalyst is burned off in regenerating vessels by controlled combustion. The flue gases from the catalyst regenerator may contain fine catalyst dust, and the products of combustion of the coke may include some of the impurities contained in the charging stock. Cracking unit regenerators are usually large, operate continuously, and are potential sources of dust, carbon monoxide, hydrocarbon (nearly all methane), and sulfur-oxide emissions. Reforming and hydrogen treating units usually regenerate catalysts intermittently and are a less important source of emissions. 15/

The catalyst regenerator is a major particulate emission source, and it is discussed in more detail in the following sections.

22.2.1 Catalyst Regenerator

Catalytic cracking is the backbone of the modern refinery. The capacity of these units amounts to about 4 million barrels per day, equivalent to about 40% of total refinery crude capacity. Cracking over a catalyst, usually an alumina-silicate, is accomplished at slightly greater than atmospheric pressures and about 900°F. It gives a higher gasoline yield and better quality gasoline than thermal cracking. The charge stock is usually gas oil, a distillate intermediate between kerosene and fuel cil. Catalytic cracking yields a "synthetic crude" which is separated into gaseous hydrocarbons, gasoline, gas oil, and fuel cil.

During the cracking process, which is usually continuous, coke deposits on the catalyst and is burned off in separate regenerating vessels.

Catalytic cracking units may be classified according to the method used for catalyst transfer. There are four main methods: (1) fixedbed, utilizing a number of reaction-regeneration chambers in a batch-type operation, (2) moving-bed, (3) fluidized-bed, and (4) a once-through catalyst system which does not attempt catalyst regeneration. Fixed-bed and once-through systems are no longer used to any great extent. The moving-bed system, typified by the Thermofor Catalytic Cracking Units (TCC) and the Houdriflow Units, and the fluidized-bed or Fluid Catalytic Cracking Units (FCC), are now almost universally used in refinery operations. A typical flow diagram of a fluid cracking unit is shown in Figure 22-1. In the production of high-octane gasoline, oil and powdered catalyst are mixed in a reactor. Spent catalyst, containing residual carbon (or coke) from the catalytic cracking process taking place in a reactor, is mixed with combustion air and fed to the regenerator in order to reactivate the catalyst by burning off the coke or residual carbon formed on the catalyst during the cracking process. After regeneration, the hot incinerated catalyst is mixed with crude oil and is transported back to the reactor where the oil is distilled off ("cracked") and the cycle repeated.

The gaseous products of combustion from the top of the regenerator are exhausted through a series of mechanical collectors which return their catch directly to the fluid bed. The finer fractions of the catalyst escape along with the discharged gas. The exhaust gases may be further cleaned with additional cyclones or an electrostatic precipitator.

In order to protect the collectors and other down-stream equipment against high-temperature damage, temperature control water sprays are used in the combustion zone over the fluid bed. The regenerator is followed by waste-heat steam boilers in order to recover some of the heat energy and reduce the gas temperature. Further gas cleaning is then accomplished by electrostatic precipitators in many plants.

Large amounts of carbon monoxide gases are discharged with the regeneration flue gases of an FCC unit. The carbon monoxide waste-heat boiler is a means of using the heat of combustion of carbon monoxide and other combustibles, and the sensible heat of the regeneration gases. Regeneration gases from an FCC unit are normally delivered to the inlet of the CO boiler at about 1100°F and 2 psig. $\frac{4}{}$

22.3 CATALYST REGENERATOR EMISSION RATES

Due to the high extent of control emission rates from catalytic cracking units could not be calculated using the methods of emission factors. Available data indicate that one 6,000 BPSD (barrel/stream day) FCC unit emits 0.135 ton of dust per day based on 0.016% dust in the air stream out of the final separator. 13/ The total capacity of FCC units is 3,609,000 BPSD. By direct ratio:

Emission from FCC = $\frac{3,609,000}{6,000}$ (0.135 ton/day)

= 81 tons/day = 24,000 tons/year



Figure 22-1 - Flow Diagram of Fluid Cracking Unit $\frac{10}{}$

The emissions may be calculated by another method. Information from Reference 14 indicates catalyst "losses" range from 0.05-0.1 lb/bbl fresh feed. Using the average of 0.075 lb/bbl, the emissions would be:

 $(0.075 \frac{1b}{bbl})(3.609 \times 10^6 \frac{bbl}{day})(330 \frac{day}{yr})(\frac{Ton}{2,000 lb}) = 44,700 \text{ tons/year}$

The latter figure of 44,700 tons/year is probably more representative because the former figure is based on data from only one plant.

22.4. EFFLUENT CHARACTERISTICS

Available data on the chemical and physical properties of effluents from catalytic cracking units are summarized in Table 22-2. Particle size of particulates at the inlet of secondary collectors ranges from 10-45 wt. % less than 2 μ .

22.5. CONTROL PRACTICES AND EQUIPMENT FOR FCC UNITS

22.5.1 Cyclones

The use of cyclones, in one, two or three stages is common practice for control of dust from FCC units. In typical installations, multistage cyclones are located in the regenerator vessel for catalyst recovery and re-utilization. In some cases external cyclones are installed to reduce the particulate content of the flue gases. Catalyst dust losses from the regenerator equipred with internal cyclones and, in some cases, supplemented by external cyclone equipment can range in the order of 100 to 350 lb/hr.

The maximum efficiency which can be obtained with external cyclones would depend on the efficiency of the preceding cyclones, but it may range as high as 90% recovery of the solids leaving the preceding vessel. The installed cost for a set of external cyclones designed for maximum efficiency will run between \$1.25 and \$1.75/acfm of gas leaving the vessel (before the pressure regulating valve) for units discharging between 40,000-60,000 acfm of gas. The cost of a system designed to recover approximately 60% of the solids leaving the vessel would be about half as much as the system designed for maximum efficiency.⁷ These costs are two to three times higher than the general cost figures in Appendix A but installation in a refinery FCC unit is a special application involving different materials of construction, higher pressures and more difficult installation problems.

TAUE 20-0

EFFLUENT_CHARACTERICTICS - PETROLEUM REFINIEG*

A. Particulate

| Source | Particle Size | Solids Loading | Chemical <u>Composition</u> | Particle Density | Electrical <u>Resistivity</u> | Moistare <u>Content</u> | Tixing |
|--------------------------------|--|----------------|---|---------------------|----------------------------------|----------------------------|--------|
| Petroleum Refining | | | | | | | |
| Catalytic cracking unit. | Cyclone Inlet: 21-45 < 2 avg. 27 < 2 33-72 < 5 avg. 49 < 5 47-89 < 10 avg. 64 < 10 Precipitator <u>Inlet (Bahco)</u> 10 < 2, 20 < 4 35 < 8, 40 < 10 62 < 25 | 5-25 | Dependent on catalyst type. Varies from natural earth clays to the synthetic varieties which are mostly oxides of silica and alumina. | 2.2-3.1 | See Figure 22-2 | | |

B. <u>Carrier Gas</u>

| Source | Flowrate | Temperature | Moisture Content | Chemical Composition | Toxicity | Corrosivity | <u>Odor</u> | Flammability Limits | Optical Froperties |
|-------------------------------|-----------------------|----------------------------|---------------------|--|-------------|-------------|-------------|------------------------|-----------------------|
| Catalytic cracking unit | (a) 70.5 (l plant) | Outlet Temp. 10:50-1150 | 10-30 | Dry: Flue Gas CO ₂ : 6-9 CO: 6-7 O ₂ : 1-3 N ₂ : 81-87 SO ₂ : trace Hydrocarbons: trace | Contains CO | | | | |

+ See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

483



Figure 22-2 - Electrical Resistivity of Dust from Catalytic Cracking $Unit \frac{10}{}$ (Dust at Precipitator Inlet)

The application of a special third-stage, high-efficiency, multipletube, swirl-vane type centrifugal separator to FCC units is described in two recent articles. $\frac{9}{9}$ This third-stage separator allows the main body of the gas stream to be utilized in a turboexpander without serious problems.

22.5.2 Electrostatic Precipitators

A third mechanical cyclone external to the regenerator improves dust removal but generally it is not sufficient to comply with stringent emissions standards. Electrostatic precipitators have been used for this service with good success and some refiners have reported catalyst dust losses as low as 40-60 lb/hr, although typical current installations have higher emission rates.³/ The precipitator may be preceded by a power recovery turbine or a CO boiler. Schematic flow diagrams are shown in Figures 22-3 and 22-4.⁶/

The fluid-bed catalytic cracking units may emit 0.0009% of the catalyst circulated when equipped with electrical precipitators, or 0.005% when not so equipped. This may be contrasted with moving-bed catalytic crackers that emit 0.002% of the catalyst circulated when equipped with centrifugal separators.²/

Reference 12 reports on a study of stack losses from a FCC unit equipped with cyclones and an electrostatic precipitator. The catalyst carryover and the weight percentage of 0-20 μ material in the carryover are shown in Figures 22-5 to 22-7 for the operating conditions given in Table 22-3. Figure 22-5 shows that catalyst carryover from the cyclone increases rapidly as the quantity of fines in the air stream increases. It was therefore concluded that carryover of material to the precipitator, and hence stack loss, may be controlled by regulation of the amount of fines in the unit. Figure 22-6 is a calculated curve of stack loss as a function of particle size distribution of catalyst carried over from the cyclones for three different precipitator collection efficiencies (computed from Figure 22-5 and a fractional efficiency curve). Figure 22-7 is a calculated curve of size distribution of the stack loss, derived in the same manner as Figure 22-6. $\frac{12}{2}$

TABLE 22-3

TYPICAL PLANT OPERATING CONDITIONS

| Fresh feed rate to reactor, bbl/day | 25,000 |
|-------------------------------------|---------|
| Air rate, 1b/hr | 235,000 |
| Coke burning ratio, lb/hr | 20,000 |
| Fresh catalyst-addition rate, | |
| tons/day | 6.1 |
| Fresh catalyst type | MSA-2 |



Figure 22-3 - Schematic Flow for Precipitator Installed After Power-Recovery Turbine⁶/

486



Figure 22-4 - Schematic Flow for Precipitator Installed After CO Boiler⁶/

487

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Figure 22-5 - Relationship Between Quantity of Catalyst Carryover and Particle Size^{12/}



NOTE: THE FIGURES AT THE LOWER END OF EACH CURVE ARE AVERAGE COLLECTION EFFICIENCY AT 30 % 0-20 MICRON MATERIAL IN CYCLONE CARRYOVER

Figure 22-6 - Calculated Stack Losses as a Function of Particle-Size Distribution of Cyclone Carryover¹²/



Figure 22-7 - Particle-Size Stack Loss Distribution Compared to Cyclone Carryover Particle Size12/

Typical costs for a precipitator following an expansion turbine at 900°F are $\frac{2}{scfm}$, while the cost at 700°F following a CO boiler is only about $\frac{1.50}{scfm}$. Water injection into the effluent stream to further reduce the temperature to about 550°F will reduce the cost still more. $\frac{6}{}$ These costs compare well with the general figure for purchase costs of electrostatic precipitators given in Appendix A.

Electrostatic precipitators can continuously achieve 99% efficiencies, but in order to obtain these high efficiencies in precipitators following regenerators, it is sometimes necessary to add a small amount of ammonia to the gases entering the precipitator to lower the resistivity of the material handled by the precipitator. In designing these units, the following items are taken into consideration.⁷/

1. With periods of continuous operation for FCC units and fluid coking units extending to three years or more, one should select a precipitator with more than one chamber so that part of the unit can be isolated from the gas stream for maintenance while all of the gases pass through the rest of the units.

2. The precipitator should have a large number of bus sections which are individually energized to achieve the highest power input and to minimize any decrease in efficiency if any one section is shorting out.

The dust concentration entering the precipitator depends on the type of catalyst used, the particular process and the kind of mechanical collectors used. The normal dust concentration varies between 5 and 25 grains/scf dry. It has been reported that no new catalyst recovery precipitators have been sold in recent years in this country. $\underline{11}/$

Changes in fuel demands have reduced the number of catalytic cracking units and consequently the number of new electrostatic precipitators needed for this service has declined. However, electrostatic precipitators are still being used on some existing catalytic crackers and at least three units were sold for this purpose during the 1966-1967 period. $\frac{16}{}$ A summary of performance data for precipitators in fluid catalytic cracking applications during the period 1951-1962 is shown in Table 22-4. $\frac{17}{}$

TABLE 22-4

A SUMMARY OF PERFORMANCE DATA* OF PRECIPITATORS IN FLUID CATALYTIC CRACKING APPLICATION (1951-1962)17/

| Parameter | Maximum | Minimum | Average |
|-------------------------------|--------------|---------|---------|
| Gas Volume, 1000's acfm/Pptr. | 254 | 6 | 152.6 |
| Gas Temperature, °F. | 850 | 45C | 610 |
| Inlet Loading, 1b/hr | 2,800 | 77 | 1,444 |
| Coll. Efficiency, % | 99 .7 | 80 | 95 |

* These data based on seven installations.

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CHAPTER 23

ACID MANUFACTURE

23.1 INTRODUCTION

Acid manufacturing processes include those for sulfuric, phosphoric, nitric, and hydrochloric. Only sulfuric and phosphoric acid manufacture discharges significant particulate emissions.

More sulfuric acid is produced in the United States than any other chemical. The chamber process for the production of sulfuric acid has been largely displaced by the contact process. About 97% of current output is from contact plants. Elemental sulfur accounts for about 75% of all raw materials consumed in sulfuric acid production. Most of the remaining new acid comes from pyrites or other iron sulfides, smelter gas, hydrogen sulfide, crude sulfur, and copper, zinc, and lead ores. Increasing amounts of used sulfuric acid are recovered for reuse. Primary sources are petroleum refining, alcohol manufacture, nitric acid and chlorine drying, and detergent and other sulfonations.

The principal emissions from sulfuric acid plants are acid mists and sulfur dioxide.

Phosphoric acid is produced in two distinct processes. The wetprocess acid is produced and consumed primarily in the fertilizer industry. The wet process for producing phosphoric acid is discussed in Chapter 12. The other commercial process for manufacturing phosphoric acid is the thermal process, also referred to as the furnace or phosphorus burning process. The thermal process acid is used in plasticizers, detergents, pharmaceuticals, and food grade acid.

The principal emission from the thermal process is acid mist.

Manufacturing processes, particulate emission sources, particulate emission rates, effluent characteristics, and control practices and equipment for sulfuric and phosphoric acid production are discussed in the following sections.
23.2 SULFURIC ACID MANUFACTURE

23.2.1 New Acid

All sulfuric acid is made by either the chamber or the contact process. Elemental sulfur, or any sulfur-bearing material, is a potential raw material for both these processes. The 215 contact-process establishments account for about 97% of the U. S. production. The 35 chamberprocess establishments account for the balance of U. S. production.

23.2.1.1 <u>Chamber Process</u>: Originally the chamber process employed sulfur dioxide gas produced from sulfur, but roaster gas or smelter gas was substituted later. The process employs the following principal units in addition to the combustion chamber or SO_2 source (see Figure 23-1):

1. The Glover tower which receives the hot burner gas. It is fed at the top with the nitrous vitricl from the Gay-Lussac tower, and with 52° Bé (65%) acid from the chambers. The functions of the Glover Tower are to denitrify the Gay-Lussac acid, thus reducing niter requirements to a small makeup for process loss; to evaporate water from the chamber acid, thus concentrating it to about 60° Bé (78%); cooling the gas to the point at which it can be safely introduced into the lead chambers; and supplying water vapor, equivalent to about one-third of the water requirement of the set (when producing acid of 52° Bé).

2. A series of large lead chambers, usually comprising from three to as many as ten, in which the reactions between sulfur dioxide, oxygen from the air, oxides of nitrogen, and water are carried cut with resultant production of chamber acid.

3. Usually two Gay-Lussac towers in series, in which the oxides of nitrogen leaving the final chamber are absorbed in sulfuric acid of about 60° Bé, and form nitrous vitriol.

4. An ejector or fan to provide the necessary flow of air through the system. The ejector may be located in the exit stack from the Gay-Lussac tower; a fan is usually placed between the final chamber and Gay-Lussac tower. Occasionally the fan is placed between the Glover tower and first chamber, although this location is not preferred because of its high temperature.

23.2.1.2 <u>Contact Process</u>: The contact process was first discovered in 1631 by Phillips, an Englishman, whose patent included the essential features of the modern contact process, namely, the passing of a mixture of sulfur dioxide over a catalyst followed by absorption of the sulfur trioxide in water.

Figure 23-2 illustrates a typical flow diagram for this process. The flow diagram can be divided into the following sequences: $\frac{2}{2}$



Figure 23-1 - Simplified Flow Diagram of Typical Lead-Chamber Process for Sulfuric Acid Manufacture (Based on Use of Elemental Sulfur as the Raw Material) $\frac{1}{2}$



Figure 23-2 - Sulfuric Acid Manufacture by the Contact $Process^{2/2}$

- 1. Transportation of sulfur or sulfides to plant
- 2. Melting of sulfur
- 3. Pumping and atomizing of melted sulfur
- 4. Burning of sulfur
- 5. Drying of combustion air
- 6. Recovery of heat from or cooling of hot SO_2 gas
- 7. Purification of SO2 gas
- 8. Oxidation of SO2 to SO3 in converters
- 9. Temperature control to secure good yields of SO_{π}
- 10. Absorption of SO3 in strong acid
- 11. Cooling of acid from absorbers
- 12. Pumping acid over absorption towers

23.2.2 Regenerated Acid

Substantial quantities of "fresh clean acid" are made by regeneration or decomposition of spent acid from petroleum refineries or other chemical processes. Sulfuric acid may be concentrated to around 66° Bé by heat. Any further fortification is usually done by the addition of oleum or sulfur trioxide. Two types of equipment for concentrating dilute acid operate under a vacuum while the third operates at atmospheric pressure using air-blown combustion gases.

A typical air-blown concentrator is shown in Figure 23-3. The burner supplies the hot gases at about $1100^{\circ}F$ by the combustion of oil or fuel gas. These hot combustion gases are blown countercurrent to the sulfuric acid in two compartments in the concentrating drum and remove water as they bubble up through the acid. The off-gases at 440 to 475°F from the first compartment of the drum pass to the second compartment along with a portion of the hot gases from the combustion furnace. They leave at 340 to 360°F to enter a gas-cooling drum where they are cooled to 230 to 260°F in raising the dilute acid to its boiling point. Since some sulfuric acid is entrained as a mist, the hot gases then pass through a Cottrell-type precipitator for the acid mist before discharge to the atmosphere. A Venturi scrubber with cyclone separator is also giving competitive results



Figure 23-3 - Sulfuric Acid Concentrator, Drum Type. $\frac{2}{}$

in removing acid mist by washing with feed acid. This procedure will give an acid with a final concentration of 93% or slightly higher. The hot gases also burn out any impurities that may be in a spent acid being concentrated. $\frac{2}{}$

There are five types of vacuum concentrators which will permit concentration of practically any acid, though clean acid is preferred to avoid fouling of interfaces. The necessary heat is supplied by high-pressure steam or Dow-therm. The Type E concentrator is the largest and desirable for high concentrations. For the latter reason, this type of concentrator is employed on relatively clean acids such as some nitration acids. It is a vertical steel shell lined first with lead followed by acid-proof brick. The metallic tubular heaters inserted through the vertical wall of the vessel are constructed of Duriron or Hastelloy D. Usually there are two or more units in series. The Type D concentrator is a small batch unit with vertical tubes in a vertical cylindrical tank, suitable for acid concentrations up to 93%. The Type C unit consists of many small compartments with individual heaters in series through which the acid to be concentrated flows continuously. The Type B concentrator, a batch unit, is a vertical tank with lead heating coils used mainly for acid concentration up to 80%. The Type A unit can be operated continuously or batchwise. This special corrosion-resistant, high-circulation evaporator is used quite often for the removal of sodium sulfate from the waste acid liquor being discharged from the viscose spinning bath, as well as reconcentrating the remaining acid values. Types C and E have a practical concentration limit of 95% acid.2/

23.3 EMISSION RATES

23.3.1 New Acid

23.2.1.1 <u>Chamber Plants</u>: The primary source of emissions in the chamber process is the final Gay-Lussac tower. Emissions include nitrogen oxides, sulfur dioxide, and sulfuric-acid mist and spray.

Concentrations of total nitrogen oxides in these exit gases range from about 0.1 to 0.2 vol. %. Sulfur dioxide concentrations occur in the same range. About 50 to 60% of the total nitrogen oxides is nitrogen dioxide, which characterizes the exit gas by a reddish-brown color.

Combined sulfuric acid mist and spray in the exit gas varies from 5 to 50 mg/scf. The sulfuric acid mist contains about 10% dissolved nitrogen oxides.

23.3.1.2 <u>Contact Plants</u>: The major source of emissions from contact sulfuric acid plants is the exit gas from the absorber. This gas contains unreacted sulfur dioxide, sulfuric acid spray and mist, and unabsorbed sulfur trioxide. Trace amounts of nitrogen oxides may also be present under some conditions, e.g., use of a raw material feed containing nitrogen compounds. Acid mist emissions prior to any control equipment average between 5-10 mg/scf for sulfur-burning plants producing no oleum and about 15-30 mg/scf for those plants producing oleum.

Unconverted sulfur dioxide gas, which is colorless, passes through the absorption system and is discharged to the atmosphere. The quantity of this gas emitted is a direct function of the degree of conversion of sulfur dioxide to sulfur trioxide and may vary from 0.1 to 0.5% by volume of the stack gases. During startup or during some emergency shutdowns, higher concentrations will occur.

Unabsorbed sulfur trioxide usually constitutes a small part of the absorber exit gas. When discharged to the atmosphere it is hydrated and forms a visible white plume of acid mist. Although the concentration of unabsorbed sulfur trioxide can vary appreciably, from 0.5 to 48 mg/scf of gas, it is usually closer to the lower figure and is a small part of the total acid mist emission. \underline{l} Other emission sources for this type of sulfuric acid plant include:

- 1. acid concentrators
- 2. tank car and drum-loading
- 3. storage tank vents
- 4. storage piles

Table 23-1 summarizes particulate emission rates for chamber and contact plants. Chamber plants currently emit about 2,000 tons/yr, while contact plants emit about 4,000 tons/year.

23.3.2 Regenerated Acid

The concentration of sulfuric acid in vacuum-type concentrators does not produce atmospheric pollution problems.

The effluent gases from air-blown concentrators contain sulfuric acid mist and sulfur dioxide resulting from the decomposition of sulfuric acid by carbonacecus materials in spent acid. 13/ Spent gases go to a scrubbing tower, or more generally to an electrostatic precipitator, for the removal of sulfuric acid mist. Limited data in the open literature indicate that fune emission rates are a function of plant operating and maintenance practices. 14/

Emission rates for acid regenerators are summarized in Table 23-1. Emissions are estimated at 8,000 tons/year.

TABLE 23-1

Efficiency Application of Control of Control Net Control Emissions Cc·Ct ton/yr Source Quantity of Material Emission Factor $C_{\rm C}$ C_t I. Sulfuric Acid 28,000,000 tons of H₂SO₄ A. Processing Units 1. Gay-Lussac tower 5 lb/ton II_2SO_4 (chamber process) 1,000,000 tons of H₂SO₄ 0.0 0.0 0.0 2,000 2. Absorber (contact process) 27,000,000 tons of H2S04 $2 lb/ton H_2SO_4$ 0.95 0.90 0.85 4,000 B. Spent-Acid Concentrators 1. Air-blown 11,200,000 tons of spent 30 lb/ton of spent 0.95 0.85 0.80 8,000 acid acid 2. Vacuum Neg. II. Phosphoric Acid - Thermal Process 1,020,000 tons of P₂0₅ 134 lb. particulate/ 0.97 1.0 0.97 2,000 ton of P205 produced

Total from Acids

16,000

PARTICULATE EMISSIONS MINERAL ACIDS

503

23.4 EFFLUENT CHARACTERISTICS

The chemical and physical properties of sulfuric acid plant effluents are summarized in Table 23-2. Acid mists emitted from chamber plants contain particles which are 10 wt. % less than 3 μ . Contact plants emit particulates which range from 7-95 wt. % less than 3 μ with an arithmetic mean of 64 wt. % less than 3 μ . A large percentage of smaller particles is emitted when producing cleum. Approximately 85-95 wt. % of the particles are less than 2 μ when producing oleum as compared to 30% less than 2 μ when producing oleum as compared to 30% less than 2 μ when producing 98% acid.

23.5 CONTROL PRACTICES AND EQUIPMENT FOR SULFURIC ACID PLANTS

Recovery equipment is rarely employed in chamber plants. 1/2 Electrostatic precipitators, packed-bed separators, mesh-type mist eliminators, ceramic filters and sonic agglomerators have been used to reduce the emission of acid spray and mist from contact acid plants. 1/2 Most modern plants are equipped with high-efficiency electrostatic precipitators or mesh-type eliminators in which 99% of the mist is recovered. 3/2

The electrostatic precipitator and mesh-type eliminator can provide removal efficiency of up to 99.9%. However, when cleum is produced, the portion of acid mist particles smaller than 3 μ in diameter is higher. This size seriously affects the low-pressure drop mesh-type eliminators; efficiency decreases sharply, and may be less than 40%.1/

Also, small amounts of nitrogen oxides in the inlet gas to the absorber interfere with the absorption of sulfur trioxide, and hence cause visible acid mist in the absorber exit gases.=

The visibility of acid mist depends more on particle size than on mist loading. Thus, a high percentage of particles 3 μ or less in the acid mist usually causes a heavy plume from the absorber stack. Highefficiency control devices do not necessarily result in an invisible plume unless there are few particles less than 3 μ and inlet mist-loading is not excessive. $\underline{l}/$

Acid mist composed of particles of less than 10 μ in size is visible in the absorber tail gas if present in amounts greater than 1 mg/ ft³. Larger particles deposit readily on dust and stack walls and contribute little to the opacity of the plume. $\frac{4}{}$ Internal spray catchers are installed in the top section of many absorbers to aid in the removal of large acid particles entrained in the exit gas. $\frac{1}{}$ From a plume visitility standpoint, plants producing a maximum of 99% acid (i.e., no oleum) often have clean stacks if bright, or uncontaminated, sulfur is used and the absorber is operating properly. However, plants producing oleum

TABLE 23-2

EFFLUENT CHARACTERISTICS - ACID MANUFACTURE

| A. Particulate (Part | 1) | | | | | | |
|-------------------------------------|--|--|--------------------------------|----------------------------|----------------------------------|---------------------|---------------|
| Source | Particle Size | Solids Londing | Chemical Composition | Particle <u>Density</u> | Electrical <u>Resistivity</u> | Noisture Content | Toxicity |
| Sulfuric acid a. chamber plant | 90-96 > 3 | D.08-C.5 | H ₂ SO4 | 1.7 | | | 1.0, irritent |
| b. contact plant | 7.5-95 < 3; arith. mean 63.5 < 3 (size dependent on plant type) | 0.017-0.76; mrith. mean - 0.2 | н ₂ 50 ₄ | 1.7 - 1.8 | | | 1.0, irritent |
| c. regenerator (air-blowe) | | 0,9-1.8 | H ₂ BO | | | | 1.0, irritant |
| Phospheric acid; thermal process | 0.4-2.6; mass median diameter - 1.6 | 1,55-93 without collector 0,001-0,26 with collector | H ₃ PO ₄ | 1.57 - 1.66 | | | 1.0, irritant |

A. <u>Particulate</u> (Part II)

| Scurce | Solubility | Wettebility | Hygroscopic Characteristics | Flammatility or Explosive Limits | Handling Characteristics | Optical Properties | Odor |
|-------------------------------------|-----------------------------------|-------------|--------------------------------|-------------------------------------|--------------------------|-----------------------|------|
| Sulfuric acid a. chamber plant | s. H ₂ 0 d. alcohol | | | | Highly corresive | | |
| 5. contact plant | s. H ₂ O d. alcohol | | | | Highly corresive | | |
| o. regenerator (air-blown) | s. H ₂ 0 d. alcohol | | | | Highly corresive | | |
| Phespheric sold; thermal process | s. H ₂ 0 d. alcohol | | | | Co rr osive | | |

F. <u>Carrier Gas</u>

| Source | Flow R | ate T | emperature | Moisture Content | Chemical Composition | Texicity | Corresivity | Oder | Flammability Limits | Optical Properties |
|--|------------------|---------------|------------|---------------------|---|-----------------------|-------------|------|------------------------|-------------------------------|
| Sulfurit acid | | | | | | | | | | |
| a, chamter plant | 1) 2-1 t) 100 | -16C | 105 | 5-25 | $NO_{x} = 0.1-0.2$ $NO_{2} = 0.05-0.12$ $SO_{2} = 0.1-0.2$ $O_{2} = 6-17$ $N_{2} = balance$ | SO2 5; lrritant | Corrosive | | | Cpacity - medium |
| t, contact plant | a) 5-6 t) 72- | 2 130 | 76-212 | | SO ₂ - 0.13-0.54 arith. mean - 0.26; air - balance | SOp 5; irritent | Corresive | | | Opaciny - none to danse |
| u, regenerator (air-blown) | ▲) 58. (on | 5 e plant) | 330 | | | | | | | |
| Phosphoric deid; the rma l process | a) 3.4 b) 35- | -30.2 160 | 136-201 | 10-60 | H ₂ O, NO _X , Air-balance | | Corresive | | | 0-100% opacity |

· See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

generally need either high-efficiency electrostatic precipitators or high-efficiency mist collectors. Table 23-3 presents a summary of "feasible systems" for acid mist control. $\underline{16}/$

The concentrating of sulfuric acid in air-blown concentrators can also result in emissions of sulfuric acid mist and spray. These emissions can be controlled by the use of electrostatic precipitators, Venturi scrubbers or fiber-mesh eliminators. $\frac{1}{2}$

TABLE 23-3

FEASIBLE SYSTEMS FOR ACID MIST CONTROLL6/

| | | Efficiency > 3 µ (%) | Efficiency く 3 μ (爱) | Emission Level 99% Acid Plants ^a / (mg/scf) | Enission Level Oleum Plants ^a / (mg/scf) |
|----|---------------------------------|----------------------------|----------------------------|--|---|
| l. | Dual Mist Pads | 99+ | 15-30 | 2 | to 5 |
| 2. | Tubular-Type Mist Eliminator | 100 | 95 - 99÷ | 0.1 | 0.1 |
| 3. | Panel-Type Mist Eliminator | 100 | 90-9 8 | 0.5 | 0.5 |
| 4. | Electrostatic Precipitator | 99 | Near 100 | 0.1 | 0.5 |
| 5. | Venturi Scrubber | 9 8 | Low | 3 | Ineffective with 3 μ mist |

a/ Based upon manufacturers' generally expected results.

One company studied the removal of sulfuric acid mist, on pilot plant scale, by low-pressure water sprays, high-pressure water sprays, and bag filters, and by decomposition with heat. This study led to installation of a high-pressure water spray system on a facility concentrating 700 tons/day of acid from 70% to 95% in air-blown concentrators. The unit was designed to spray 500 gpm of water at 540 psi spray nozzle pressure. Fuel gas burners were installed in the base of the acid fume stack to raise the temperature of the effluent gases from 140°F to 212°F.5/

23.5.1 Control Equipment

23.5.1.1 <u>Wire-Mesh Mist Eliminators</u>: This control device has the lowest first cost for effective removal of particles larger than about 3 μ in diameter. However, corrosion possibilities may require frequent replacement of this type of control device; therefore costs will rise and these increased costs must be considered.⁴/

The wire mesh eliminator is commonly constructed with two beds in series and operates with pressure drops of 1-3 in. of water. $\frac{1}{}$ Typical gas velocities for these units range from 11 to 18 ft/sec. $\frac{4}{}$

23.5.1.2 Glass-Fiber Mist Eliminators: The high-efficiency glass-fiber mist eliminator is capable of operating with collection efficiencies of over 99%. Pressure drop is usually 5-10 in. w.g. The glass-fiber mist eliminator is also capable of maintaining high efficiency at varying tail-gas flow rates. $\frac{1}{}$

A recent development in this area involves the use of a teflor fiber mist pad. This device is reported to be 98% efficient even when inlet loading is as low as $10 \text{ mg/ft}^3.6/$

23.5.1.3 <u>Electrostatic Precipitators</u>: Electrostatic precipitators are highly efficient regardless of size of the acid-mist particles. They operate with pressure drops less than 1 in. w.g.

Electrostatic precipitators may be either wet or dry type. The dry type, which is suitable only for concentrated acid, is much less expensive but more susceptible to corrosion. Wet-type precipitators are suitable for use only with dilute acid, and this necessitates prior humidification of stack gases. This also permits removal of SO₃ by converting it to acid mist. However, the humidification step appreciably increases the cost of a wet-type installation. $\frac{1}{2}$

The lead constructed electrostatic precipitator, for low-strength acid mist emissions, is used throughout the industry as the primary means of emission control. The use of mild steel electrostatic precipitators for oleum stack cleanup has been reported as successful with considerable savings in $\cos t$.^{7/}

23.5.1.4 <u>Ceramic Filters</u>: This German device is reported to operate with high efficiency at constant tail-gas flow rates. It has not been accepted in the U. S. because of high maintenance costs and inflexibility in handling varying gas volumes. $\frac{1}{2}$

23.5.1.5 <u>Venturi Scrubbers</u>: Venturi scrubbers are capable of high efficiency but at the expense of high pressure drop. They have not been used on contact acid plants, but have been used on sulfuric-acid concentrators to give outlet (i.e., grain loading) mist loadings of 0.5-3.0 mg/ft³. $\frac{1}{}$

23.5.1.6 <u>Packed Bed Separators</u>: These low-efficiency devices were used in the past, but none are known to be operating today.1/

23.6 PHOSPHORIC ACID MANUFACTURE

Phosphoric acid is manufactured by two processes: 1) the thermal process and (2) the wet process. The thermal process proceeds by burning elemental phosphorous to the pentoxide, followed by a hydration step. The wet-acid process involves treatment of phosphate rock with sulfuric acid. About 75% of the phosphoric acid produced comes from the wet acid process, and about 92% of the wet-process phosphoric acid goes into fertilizer production. About 19% of the thermal process phosphoric acid goes into fertilizer production, with the rest of the acid from both processes going into the production of other industrial chemicals.

23.6.1 Thermal Process

In the manufacture of phosphoric acid from elemental phosphorus, three steps are involved: (1) burning of the phosphorus, (2) hydration of the resulting phosphorus pentoxide, and (3) collection of the mists formed. A schematic diagram of the thermal process is shown in Figure 23-4. In most plants the elemental phosphorus is burned as a liquid. The problem of building a burner for liquid phosphorus is complicated by the fact that red phosphorus tends to form at elevated temperatures and can plug the burner completely or give rise to color in the resulting acid. The build-up of red phosphorus is usually avoided by a design in which rapid atomization of the phosphorus takes place.



Figure 23-4 - Flow Diagram for Typical Thermal-Process Phosphoric Acid Plant 9/

Phosphorus is transferred from the liquid-phosphorus feed tank to the burner tower by a pump or by liquid displacement at feed rates that range from 1 to 5 gal/min. At the burner the phosphorus is mixed with air and is oxidized at temperatures of 3000° to 5000°F in the combustion chamber. $\frac{8}{7}$ The resulting mixture of phosphorus pentoxide vapor and excess air passes from the combustion tower and into the hydrator.

Although many plants have refractory or graphite-lined combustion towers, a few new burning towers are constructed of water-jacketed stainless steel. In stainless steel towers weak phosphoric acid introduced into the combustion tower flows down the walls to remove excess heat. The phosphorus pentoxide vapors from the combustion tower are contacted with weak and product acid to hydrate the oxide to phosphoric acid and to absorb acid mist. These steps may be accomplished in one unit, but many plants use separate absorbing towers. In some new designs the acid sprayed into the hydrator is cooled prior to recycle. This spraying permits use of a smaller quantity of acid and allows the production of higher strength acid.

Some product acid is drained from the bottom of the hydratorabsorber. Gases containing acid mist leave the hydrator-absorber and enter air pollution abatement equipment.

The yields from thermal production of phosphoric acid are exceptionally high. In efficient plants about 99.9% of the phosphorus burned is recovered as acid. The loss of acid through leaks and discharges to sewers is usually negligible. Losses of phosphoric acid to the atmosphere represent direct product loss; therefore, efficient collection devices are normally installed in the gas stream before the gas is discharged from the plant.

23.6.2 The Wet Process

The cldest and still the most economical method for making crude phosphoric acid is to treat phosphate rock with sulfuric acid, thereby precipitating calcium sulfate and releasing phosphoric acid. However, to make phosphoric acid for any application other than fertilizers, it is necessary to purify the crude material obtained by the wet process. This purification may range from the removal of coloring materials such as iron and vanadium to the preparation of a food-grade acid. The wet-acid process for the manufacture of phosphoric acid is described in the chapter on Fertilizer Manufacturing.

23.6.3 Emission Rates

The principal atmospheric emission from the manufacture of phosphoric acid by the thermal process is acid mist in the absorber discharge gas. In the normal operation of the plants the hydration of phosphorus pentoxide (P_4O_{10}) creates phosphoric acid mist. Acid mist loadings within the process can be quite high. Loadings as high as 6,000 mg/dry sof of stack gas have been reported. It is not uncommon for as much as half of the total phosphorus pentoxide to be present as liquid phosphoric acid particles suspended in the gas stream. Economical operation of the process depends on agglomeration of the acid mist particles and subsequent separation from the gas stream. For this reason all plants are equipped with some type of emission control equipment.

Thermal-process acid manufacture employs high-temperature combustion that is normally conducive to the formation of nitrogen oxides. Many factors such as flame temperature, residence time, and quantity of excess air affect the amount of nitrogen oxides formed.

No serious problems are encountered in the startup or shutdown of a thermal phosphoric acid manufacturing unit that affect losses from the final collector. Maintenance of proper liquid flows and pressure differentials on the absorbers and collectors allows little or no increase in acid mist discharged to the atmosphere during either startup or shutdown.

Maintenance is not usually considered to be a major problem. Sprays, fans, mist eliminators, and other equipment obviously must be maintained in good operating condition. If a continuous-emission monitor is used on the collector exhaust, problems with the abatement equipment will be apparent to the operator quickly. Operators are normally concerned with keeping losses at a minimum because any loss is a direct loss of product.

Table 23-1 summarizes particulate emission rates for phosphoric manufacture by the thermal process. Emissions currently total about 2,000 tons/year.

23.6.4 Effluent Characteristics

The chemical and physical properties of thermal phosphoric acid plant effluents are summarized in Table 23-2. The mass median diameter of the emitted particulates is 1.6μ .

Data on the wet process are presented in the chapter on Fertilizer Manufacturing.

23.6.5 Control Practices and Equipment

Venturi scrubbers, packed scrubbers, glass-fiber mist eliminators, wire-mesh mist eliminators, and electrostatic precipitators are used as abatement equipment at phosphoric acid plants.<u>9</u>/ Operating practices have little effect on emissions of acid mist. The acid mists escaping collection are extremely hygroscopic so that visible emissions are pronounced unless high collection efficiencies are achieved.3/ The stack gases leaving phosphoric acid plants can be made completely invisible when the mist loading is reduced to 0.02 mg. of P_2O_5/scf of stack gas, the concentration of the mist in the collector is at least 75% phosphoric acid, and the stack gas temperature is above $176^{\circ}F.9/$

23.6.5.1 Scrubbers: Packed and open tower scrubbers have been used widely to collect phosphoric acid mist. An important factor in efficient collection is gas velocity. The effect of gas velocity on efficiency in a pilot plant packed tower is given in Figure 23-5.9/

Scrubbing is inexpensive and simple, but high collection efficiency is not usually obtained. Some plants have improved efficiency by installing wire-mesh mist eliminators after the scrubber.

23.6.5.2 <u>Venturi Scrubbers</u>: Venturi scrubbers are capable of operating at high collection efficiencies on phosphoric acid mist.⁹/ The extremely small size of the mist particles usually requires pressure differentials in excess of 40 in. of water. Figure $23-6\frac{17}{}$ illustrates the effect of particle size on collection efficiency. It is reported that Venturi scrubbers can reduce emissions to 0.10 mg/scf.10/

Venturi scrubbers are not used solely for abatement as they can actually hydrate part of the phosphorus pentoxide vapor, agglomerate the mist particles and cool the stack gases; they may then be followed by cyclonic separators. This combination can recover up to 99.9% of the acid mist at pressure drops of 35-60 in. w.g.

23.6.5.3 <u>Cyclonic Separators</u>: Cyclonic-type collectors are used in some plants but because of the small particle size of the emitted acid mist, other devices usually supplement these collectors. Supplemental collectors are typically wire-mesh mist eliminator pads of low pressure differential.

23.6.5.4 <u>Glass-Fiber Mist Eliminators</u>: Glass-fiber mist eliminators are capable of high collection efficiency in removing phosphoric acid mist from absorber effluent gas streams. When the mist eliminators are operating at a superficial vapor velocity of less than 1 fps and at pressure differentials of about 20 in. of water, collection efficiencies of 99.9% are attainable.<u>11</u>/ It is reported that these units can reduce emissions to as low as 0.10 mg/scf.<u>10</u>/

23.6.5.5 <u>High-Energy Wire-Mesh Contactors</u>: This is a recently developed device which is reported to give collection efficiencies that exceed 99.9% at pressure differentials ranging from 35 to 41 in. of water. $\frac{12}{}$



Tower Packing: 18 Ft. of 1-In. Carbon Raschig Rings Acid Concentrations: $81-87\% E_3PO_4$ Inlet Gas Temperature: 440° - $550^\circ F$ P_2O_3 Content of Gas: 2.0 - 2.5 Lb/1,000 Ft³

Figure 23-5 - Effect of Gas Velocity on Phosphoric Acid Recovery in Pilot-Plant Packed Tower9/



Figure 23-6 - Collection Efficiency of Venturi Scrubber as a Function of Particle Size for Phosphoric Acid Mist<u>17</u>/

The unit has the advantage of operating at relatively high superficial vapor velocities of 20 to 30 fps which results in low capital cost. $\frac{9}{1.50}$ Installed cost is reported to be approximately \$1.50 per acfm of stack gas. $\frac{12}{1.50}$

23.6,5.6 <u>Electrostatic Precipitators</u>: Phosphorus pentoxide losses from electrostatic precipitators are affected only slightly by rate of gas flow or by temperature, as long as design conditions are not exceeded. Acid mist losses are affected by cleanliness of the equipment and the electrical conditions employed. Precipitators operate at a pressure drop of about 0.5 in. of water. Table 23-4 shows electrostatic precipitator data for six installations.⁹/

TABLE 23-4

OPERATING CHARACTERISTICS OF PHOSPHORIC ACID MIST ELECTROSTATIC PRECIPITATORS9/

| Instal- lation | Gas Flow Rate <u>a</u> / (scfm) | Inlet Temper- ature (°F) | Inlet Mist Conc. <u>As Noted</u> | Outlet Mist Conc. <u>As Noted</u> | Collector Efficiency (%) | Rated Capacity (%) |
|-------------------|--|-----------------------------------|---|--|--------------------------------|--------------------------|
| 1 | 3,160 | 227 | 7.45 ^b / | 0.080/ | 98.9 | 147 |
| 2 | 14,100 | 292 | 14.21 <u>b</u> / | 0.415 <u>b</u> / | 97.1 | 119 |
| 3 | 3,540 | 173 | 3468 <u>c</u> / | 0.10 ^c / | 9 9. 9+ | 75 |
| 4 | 3,900 | 192 | /ع ₃₆₅₀ د/ | 0.16 <u>e</u> / | 99.9+ | 114 |
| 5 | 3,570 | 1 9 5 | 4060C/ | 0.24c/ | 99.9+ | 104 |
| 6 | 7,300 | 234 | 278 d / | 10.43 <u>d</u> / | 96.3 | 101 |

a/ 29.92 in. Hg and 32°F.

<u>b</u>/ Grains/scf dry gas as P_2O_5 .

c/ Milligrams 80% H₃PO₄/cf dry gas at temperature.

 \underline{d} / Milligrams mist/scf dry gas at 60°F as P₂0₅.

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CHAPTER 24

INCINERATION

24.1 INTRODUCTION

Incineration is not strictly an industrial process. However, incineration is used in many industries for waste disposal, and this combustion process is a significant source of particulate pollution on a nationwide basis. This chapter on incineration is included for the sake of completeness.

Incineration is a combustion process, and like all combustion processes incineration will cause air pollution unless carefully controlled. In comparison with the potential air pollution emissions from electric generating plants and chemical/manufacturing industries, incineration appears as a relatively unimportant source. This perspective is deceiving, however, since incinerators are often located in residential areas and are often equipped with inadequate or no control equipment. $\frac{1}{2}$

The air pollutants arising from incineration of solid wastes fall into three categories: (1) mineral particulate; (2) combustible solids and gases; and (3) noncombustible gases. Emissions are dependent upon incinerator design and operating factors, refuse composition, refusecharging rate, and combustion efficiency.

To facilitate discussion, incinerators will be grouped into three types: (1) municipal; (2) commercial; and (3) apartment house. Emission sources, emission rates, chemical and physical properties of effluents, control practices, and control equipment are discussed for each incinerator group in the following sections.

24.2 MUNICIPAL INCINERATION

Municipal incineration is a useful, effective method of solid waste disposal. However, poor design, management, or operator judgment, may culminate in ineffective, costly operations that in turn result in air pollution, odor, and other problems. The basic elements of a municipal incinerator are the storage pit, where refuse is deposited from collection trucks; the furnace, where the refuse is ignited and most of the combustion takes place; the secondary combustion chamber where additional combustion of volatile gases and particulate matter occurs; a settling chamber; and the stack or chimney. In addition, a plant will usually have scales to weigh incoming vehicles, a means of transferring refuse from the storage pit to the furnace and a residue removal system. $\frac{2}{}$

The general types of incinerators for municipal use can be divided into two classes: (1) batch, or intermittant feed incinerators, where refuse is admitted into the furnace at intervals; and (2) continuousfeed furnaces, wherein refuse is fed into the furnace in a steady flow. The former furnaces generally burn down each charge on the grates before admitting another charge. To some extent batch feed furnaces may operate in an approximately continuous fashion by admitting increments of refuse at close intervals. Continuous-feed furnaces utilize one or more forms of mechanical grates. Residue is usually dumped and removed continuously. Some types of grates convey a tumbling action to the refuse to provide more rapid and complete burning and to promote ash removal.²/ Design details of various units are presented in References 2-4.

24.2.1 Emission Sources and Rates

Particulates from refuse incineration originate from dust raised in the refuse dumping and handling processes, smoke discharged through semiporous furnace walls and stoking doors, and entrained dust in the gases discharged from the furnaces. The first two are minor sources and are extraneous to the burning process.

The mass emission rate for particulates from the combustion process is a function of many variables: (1) undergrate air velocity; (2) refuse ash content; (3) burning rate or combustion quality; (4) grate agitation in a continuous feed incinerator; (5) size, method, and frequency of feeding for batch units; and (6) combustion chamber design. Items 1 and 2 are the major factors.

A systematic study by the Public Health Service of the effects of underfire air, secondary air, excess air, charging rate, stoking interval, and fuel moisture content on particulate emission rates from an experimental incinerator led to the conclusion that the velocity of the underfire air was the dominant factor influencing the emission rate. 1.5/ Subsequent field evaluation of emission rates from municipal units indicated that the effect of underfire air rate was less pronounced than that observed in the experimental unit. For the two municipal incinerators tested, the effect was small for undergrate velocities below 35 to 40 scfm/sq ft of grate area; but significant above that rate. $\underline{1,6}/$ Test results reported by other investigators parallel the effects noted in the experimental unit. $\underline{7}/$ Figure 24-1 illustrates a comparison of the data on the experimental incinerator and the field tests. The spread in the data is not surprising in view of probable differences in refuse composition, furnace size, and other factors. $\underline{1}/$

The influence of refuse ash content on emission rates was also studied in an experimental incinerator. 5^{-1} In one series of laboratory tests the level of underfire combustion air was varied from 3 to 60 scfm/ sq ft of grate area, and the resulting particulate emissions ranged from 1.6 to 8.6 lb/ton of combustible material burned. The fuel was a mixture of newspaper, cardboard, and wood chips. When a high ash content paper was substituted for the newspaper portion, a similar series of tests produced even higher particulate emissions, ranging from 3.2 to 35 lb/ton of combustible material for the same range of underfire air flow rates.

In a second laboratory study which was made to evaluate emissions produced by burning a high volatile material composed of asphalt felt roofing and newspaper, tests were made under conditions in which the level of underfire air was varied while all other variables were held constant. The resulting particulate emissions increased from 5.3 to 19.8 lb/ton of fuel burned. In this case, the level of underfire air ranged from 6 to 34 scfm/ sq ft of grate area on tests made at 100% excess combustion air. With 200% excess air, particulate emissions increased from 11.2 to 47.2 lb/ton of material burned when underfire air was varied from 8.5 to 50 scfm/sq ft of grate area.

The dependence of particulate emission rate on ash content of the refuse has also been noted by German investigators. \pm / These findings show that the ash content of the refuse is a major factor in determining emission rates.

Reference 1 contains a discussion of the influence of secondary variables on emission rates.

24.2.1.1 <u>Summary of Emission Rates</u>: Particulate emissions from municipal incineration have been estimated at 100,000 tons/year.1/ Table 24-1 gives the distribution of the various types of emissions from municipal incinerators.

519



Figure 24-1 - Effect of Underfire Air Rate on Furnace Emission1/

TABLE 24-1

$\frac{\text{ESTIMATED MUNICIPAL INCINERATOR EMISSIONS}^{1/}}{(\text{thousands of tons/year})}$

| | 1968 Emiss | ons Estimate | | |
|--------------------------|------------|--------------|--|--|
| Pcllutant | Furnace | Stack | | |
| Mineral particulate | 90 | 56 | | |
| Combustible particulate | 38 | 32 | | |
| Carbon monoxide | 280 | 280 | | |
| Hydrccarbons | 22 | 22 | | |
| Sulfur dioxide | 32 | 32 | | |
| Nitrogen oxides | 26 | 22 | | |
| Hydrogen chloride | 8 | 6 | | |
| Volatile metals (lead) | 0.3 | 0.3 | | |
| Polynuclear hydrocarbons | 0.01 | 0.005 | | |
| Total | 496. | 450. | | |

24.2.2 Effluent Characteristics

The physical and chemical characteristics of effluents from municipal incinerators are presented in Table 24-2. The particle size, particulate grain loading, and particulate chemical composition are highly variable and depend upon combustion efficiency, underfire airflow, incinerator design, and character of refuse. Furnaces operated in excess of design capacity generally emit a low percentage of particles smaller than 10 μ in size, while furnaces operated at less than capacity and low underfire air rates emit larger percentages of particles smaller than 10 μ in size. Electron micrographs (30-80,000 magnification) of particulate material from stacks show a very heterogeneous material. No characteristic shapes predominate. Occasional shapes could be identified such as the round spheres indicative of carbon particles, or cubes indicating magnesium oxide or the needle shape forms of zinc oxide. $\frac{1}{2}$

The toxic and corrosive properties of the effluents from municipal incinerators are dependent upon the composition of the refuse burned in the unit. In addition to the fly ash and normal gaseous products of combustion (i.e., CO₂, CO, etc.), polynuclear hydrocarbons, organic acids, and aldehydes are liberated during incineration. The combustion of halogenated hydrocarbons can result in the formation of decomposition products which are corrosive and toxic, e.g., fluorides and chlorides can be emitted when aerosol cans or PVC containing materials are included in the refuse. The thermal decomposition of polyurethane-type plastics could constitute a toxic hazard because of the liberation of phosgene and/or toluene diisocyanate. The quantity and nature of these emissions are also dependent upon operating factors and incinerator design.

24.2.3 Control Practices and Equipment

A NAPCA report on municipal incineration presents average efficiency data for air pollution control systems used on municipal incinerators. Table 24-3 summarizes the efficiency data. \bot The actual application of these devices, together with investment and operating cost, is shown in Table 24-4. \bot Table 24-5 indicates the maximum efficiency of incinerator control equipment. 9/

Data for installed cost and operating cost are shown in Figures 24-2 to 24-6. It should be noted that Figures 24-4 through 24-6 show annual operating costs based on operating periods of one, two and three shifts per day, respectively. An explanation of the basis for these costs is given in Section VII of Reference 1. The installed costs shown in Figure 24-3 are higher, by as much as 200% in some cases, than the general cost data given in Appendix A.

TABLE 24-2

EFFLUENT CHARACTERISTICS - INCINERATION

| ÷ | <u>elert, ulate</u> (Bal | rt I' | | | | | | | | | | |
|---------------|--------------------------------------|--|---|---|--|---|------------------------------|------------------------------------|---|---|---|-----------------------|
| <u>5</u> | ्राम् २२ | Particus Sile | Solids Loudi | Chemica ng Composit | al tion | Particle Density | Electri | ical Resisti | vity <u>Moist</u> | ure Content | <u>. Deci Ita</u> | |
| 1.' | Municipa: Incinerator | $\frac{C(n) \cos \beta}{2} \cos (1 + \frac{1}{2}) \cos (1 + \frac{1}{2$ | Highly depend on operating orderes. Rango: 0.1-0 at 125 CO ₂ . | lent <u>Fly Ash</u> pro- SiG ₂ : 1 Al ₂ C ₃ : 6 1.9 Fe ₂ C ₃ : 4 lvg. CaO: 9-2 CaO: 9-2 | 4-52 8-28 4-19 22 | <u>.</u> .8-3.8 | See Fig detaile | gure 24-2 fo Holdaua | r | | Dependent up composition refuse turns | yor. of od |
| | | 40 < 30 27-43 < 20, avg. < 35 < 20 23-38 < 10, avg. 25 < 10 15.5-23.5 < 2, avg. 17.2 < 2 | | Na ₂ 0 + N 3-10 TiO ₂ : 0. Also org acids ar nuclear carbons | (20: ,7=2.8 md pcly- hydro- | | NOT | REPRO | DUCIBL | E | | |
| 11 | lommercial Incinentator | | 0.06-0.5 at 1 CC., avs. 0.2 | a | | | | | | | | |
| 117. | Apartment Hourd In- Laterator | | 0.02-1.61 | | | | | | | | | |
| ••••• | Portfunist+ (Par | ·: (i) | | | | | | | | | | |
| <u>-</u> | <u>210-7-</u> | Schudility | Wetsutility | Hygroscopi Characterict | .c F 1192 E | lamability (ploiive Li | or tito | Randling Characteric | Cpris Lics Proper | α: <u>ties</u> <u>ς</u> | dor | |
| Ξ. | Municipa. Incinerator | Contains Water Islupic Com- Fonents | Elffinult to Wei | | | | | Agglomerate | | | | |
| :. | Comercia: Incinerator | Containt water Sclubly com- ponents | Difficult to wet | | | | | | | | | |
| :: : . | Apartment Hours In- Viorrator | Containu walkr Soluoi- 1984 genenic | Difficult to wet | | | | | | | | | |
| ۳ | Jarnaen Bus | | | | | | | | | | | |
| ÷ | our co | Fich Role | Temperature | Muistare Content | Chenst Composition | ani <u>ition</u> | Texte | <u>119</u> | Corresivity | Ner | Flammability or <u>Septendes Liti</u> | Cprinii Properties |
| 2. 1 | Mario(pi. Reciperator | (2) 34-350, avg. 70 (1. 153-388, avg. 220 | 253-100 | | C(2. C) Hg() Typlcs1 C(2. C) C(2. C) C) C(2. C) C) C(2. C) C(2. C) C) C(2. C) C) C) C) C(2. C) C) C) C) C(2. C) C) C) C) C) C) C) C) C) C) C) C) C) C | , CO, Ng, <u>oumposi-</u> C C dehydes | Lepende composi refuse | nt upon I tion of a burged g | Dependent upon responsition of wfuse burned | | | |
| 11. | Comparised Intinerator | (1) 0.0:=. (Limited dwta) | 400-1,400 | | ССр, СС С _р , Н _р С | , X ₂ , | | | | | | |
| 111. | Apertment Roure In- Callerator | (.) 0.1-2.4 (limited data) | <u>, 30-3</u> 35 | | ರಿಂ ₂ , ೦೧ ಸ್ತರಿ, ೫೦ | , ^N 2, x, ^C 2 | | | | May be odorous because of incom- pleta combus- tion | | |

• See Coding Key, Table 5-1, Chapter 5, page 45, for units for individual effluent properties.

TABLE 24-3

AIR POLLUTION CONTROL SYSTEM AVERAGE CONTROL EFFICIENCY1/

. .

| | APC System Removal Efficiency (wt. %) | | | | | | | | | | |
|-----------------------------------|---------------------------------------|------------------------------|--------------------|--------------------|-------------------|------------------|----------------------|-------------------------------|---------------------------|--|--|
| Npe | Mineral Particulate | Combustible Particulatea/ | Carbon Monoxide | Nitrogen Oxides | Hydro- carbons | Sulfur Oxides | Hydrogen Chloride | Polynuclear Rydrocarbonsb/ | Volatile <u>Metals</u> | | |
| None (Flue Settling Only) | 20 | 2 | 0 | 0 | 0 | 0 | 0 | 10 | 2 | | |
| Dry Expansion Chamber | 20 | 2 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | | |
| Wet Bottom Expansion Chamber | 33 | 4 | 0 | 7 | 0 | 0 | 10 | 22 | 4 | | |
| Spray Chamber | 40 | 5 | 0 | 25 | 0 | 0.1 | 40 | 40 | 5 | | |
| Wetted Wall Chamber | 35 | 7 | 0 | 25 | 0 | 0.1 | 40 | 40 | 7 | | |
| Wetted, Close-Spaced Baffles | 50 | 10 - | 0 | 30 | 0 | 0.5 | 50 | 85 | 10 | | |
| Mechanical Cyclone (Dry) | 70 | 30 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | | |
| Medium Energy Wet Scrubber | 90 | 80 | 0 | 65 | 0 | 1.5 | 95 | 95 | 80 | | |
| Electrostatic Precipitator | 99 | 90 | 0 | 0 | 0 | 0 | 0 | 60 | 90 | | |

⁵²⁴

a/ Assumed primarily $\leq 5 \mu$. b/ Assumed two-thirds condensed on particulate, one-third as vapor. c/ Assumed primarily a fume $\leq 5 \mu$.

TAPLE 24-4

| INCINERAT | TORS AND APC | CONCEPTS1/ | | |
|---|-------------------|------------------------------|---------------------------------------|---------------------------|
| Incineration Systems | 1968 Inventory | Average CapacityS/ TPD | Investment \$/TPD ^{C_d} / | Operating Costs \$/Ton |
| <u>Dre</u> | | | | |
| 1. Continuous, Refractory, Rocking Grate | 7.30% | 225 | \$ 8 ,4 00 | \$ 6.16 |
| 2. Continuous, Refractory, Reciprocating Grate | 4.20 | 225 | 6,400 | 5.16 |
| 3. Continuous, Refractory, Traveling Grate | 20.87 | 225 | 8,400 | 8.16 |
| 4. Continuous, Refractory, Grate & Kiln | 7.05 | 300 | 5,900 | 5.75 |
| 5. Batch, Refractory, Circular | 24.30 | 130 | 5,350 | 6.59 |
| 6. Batch, Refractory, Rectangular Cell | 23.13 | 150 | 5,100 | 7.16 |
| 7. Batch, Refractory, Hearth | 13.15 | 75 | 5,100 | 8.56 |
| 8. Continuous, Water Wall, Rocking Grate | 0.00 | 350 | 8,750 | 5.48 |
| 9. Continuous, Water Wall, Reciprocating Grate | 0.00 | 350 | 8,750 | 5.45 |
| 10. Continuous, Water Wall, Traveling Grate | 0.00 | 350 | 8,750 | 5.48 |
| 11. Continuous, Water Wall, Suspension Burning | 0.00 | 300 | 9,350 | 8.06 |
| 12. Continuous, Slagging Type I- | 0.00 | 175 | 11,800 | 8.53 |
| 13. Continuous, Slagging Type II- | 0.00 | 225 | 6,400 | 6.16 |
| 14. Continuous, Fluid Bed | 0.00 | 60 | 18,400 | 21.23 |
| 15. Continucus, Pyrolysis | 0.00 | 100 | 7,250 | 11.94 |
| Total | 100.00% | | | |
| AFC Systems | | | | |
| Tyre | | | | |
| 1. None (Flue settling only) | 17.40% | | 110 | 0.05 |
| 2. Dry Extansion Chamber | 21.65 | | 140 | 0.05 |
| 3. Net Bottom Expansion Chamber | 2.09 | | 170 | 0.14 |
| 4. Spray Chamber | 12.15 | | 175 | 0.30 |
| 5. Wetted Wall Chamber | 16.87 | | 175 | 0.30 |
| 6. Wetted, Close-Spaced Baffles | 15.84 | | 215 | 0.32 |
| 7. Mechanical Cyclone (dry) | 9.22 | | 340 | 0.77 |
| 8. Medium Energy, Wet Scrubber | 4.78 | | 780 | 0.99 |
| 9. Electrostatic precipitator | 0.00 | | 900 | 0.98 |
| 10. Fatric Filter | 0.00 | | 90 0 | 1.10 |
| 7 1 | 100 000 | | | |

. Slagging Type I comprises systems where a major part of the system is maintained at temperatures > 2800°F.

 $\underline{b}/$ Slagging Type II comprises systems where residue fusion takes place almost or entirely as a separate operation.

 \underline{c} / Capacity expressed in units of tons per 24-hr. day (TPD). \underline{d} / 1988 dollars, 2 shift/day operation.

TABLE 24-5

MAXIMUM DEMONSTRATED COLLECTION EFFICIENCY OF INCINERATOR CONTROL EQUIPMENT^{2/}

| Collection Device | Collection Efficiency (%) |
|--|---------------------------|
| Settling Chamber | 35 |
| Wetted Baffles | 53 |
| Cyclones | 75 to 80 |
| Impaction Scrubbers (with pressure drop less than ten inches of water) | 94 to 96 |
| Electrostatic Precipitators | 99+ |



Figure 24-2 - Electrical Resistivity of the < 74 μ Fraction⁷/ of Particulate Emission from the Furnace at 6% Water Vapor



Figure 24-3 - Air Pollution Control Systems Total Installed Costs 1/

528



Figure 24-4 - Air Pollution Control Systems Annual Operating Costs1/ (1 Shift/Day - 2,000 Hr/Year)



Figure 24-5 - Air Pollution Control Systems Annual Operating Costs1/ (2 Shifts/Day - 4,000 Hr/Year)



Figure 24-6 - Air Pollution Control Systems Annual Operating Costs1/ (3 Shifts/Day - 6,000 Hr/Year)
Figures 24-7 and 24-8 indicate the relationship between collection efficiency and total annual cost (including capital charges). Table 24-6 summarizes the relative in-plant space needs for the air pollution control systems (disregarding auxiliary facilities such as settling ponds, clarifiers, etc.).1/

Reference 10 describes a study of a proposed 800 ton/day incinerator plant for the District of Columbia. Estimated capital and operating costs for an electrostatic precipitator preceded by a cyclone and for a wet-scrubber system are shown in Table 24-7.10/ The costs shown are as much as 200-300% higher than costs computed from data in Table 24-4. The advantages and disadvantages of both systems were discussed in Reference 10. It is pointed out that the wet scrubber requires a rather extensive water conditioning system and also produces a large vapor plume which may be objectionable. The electrostatic precipitator system had not previously been used in the U. S. and may have potential operating problems such as corrosion, fouling, and inefficient collection of large, flaky particulate matter. Mention was made of the installation of a pilot baghouse on the municipal incinerator of the city of Pasadena, California. However, it was concluded that a baghouse filter should not be considered due to lack of sufficient satisfactory experience.10/

The cost of applying various types of control equipment to two municipal incinerator designs has also been calculated as shown in Tables 24-8 and 24-9.11,12/ These data are for a 250 ton/day furnace and control equipment efficiencies are typical for that generally attributed to these devices, except that electrostatic precipitators and high-energy wet scrubbers can exceed 99% efficiency but, of course, their cost is higher. Construction costs include cost of cooling chamber, ash separating cyclones, strainers, pumps, baffles, collector, and induced-draft fans as applicable to each alternate. Breechings and stacks are not included. Cooling water and power costs are computed on a 5-1/2 day week, 24 hr/day, 52 weeks/year, at \$0.30/1,000 gal and \$0.02/kw-hr.11/ These cost data indicate higher control costs (by as much as 200%) than Table 24-4. However, the operating costs are in closer agreement.

Although not a control device, it should be pointed out that the present excess air and the quantity of underfire air can have a very significant effect on the particulates discharged from an incinerator. This will be reflected in the emission and the operation of any associated control devices. $\underline{13}/$



Figure 24-7 - Total Annual Operating Cost vs. Particulate Removal Efficiency, 150 Tons/Day Plant; 1, 2, and 3 Shift Operation¹/



Figure 24-8 - Total Annual Operating Cost vs. Particulate Removal Efficiency, 150 and 300 Tons/Day Plant; 2-Shift Operation=/

TABLE 24-6

RELATIVE IN-PLANT SPACE REQUIREMENTS FOR AVERAGE AIR POLLUTION CONTROL SYSTEMS1/

| Equipment Type | Relative Space Require- ment (%) |
|---|-------------------------------------|
| Baghouse filter | 100 |
| Electrostatic precipitator | 90 |
| Scrubber – spray type flooded plate Venturi | 50 30 25 |
| Mechanical cyclone - multiclone 60 in. diameter tangential inlet wetted wall | 25 3 0 25 |
| Settling chamber with sprays | 60 |

TABLE 24-7

ESTIMATED CAPITAL AND OPERATING COSTS FOR TWO CONTROL SYSTEMS FOR AN 800 TON/DAY INCINERATOR¹⁰/

| Type | Capitel Cost (\$) | Annual Operating Cost (\$) |
|---|-------------------------|----------------------------------|
| Electrostatic precipitator with mechanical collector | 2,409,200 | 512,500 |
| High energy scrubber | 1,838,600 | 401,000 |

TABLE 24-8

REFRACTORY FURNACE (250 TONS/DAY)

| | <u>(1966 Costs)11,12</u> / | | | | | | | |
|----------------------------|----------------------------|---------------------------|---------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------|
| Equipment | Efficiency (%) | Stack <u>Outlet</u> a/ | Construction Cost (\$) | Annual Water Cost _(\$) | Annual Power Cost _(\$) | Annual Maint. Cost (\$) | Annual Amort. Cost (\$) | Cost/Ton Burned (\$) |
| Baffled Spray Chamber | 50 | 1.75 | 188,200 | 32,700 | 6,450 | 23,700 | 13,900 | 0.77 |
| Spray Chamber/Cyclone | 78 | 0.77 | 237,650 | 32,700 | 51,600 | 10,300 | 17,550 | 1.12 |
| Wet Scrubber | 96 | 0.14 | 400,900 | 58,400 | 105,300 | 16,800 | 29,400 | 2.10 |
| Spray Chamber/Precipitator | 9 5 | 0.175 | 434,910 = 1,700 | 32,700 | 35,300 | 10,300 | 32,100 | 1.10 |
| Spray Chamber/Fabric | | | | | | | | |
| Collector | 99+ | < 0.035 | 622,310 | 36,600 | 47,200 | 33,100 | 46,100 | 1.63 |

a/ Pounds of particulate/1,000 lb gas at 50% excess air.

TABLE 24-9

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WATER COOLED FURNACE (250 TONS/DAY) (1966 Costs)11,12/

| Equipment | Efficiency (%) | Stack <u>Outlet</u> a/ | Construction Cost (\$) | Annual Water Cost _(\$) | Annual Power Cost (\$) | Annual Maint. Cost (\$) | Annual Amort. Cost (\$) | Cost/Ton Burned (\$) |
|------------------|-------------------|---------------------------|---------------------------|----------------------------------|---------------------------------|----------------------------------|----------------------------------|----------------------------|
| Cyclone | 78 | 0.77 | 91,300 | | 29,600 | 2,000 | 6,800 | 0.38 |
| Precipitator | 96 | 0.175 | 210,300 | | 14,600 | 9,000 | 15,600 | 0.39 |
| Fabric Collector | 99+ | < 0.085 | 243,000 | | 34,400 | 12,100 | 18,000 | 0.65 |

a/ Pounds of particulate/1,000 lb gas at 50% excess air.

24.2.3.1 Spray Chambers and Wetted Baffles: The most effective spray chambers are those utilizing continuously wetted baffles. The more effective of these involve tortuous gas passages and attendant larger pressure drops. Sprayed-baffle systems with flue-gas pressure drops lower than 0.5 in. are necessary if the use of an induced draft fan is to be avoided. The chamber in which the baffles are installed is normally designed for a baffle slot velocity not exceeding 3,000 ft/min. The water consumption for sprayed baffle systems is normally about 0.5 gpm/ton of refuse burned per day. Natural draft sprayed-baffle systems are capable of meeting a criterion of 0.83 lb. of particulate/1,000 lb of flue gas (at 50% excess air) but may not be suitable for more stringent criteria. $\frac{14}{}$ The efficiency of wetted baffle collectors on two municipal incinerators has been reported as 53% and 10%.7.15/

Conversion of a wetted-baffle municipal incinerator to employ neutralization of the water with soda ash to permit recirculation has shown that the savings in water usage will amortize the cost of the additional facilities in less than two years. $\frac{15}{2}$

24.2.3.2 <u>Wet Scrubbers</u>: Wet scrubbers have been used in a few municipal incinerator applications. Water circulation rates required in scrubbers are high, and this may introduce a disposal problem or require treatment equipment to permit recirculation. The power requirements for the pumps that provide the spray water and for the induced-draft fan system are significant and should be considered in any evaluation.<u>14</u>/ The scrubbers are capable of removing gasecus air pollutants but, in so doing, the acidic solutions that result will require special selection of materials of construction.<u>14</u>/

It is reported that a Chemico Venturi scrubber is operating on the East 73rd Street incinerator in New York City and is controlling emissions to less than 0.05 grain/scf. $\frac{23}{2}$

24.2.3.3 <u>Electrostatic Precipitators</u>: Several electrostatic precipitators have been installed and successfully operated in Europe. Some have also been installed in the U. S., as shown in Table 24-10.24/ Several devices with collection efficiencies of over 95% are scheduled for new and existing units. $\frac{9}{}$ The 1,200 tons/day Des Carrieres Plant in Montreal was to be built with an electrostatic precipitator. $\frac{14}{}$

The electrostatic precipitator is capable of high collection efficiencies at low pressure drop. Gas cooling is required for protection of the precipitator from excessive temperatures. Although precipitators do not require the use of an induced-draft fan, such use is normal, primarily to produce a steadier rate of combustion and consequent rate of gas flow, thus making performance more reliable and more predictable. $\frac{14}{2}$

TABLE 24-10

ELECTROSTATIC PRECIPITATORS INSTALLED ON MUNICIPAL INCINERATORS IN NORTH AMERICA24/

| Location | Collector <u>Manufacturer</u> |
|-------------------------------------|----------------------------------|
| Refractory Units | |
| City of Stamford, Connecticut | Uriv. Oil. Prod. (Aerctech) |
| NYC South Shore Brooklyn | Research-Cottrell |
| NYC Southwest Brooklyn | Wheelabrator/Lurgi |
| Dade County, Florida | Wheelabrator/Lurgi |
| Water-Wall Units | |
| City of Montreal, Quebec (Von Roll) | Research - Cottrell |
| City of Braintree, Massachusetts | |
| (Detroit Stoker) | Wheelabrator/Lurgi |
| City of Hamilton, Ontario | |

(C&E Bciler)Wheelabrator/LurgiCity of Chicago, IllinoisWade/Rothemuhle

Major characteristics of European electrostatic precipitator units are shown in Table 24-11.16/ The success of their units is attributed to differences in the design of furnaces, grates and auxiliary equipment.

TABLE 24-11

BASIC DESIGN ELEMENTS OF EUROPEAN ELECTROSTATIC PRECIPITATORS 16/

27 Incinerator Plants 52 Precipitator Units

| Range | Median |
|--------------|---|
| 42 to 1,060 | 270 |
| 350 to 7,200 | 1,450 |
| | |
| 2.7 to 12.3 | 5.43 |
| 285 to 520 | 490 |
| | |
| 92.0 tc 99.5 | 98.0 |
| | Range 42 to 1,060 350 to 7,200 2.7 to 12.3 285 to 520 92.0 to 99.5 |

A Swedish article describes the use of multicyclone after collectors following an electrostatic precipitator to reduce emission of paper flakes which are difficult to collect in the precipitator due to their large area, low specific gravity and low resistivity. $\frac{17}{}$

24.3 COMMERCIAL INCINERATORS

Commercial and industrial incinerators for burning general refuse may be either single- or multiple-chamber types. The multiple-chamber units are usually associated with large institutional or industrial facilities, while the smaller single-chamber furnaces are used by markets and restaurants.

24.3.1 Emission Sources and Rates

While there are many factors involved in controlling the gaseous and other combustible emissions from commercial types of incinerators, the most important single factor is to maintain a sufficiently high temperature for good combustion. Temperatures above 1000°F can be maintained when burning refuse of low moisture content (after the initial warmup) by maintaining a relatively uniform release of heat from the refuse. This procedure requires frequent charging and stoking by a well-trained operator. In the majority of cases, it is not economically feasible to provide a full-time operator; most incinerators are operated by a janitor or custodian who has many other duties. Therefore, auxiliary fuel has been found to be necessary in almost all cases to maintain temperatures above 1000°F. High temperatures (plus excess air, turbulence, and residence time) effectively oxidize unburned gases and combustible particles and droplets.

Small-sized commercial incinerators with relatively poor combustion produce larger emission rates for polynuclear hydrocarbons than the intermediate and large-sized municipal units. The higher temperatures and longer residence times characteristic of the municipal incinerators account for the lower rates of polynuclear hydrocarbon emission in these units. <u>18</u>/

Pathological waste incinerators differ from the standard multiplechamber unit in several respects. Major differences are the use of large burners in the primary chamber, side loading rather than front loading, a solid hearth rather than a grate, and a somewhat different arrangement of the chambers.

No data were found on tonnage of material burned in these units, and estimates of the current level of particulate emissions from commercial and industrial incinerators were not attempted.

24.3.2 Effluent_Characteristics

The physical and chemical properties of effluents from industrial and commercial incinerators are outlined in Table 24-2. Limited data are available for these units. Particulate matter emitted is probably larger in size than that discharged from municipal incinerators because of lower quality combustion.

Grain loadings given in Table 24-2 are for units in which good combustion was attained. If these conditions are not met and poor combustion results, clouds of dense smoke are emitted and particulate loadings will be much higher than those shown in Table 24-2.

24.3.3 Control Practices and Equipment

Single-chamber units have generally proven inadequate to meet most emission regulations. Multiple-chamber units produce minimum emissions but may require a good gas washer to meet more stringent regulations. NAPCA has tentatively found that scrubbers having at least 1/2 in. H₂O pressure drop and a water rate of 4 gal/1,000 cfm are required on incinerators to meet emission standards for Federal facilities.2/

Design factors for multiple-chamber incinerators are presented and discussed in Reference 3. Initial incinerator cost depends mainly on the capacity of the unit and the degree of air pollution control desired. In a 1966 article, concerning industrial and household incinerators, E. M. Voelker of the Incinerator Institute of America presented the cost of incinerators with varying degrees of control, as shown in Figure 24-9.19/

24,4 APARTMENT HOUSE INCINERATORS

Apartment house incinerators have historically been the single chamber flue-fed type. Refuse is charged by tenants through service doors connecting into the flue at each floor. The material accumulates in the furnace and is usually ignited by the janitor or attendant early in the morning. The products of cumbustion pass up the same flue and are discharged to the atmosphere. A screened enclosure or spark arrestor is commonly mounted on top of the flue. Emissions are usually high because of low combustion temperatures and improper air regulation.

24.4.1 Emission Sources and Rates

The incinerator is the only particulate source in this type of installation. Emission rates from these units are highly variable and range from 0.8 to 10 lb/ton of refuse burned. $\frac{3,20}{}$ No estimates of national emissions were made for these units.



Figure 24-9 - Capital Cost of Incinerators with Varying Degrees of Air Pollution Control Equipment 19/

24.4.2 Effluent Characteristics

The chemical and physical characteristics of effluents from apartment house incinerators are summarized in Table 24-2. Limited data are available for these units. Poor quality combustion is probable for these units and particulate matter emitted is larger in size than that discharged from municipal units.

24.4.3 Control Practices and Equipment

Preventing the discharge of air pollutants from this type of incinerator involves the use of afterburners or conversion to multiple-chamber incineration. $\frac{3}{}$ Test data, including costs, for various secondary combustion devices and a Peabody gas scrubber are shown in Tables 24-12 and 24-13. $\frac{21}{}$

Scrubbers which increase the velocity of the gases and contact them with low-velocity water appear to be preferable to spray nozzle units because plugged nozzles reduce collection efficiency. Evaluation of impingement-type scrubbers operating at pressure drops in the range of 4 to 8 in. w.g. on flue-fed incinerators indicates efficiencies in the range of 78 to 94%.22/

A preliminary test of a dry cyclone on a flue-fed apartment incinerator showed deposition of fats on the cyclone surface indicating eventual clogging in service. $\frac{21}{}$

TABLE 24-12

PEABODY SCRUBBER PERFORMANCE ON FLUE-FED APARTMENT INCINERATORS 23/

| Refuse charge, lb/test | 275 |
|---|----------|
| Scrubber operating time, min. | 96 |
| Scrubber exhaust, avg. cfm | |
| (corrected to 70°F, 29.22 in. Hg) | 2,670 |
| Gas temperature, °F | |
| Scrubber inlet, range | 153-250 |
| Average | 196 |
| Scrubber outlet, range | 94-108 |
| Average | 102 |
| Scrubber trays, number in use | 2 |
| Pressure across fan, in. w.g. | 7.6 |
| Electric consumption, fan kw. | 5.35 |
| pump kw. | 0.4 |
| Scrubber water | |
| Input, gal/hr | 60 |
| Evaporated, gal/hr | 24 |
| To drain, gal/hr | 36 |
| Emissions | |
| Particulate matter, lb. for test | |
| Collected by scrubber water, avg. | 1.88 |
| In exhaust, avg. | 0.12 |
| Scrubber collection efficiency, % | 94 |
| Noxious gases, lb. for test, avg. | |
| In flue gas before scrubber | 8.93 |
| In scrubber exhaust | 6.92 |
| Removed by scrubber, difference | 1.91 lb. |
| Removal efficiency for noxious gases, 🖇 | 21.6 |

TABLE 24-13

PERFORMANCE AND COST OF DEVICES INSTALLED ON APARIMENT INCINERATOR23/

| | Basic Incinerator | Werner Device | One Pipe Overfire Jets | Hartmann _Device | Gas Burner and Overfire Jets | Peabody Scrubber | Peabody Scrubber and Overfire Jets |
|--------------------------------|----------------------|------------------|------------------------------|---------------------|--|---------------------|--|
| Daily Operation, minutes | | | | , | | | |
| Burning only (no. of burns) | 183(2) | 38(2) | 141(2) | $240^{a}/(3)$ | 125 <u>a</u> /(2) | 183(2) | 141(2) |
| Residue removal | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Total min., hoppers locked | 198 | 53 | 156 | 255 | 140 | 198 | 156 |
| Furnace Capacity, 1b | 275 | 240 | 275 | 200 | 275 | 275 | 275 |
| Emissions, 1b/100 lb of charge | 9 | | | | | , | |
| Particulates | 1.31 | 1.29 | 0.79 | 0.72 | 0.51 | 0.13 ^b / | 0.09 <u>b</u> / |
| Noxious gases | 2.48 | 3.01 | 1.61 | 1.75 | 0.73 | 1.94 <u>c</u> / | 1.26 <u>c</u> / |
| Cost | | | | | | | |
| Investment | \$1,200 | \$2,700 | \$1,600 | \$3,150 \$ | 2,200 | \$5,200 | \$5,600 |
| Annual, total | 166 | 426 | 250 | 1,292 | 1,117 | 1,072 | 1,151 |
| Annual, per room | \$0.30 | \$0.83 | \$0.49 | \$2.52 | \$2.18 | \$2.09 | \$2.25 |

a/ Adjusted for equal burn-out of residue.
 b/ Based on 90% collection of particulate matter.
 c/ Based on 22% removal of noxious gases.

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APPENDIX A

ECONOMIC CONSIDERATIONS IN AIR POLLUTION CONTROL

This appendix, illustrating cost relationships for the various types of collectors, has been taken from Chapter 6 of "Control Techniques for Particulate Air Pollutants," U. S. D. H. E. W., Washington, D. C., 1969. It contains three curves for each type of collector showing purchase cost, installed cost, and annualized cost of operation, as a function of gas volume handled in acfm. It also contains cost data and equations for the determination of operating and maintenance cost for each type of collector.

This cost information contains an explanation of all assumptions and cost bases used. It is included as a basis for cost comparisons with data presented in the industry chapters and as a source of data for the reader's own use in estimating the cost of collection equipment.

A.1 SELECTION OF CONTROL SYSTEM

Most air pollution emission control problems can be solved in several ways. In order to select the best method of reducing pollutant emissions, each solution should be thoroughly evaluated prior to implementation. Steps such as substitution of fuels and raw materials and modification or replacement of processes should not be overlooked as possible solutions. Such emission reduction procedures often can improve more than one pollution problem. For example, particulate matter and sulfur oxides emissions both may be reduced by switching from high-sulfur coal to natural gas or low-sulfur oil. Such steps also may have the benefit of reducing or eliminating solid waste disposal and water pollution problems. Often it is cheaper to attack two air problems together than to approach each problem individually. If steps such as process alterations and substitution of fuels are not feasible, it may be necessary to use gas-cleaning equipment.

Figure A-1 shows the factors to be considered in selection of gas-cleaning system. The first consideration is the degree of reduction of emissions which may be required to meet emission standards. The degree of emission reduction or the collection efficiency required is dependent upon the relationship between emissions and emission standards as shown at the top of the figure. This is an important factor in making the choice among control equipment alternatives. Although a control system may include two or more pieces of control equipment, collection efficiency, as used in this chapter, applies to individual pieces of control equipment. The usual ranges of collection efficiency for various equipment alternatives are shown in



Figure A-1 - Criteria for Selection of Gas-Cleaning Equipment

Table A-1. The important factors to be considered next are the gas stream and particle characteristics of the process itself, as shown in the center of Figure A-1. High gas temperatures without cooling, for example, preclude the use of fabric filters; explosive gas streams prohibit the use of electrostatic precipitators; and submicron particles cannot generally be efficiently collected with mechanical collectors. A number of factors that relate to the plant facility should also be considered, some of which are listed in Figure A-1. Each alternative will have a specific cost associated with it, and the components of this cost should be carefully examined. Those alternatives which meet the requirements of both the process and the plant facility can then be evaluated in terms of cost; on this basis, the gas-cleaning system may be selected.

TABLE A-1

AIR POLLUTION CONTROL EQUIPMENT COLLECTION EFFICIENCIES 1-3/

| Favinment Three | Efficiency Range (on a total weight basis) (d) |
|------------------------------|--|
| Eddipment Type | (%) |
| Electrostatic precipitatora/ | 80 to 99.5+ |
| Fabric filters ^{b/} | 95 to 99.9 |
| Mechanical collector | 50 to 9 5 |
| Wet collector | 75 to 99+ |
| After burner: | |
| Catalytic ^{C/} | 50 to 80 |
| Direct flame | 95 to 99 |
| | |

<u>a</u>/ Most electrostatic precipitators sold today are designed for 98 to 99.5% collection efficiency.

b/ Fabric filter collection efficiency is normally above 99.5%.

c/ Not normally applied in particulate control; has limited use because most particulates poison or desensitize the catalyst.

A.2 COST-EFFECTIVENESS RELATIONSHIPS

Meaningful quantitative relationships between control costs and pollutant reductions are useful in assessing the impact of control on product prices, profits, investments, and value added to the product.* With such

^{*} Value added is generally considered to be the economic worth added to a product by a particular process, operation, or function. $\frac{4}{2}$

relationships at hand the alternates for solution of an air pollution problem can be evaluated for more effective program implementation by the user of the control equipment and by the enforcement agency. These cost-effectiveness relationships sometimes are applied collectively to a meteorological or air quality control region, where they describe the total cost impact on polluters as a result of controlling sources; the discussion here, however, centers around cost-effectiveness as applied to an individual source. Costeffectiveness is a measure of all costs to the firm associated with a given reduction in pollutant emissions. For computing the costs for a given system, one should consider (1) raw materials and fuels used in the process, (2) alterations in process equipment, (3) control hardware and auxiliary equipment, and (4) disposal of collected emissions.

Figure A-2 shows an example of a theoretical cost-effectiveness relationship. $\frac{5}{}$ The actual total costs of control may depart from this curve because some cost elements, such as research and development expenditures and fixed charges (taxes, insurance, depreciation) are not directly related to the operation of the equipment and to the level of emissions in a given year. The cost of control is represented on the vertical axis and the quantity of pollutants emitted on the horizontal axis. Point P indicates the uncontrolled state, in which there are no control costs. As control efficiency improves, the quantity of emissions is reduced and the cost of control increases. In most cases, the marginal cost of control is smaller at the lower levels of efficiency, near Point P of the curve. The curve also illustrates that as the cost of control increases, greater increments of cost usually are required for corresponding increments of emission reduction. Process changes sometimes may result in emission reduction without increased costs. Research and development expenditures resulting in new or improved equipment design, improved process operations, or more efficient equipment operations will improve the economics of control. All these factors may substantially reduce control costs at most emission levels and shift the cost of the control curve (CC) as illustrated by CC1 in Figure A-3. Note that as control technology develops, the cost of attaining a desired emission level will be reduced from C_{a} to C_{b} .







Figure A-2 - Cost of Control

Figure A-3 - Expected New Cost of Control

Cost-effectiveness information is useful in emission control decision-making. Several feasible systems usually are available for controlling each source of emissions. In most cases, the least-cost solution for each source can be calculated at various levels of control. After evaluating each alternative and after considering future process expansions and more rigid control restrictions, sufficient information should be available on which to base an intelligent control decision.

Cost-effectiveness relationships vary from industry to industry and from plant to plant within an industry. The cost for a given control system is significantly dependent on the complexity of the installation and the characteristics of the gas stream and pollutant. Geographical location is another significant factor that influences the total annual cost; for example, the components of annual cost, such as utilities, labor, and the availability of desired sites for waste material, vary from place to place.

A.3 COST DATA

It is the purpose of this Appendix to develop basic information and techniques for estimating the costs of installing and operating control equipment. Such information can be useful in developing cost-effectiveness relationships for application of various control systems.

A.4 UNCERTAINTIES IN DEVELOPING COST RELATIONSHIPS

Cost information for control devices is given in Section A.7 where, for various types of equipment, operating capacity is plotted against cost. The upper and lower curves indicate the expected range of costs, with the expected average cost falling approximately in the middle. Although quantitative values for collection efficiency and gas volume capacity are not listed, higher collection efficiency, which involves more intricate engineering design, results in higher costs. Control equipment is designed for a nominal gas volume capacity, but under actual operating conditions the volume may vary. Similarly, the efficiency of control equipment will vary from application to application as particle characteristics, such as wettability, density, shape, and size distribution, differ. For example, a control device designed to operate on 50,000 acfm of gas with a nominal collection of 95% may have an effective operating range of from 45,000 to 55,000 acfm, and its collection efficiency may range from 90 to 97%.

The effect of these independent variations is to make single point estimates of cost versus size and efficiency difficult to determine. Based on the data available, all estimates must be constructed over an interval of uncertainty for each of the three variables. To make the cost estimation problem manageable in this report, nominal high, medium, and low collection efficiencies have been selected for each type of control equipment, except fabric filters. For fabric filters, the nominal high, medium, and low curves reflect construction variations. The purchase, installation, and total annualized costs of operation are plotted for each of the three efficiency levels over the gas volume range indicated. Purchase, installation, and total annumalized costs for fabric filters are plotted for variations in filter construction and cleaning methods.

Generalized categories of control equipment are discussed rather than specific designs because of uncertainties in size, efficiency, and cost. If required, more detailed information on the cost of various engineering innovations (e.g., packed towers of specific design to accommodate a corresive gas stream) should be requested from the manufacturers of the specific equipment. Cost variations associated with wet collectors are reported in Table A-2. $\frac{3}{}$

Other difficulties exist in developing cost information for existing control devices, especially cost estimates on the maintenance and operation of control equipment. Individual firms may remember what a control device cost originally, but they may forget what it costs to install and operate. In addition, internal bookkeeping and auditing systems often bury these expenditures in total plant operating costs. For example, water and electricity used by a control operation are not always separately metered and accountable as a specific air pollution control cost item. Some of these costs can be identified and assessed on the basis of industrial experience or engineering estimates.

| | Cost, dollars/cfm Capacity, cfm | | | | |
|---|------------------------------------|-------|--------|--------|--|
| Type of Collector a/ | 1,000 | 5,000 | 20,000 | 40,000 | |
| Cyclonic: <u>b,c</u> / | | | | | |
| Small diameter multiples | 0.50 | 0.30 | 0.20 | 0.20 | |
| Single chamber, constant water level | 1. 4 0 | 0.45 | 0.35 | 0.25 | |
| Single chamber, multiple stage, overhead line pressure water feed | 0.95 | 0.40 | 0.25 | 0.20 | |
| Single chamber, internal nozzle spray | 3.00 | 1.50 | 1.00 | 0.75 | |
| Self-induced sprayb-d/ | 0.80 | 0.40 | 0.25 | 0.25 | |
| Wet impingement ^{b,c/} | 1.00 | 0.50 | 0.25 | 0.25 | |
| Venturi <mark>c,d</mark> / | 3.00 | 1.50 | 1.20 | 0.50 | |
| Variable pressure drop inertia <u>lc,d</u> / | 1.00 | - | - | 0.30 | |
| Mechanical ^{c,d} | 1.75 | 0.75 | 0.35 | | |

APPROXIMATE COST OF WET COLLECTORS IN $1965\frac{3}{}$

a/ Basic designs, mild steel construction.

- b/ Add 30 to 40% to base price for fan, drive, and motor (standard construction materials).
- <u>c</u>/ Special materials construction costs for 1,000- to 40,000-cfm range units are approximately as follows:

Rubber lining - base increase of 65 to 115%. Type 304 stainless steel - base increase of 30 to 60%. Type 316 stainless steel - base increase of 45 to 100%.

<u>d</u>/ Add from 10 to 40% to base price per additional stage as in some cyclonic and wet impingement designs

A.5 DESCRIPTION OF CONTROL COST ELEMENTS

A.5.1 General

The actual cost of installing and operating air pollution control equipment is a function of many direct and indirect cost factors. An analysis of the control costs for a specific source should include an evaluation of all relevant factors, as outlined in Figure A-4. The control system must be designed and operated as an integral part of the process; this will minimize the cost of control for a given emission level. The definable control costs are those that are directly associated with the installation and operation of control systems. These expenditure items from the viewpoint of the control equipment user have a breakdown for accounting purposes as follows:

> Capital Investment Engineering studies Land Control hardware* Auxiliary equipment* Operating supply inventory Installation* Startup Structure modification Maintenance and Operation

Utilities* Labor* Supplies and materials* Treatment and disposal of collected material

Capital Charges Taxes* Insurance* Interest*

* Denotes cost items considered in this report.

Of the expenditure items shown above, only those denoted by an asterisk were considered in developing the cost estimates used in this Appendix. Other factors, such as engineering studies, land acquisition, operating supply inventory, and structural modification, vary in cost from place to place and therefore were not included. Costs for the treatment and disposal of collected material, while also not included, are discussed in some detail in Section A.8.



Figure A-4 - Diagram of Cost Evaluation for a Gas-Cleaning System

A.5.2 Capital Investment

The "installed cost" quoted by a manufacturer of air pollution equipment usually is based on his engineering study of the actual emission source. This cost includes three of the eight capital investment items-control hardware costs, auxiliary equipment costs, and costs for field installation.

The <u>purchase cost</u> curves that are shown in Section A.7 illustrate the control hardware costs for various types of control equipment. These purchase costs are the amounts charged by manufacturer for equipment of standard construction materials. Basic control hardware includes built-in instrumentation and pumps. Purchase cost usually varies with the size and collection efficiency of the control device. The purchase costs plotted on the curves are typical for the efficiencies indicated, but these costs may vary $\frac{1}{2}$ 20% from the values shown. Of course, equipment fabricated with special materials (e.g., stainless steel or ceramic coatings) for extremely high temperatures or corrosive gas streams may cost much more.

The remaining capital investment items, auxiliary equipment and installation costs, are aggregated together and referred to as "total installation costs." These costs are shown in Table A-3, expressed as percentages of the purchase costs. These costs include a reasonable increment for the following items: (1) erection, (2) insulation material, (3) transportation of equipment, (4) site preparation, (5) clarifiers and liquid treatment systems (for wet collectors), and (6) auxiliary equipment such as fans, ductwork, motors, and control instrumentation. The low values listed in the table are for minimal transportation and simple layout and installation of control devices. High values are for higher transportation cost and for difficult layout and installation problems. The extreme high values are for unusually complex installations on existing process equipment. Table A-4 lists the major cost categories and related conditions that establish the installation cost range from low to high. The "installed cost" estimates reported in Section A-7 are the sum of the purchase costs and the total installation costs.

A.5.3 Maintenance and Operation

The following sections describe the working equations for the operation and maintenance costs of various control devices. Numerical values for the variables expressed in these equations are found in Tables A-5 and A-6.

TOTAL INSTALLATION COST FOR VARIOUS TYPES OF CONTROL DEVICES EXPRESSED AS A PERCENTAGE OF PURCHASE COSTS

| | | Cos | t, Percent | |
|---|------------|------------|------------|--------------------|
| Equipment Type | Low | Typical | High | Extreme High |
| Gravitational | 33 | 67 | 100 | - |
| Dry centrifugal | 35 | 50 | 100 | 400 |
| Wet collector: Low, medium energy High energy ^{B/} | 50 100 | 100 200 | 200 400 | 40 0 500 |
| Electrostatic precipitators | 4 0 | 70 | 100 | 400 |
| Fabric filters | 50 | 75 | 100 | 400 |
| Afterburners | 10 | 25 | 100 | 40 0 |

a/ High-energy wet collectors usually require more expensive fans and motors.

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| | CONDITIONS AFFECTING INSTALLED COST OF CONTROL DEVICES | | | | |
|--------------------------------------|---|---|--|--|--|
| Cost Category | Low Cost | High_Cost | | | |
| Equipment transportation | Minimum distance; simple loading and unloading procedures | Long distance; complex procedure for loading and unloading | | | |
| Plant age | Hardware designed as an integral part of new plant | Hardware installed into confines of old plant requiring structural or process modification or alteration | | | |
| Available space | Vacant area for location of control system | Little vacant space requires extensive steel support construction and site preparation | | | |
| Corrosiveness of gas | Noncorrosive gas | Acidic emissions requiring high alloy accessory equipment using special handling and con- struction techniques | | | |
| Complexity of startup | Simple startup, no exten- sive adjustment required | Requires extensive adjustments; testing; con- siderable down time | | | |
| Instrumentation | Little required | Complex instrumentation required to assure reliability of control or constant monitoring of gas stream | | | |
| Guarantee on performance | None needed | Required to assure designed control efficiency | | | |
| Degree of assembly | Control hardware shipped completely assembled | Control hardware to be assembled and erected in the field | | | |
| Degree of engineering design | Autonomous "package" con- trol system | Control system requiring extensive integration into process, insulation to correct tem- perature problem, noise abatement | | | |
| Utilities | Electricity, water, waste disposal facilities readily available | Electrical and waste treatment facilities must be expanded, water supply must be developed or expanded | | | |
| Collected waste material handling | No special treatment facilities or handling required | Special treatment facilities and/or handling required | | | |
| Laber | Low wages in geographical area | Overtime and/or high wages in geographical area | | | |

558

ANNUAL MAINTENANCE COSTS FOR ALL GENERIC TYPES OF CONTROL DEVICES

| Generic Type | Dollars Per ACFM | | | |
|------------------------------|------------------|---------------------|---------------------|--|
| | Low | Typical | High | |
| Gravitational and dry | | | | |
| centrifugal collectors | 0.005 | 0.015 | 0.025 | |
| Wet collectors | 0.02 | 0.04 | 0.06 | |
| Electrostatic precipitators: | | | | |
| High voltage | 0.01 | 0.02 | 0.03 | |
| Low voltage | 0.005 | 0.014 | 0.02 | |
| Fabric filters | 0.02 | 0.05 | 0.08 | |
| Afterburners: | | | | |
| Direct flame | 0.03 <u>a</u> / | 0.06 ^b / | 0.10 ^b / | |
| Catalytic | 0.07 | 0.20 | 0.35 | |

Metal liner with outside insulation. Refractory lined. <u>a</u>/ b/

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| Fan Efficiency = 60% | | Pump Efficiency : | Pump Efficiency = 50% | | | | | |
|--|--|------------------------|-----------------------|--|--|--|--|--|
| Power Cost, Dollars/Kilowett-Hr ^{B/} | | | | | | | | |
| | Low | Typical | | High | | | | |
| All devices | 0.0 05 | 0.011 | | 0.020 | | | | |
| Hours of Operation | | | | | | | | |
| 0,760 hr/yr - 24 hr/day x 365 days/yr = 0,760 | | | | | | | | |
| Power requirements vs. efficiency for high-voltage electrostatic precipitators, 10 ⁻³ kw/acfm | | | | | | | | |
| | Low | Medium | | High | | | | |
| | 0.26 | 0.26 | | | | | | |
| Power requirements vs. efficiency | 7 for low-voltage el | Lectrostatic precipite | ators 10-3 | kw/acfr. | | | | |
| | Low | | | High | | | | |
| | | | C.040 | | | | | |
| Liquor cost in | n 10 ⁻³ dollars/gal (| (for wet system) | | | | | | |
| | Low | Typical | | High | | | | |
| Wet scrubber | 0.35 | 0.50 | | 1.00 | | | | |
| Makeup liq | quor requirements, (| 0.0005 gal/hr-acfm | | | | | | |
| | Power Requireme | ents | | ······································ | | | | |
| Low Efficiency | | y Medium Eff; | Medium Efficiency | | | | | |
| "Sorubbing" (contact) power, horsepower/scfm 0.0013 | | 0.0035 | 0.0035 0.015 | | | | | |
| | Scrubber Liquor | Data | | | | | | |
| | Low | Typical | | H≟gh | | | | |
| Liquor circulation rate, gal/acfm | iquor circulation rate, gal/acfm 0.001 | | 0.003 | | | | | |
| Minimum head requirements, feet water | 30 | 30 | | | | | | |
| Pressure drop through equipment, inches of water | | | | | | | | |
| Generic Type | Low | Typical | | High | | | | |
| Dry centrifugal collector | - | 2-3 | | 4 | | | | |
| Fabric filter | 2-3 | 4-5 | | 6-8 | | | | |
| Afterburners | 0.5 | 1.0 | | 2 | | | | |
| Electrostatic precipitators and gravitational collectors | 0.1 | 0.5 | | 1 | | | | |
| a/ Based on national average of large consumers. b/ 1 paig = 2.3 ft. water. | | | | | | | | |

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A.5.3.1 <u>General</u>: The costs of operation and maintenance will vary widely because of different policies of control equipment users. This variance will depend on such factors as the quality and suitability of the control equipment, the user's understanding of its operation, and his vigilance in maintaining it. Maintenance and operation usually are very difficult to define and assess, but often may be a significant portion of the overall cost of controlling air pollutant emissions. Although the combined operating and maintenance costs may be as low as 10% of the annualized total cost for a gravitational settling chamber, for example, they may be as high as 90% of the total annualized cost for a high-efficiency wet collector.

Maintenance cost is the expenditure required to sustain the operation of a control device at its designed efficiency with a scheduled maintenance program and necessary replacement of any defective parts. On an annual basis, maintenance cost in the following equations is assumed proportional to the capacity of the device in acfm. Table A-5 shows annual maintenance cost factors for all types of particulate control devices. Simple, lowefficiency control devices have low maintenance costs; complex, high-efficiency devices have high maintenance costs.

Annual operating cost is the expense of operating a control device at its designed collection efficiency. This cost depends on the following factors: (1) the gas volume cleaned, (2) the pressure drop across the system, (3) the operating time, (4) the consumption and cost of electricity, (5) the mechanical efficiency of the fan, and (6) the scrubbing-liquor consumption and costs (where applicable).

A.5.3.2 Gravitational and Centrifugal Mechanical Collectors: In general, the only significant cost for operating mechanical collectors is the electric power cost, which varies with the unit size and the pressure drop. Since pressure drop in gravitational collectors is low, operational costs associated with these units are considered to be insignificant. Maintenance cost includes the costs of servicing the fan motor, replacing any lining worn by abrasion, and, for multicyclone collectors, flushing the clogged small diameter tubes.

Cost equation - The theoretical annual cost (G) of operation and maintenance for centrifugal collectors can be expressed as follows:

$$G = S \left[\frac{0.7457 \text{ PHK}}{63562} + M \right]$$
 (1)

where:

S = design capacity of the collector, acfm P = pressure drop, inches of water (see Table A-6) E = fan efficiency, assumed to be 60% (expressed as 0.6) 0.7457 = a constant (1 horsepower = 0.7457 kilowatt) H = annual operating time (assumed 8,760 hr.) K = power cost, dollars/kilowatt-hr (see Table A-6) M = maintenance cost, dollars/acfm (see Table A-5)

For computational purposes the cost formula can be simplified as follows:

$$G = S \left[195.5 \times 10^{-6} \text{ PHK} + M \right]$$
 (2)

A.5.3.3. <u>Wet Collectors</u>: The operating costs for a wet collector include power and scrubbing-liquor costs. Power costs vary with equipment size, liquor circulation rate, and pressure drop. Liquor consumption varies with equipment size and stack gas temperature. Maintenance includes servicing the fan or compressor motor, servicing the pump, replacing worn linings, cleaning piping, and any necessary chemical treatment of the liquor in the circulation system.

Cost equation - The theoretical annual cost (G) of operation and maintenance for wet collectors can be expressed as follows:

$$G = S \left[0.7457 \text{ HX} \left(\frac{P}{6356E} + \frac{Qg}{1722F} + \frac{Qh}{3960F} \right) + \text{ WHL} + M \right]$$
(3)

where:

S = design capacity of the wet collector, acfm
0.7457 = a constant (1 horsepower = 0.7457 kilowatts)
H = annual operating time (assumed 8,760 hr.)

K = power costs, dollars/kilowatt-hr

P = pressure drop across fan, inches of water (see Table A-6)

Q = liquor circulation, gal/acfm (see Table A-6)

g = liquor pressure at the collector, psig (see Table A-6)

h = physical height liquor is pumped in circulation system, feet (see Table A-6)

W = make-up liquor consumption, gal/hr/acfm (see Table A-6)

L = liquor cost, dollars/gal (see Table A-6)

M = maintenance cost, dollars/acfm (see Table A-5)

E = fan efficiency, assumed to be 60% (expressed as 0.60)

F = pump efficiency, assumed to be 50% (expressed as 0.50)

The above equation can be simplified according to Semrau's total "contacting power" concept. $\frac{6}{}$ Semrau shows that efficiency is proportional to the total energy input to meet fan and nozzle power requirements. The scrubbing (contact) power factors in Table A-6 were calculated from typical performance data listed in manufacturers' brochures. These factors are in general agreement with data reported by Semrau. Using Semrau's concept the equation for operating cost can be simplified as follows:

$$G = S \left[0.7457 \text{ HK} \left(Z + \frac{\text{Qh}}{1980} \right) + \text{ WHL} + M \right]$$

1. Fan horsepower/acfm
$$\left(=\frac{P}{6356E}\right)$$
, and
2. Pump horsepower/acfm $\left(=\frac{Qg}{1722F}$ the power to atomize water $\right)$

The pump horsepower, Qh/1980, required to provide pressure head is not included in the contact power requirements.

A 5.3.4 <u>Electrostatic Precipitators</u>: The only operating cost considered in the operation of electrostatic precipitators is the power cost for ionizing the gas and operating the fan. As the pressure drop across the equipment is usually less than 1/2 in. of water, the cost of operating the fan is assumed to be negligible. The power cost varies with the efficiency and the size of the equipment.

Maintenance usually requires the services of an engineer or highly trained operator, in addition to regular maintenance personnel. Maintenance includes servicing fans and replacing damaged wires and rectifiers.

<u>Cost equation</u> - The theoretical annual cost (G) for operation and maintenance of electrostatic precipitators is as follows:

$$G = S [JHK + M]$$
(4)

where

S = design capacity of the electrostatic precipitator, acfm

J = power requirements, kilowatts/acfm (See Table A-6)

H = annual operating time (assumed 8,760 hr.)

K = power cost, dollars/kilowatt-hr (see Table A-6)

M = maintenance cost, dollars/acfm (see Table A-5)

A.5.3.5 Fabric Filters: Operating costs for fabric filters include power costs for operating the fan and the bag cleaning device. These costs vary directly with size of equipment and the pressure drop. Maintenance costs include costs for servicing the fan and shaking mechanism, emptying the hoppers, and replacing the worn bags.

<u>Cost equation</u> - The theoretical annual cost (G) for operation and maintenance of fabric filters is as follows:

$$G = S \left[\frac{0.7457}{6356E} PHK + M \right]$$
(5)

where:

- S = design capacity of the fabric filter, acfm
- P = pressure drop, inches of water (see Table A-6)
- E = fan efficiency, which is assumed to be 60% (expressed as 0.60)
- 0.7457 = a constant (1 horsepower = 0.7457 kilowatt)
 - H = annual operating time (assumed 8,760 hr.)
 - K = power cost, dollars per kilowatt-hr. (see Table A-6)
 - M = maintenance cost, dollars/acfm (see Table A-5)

For computational purposes, the cost formula can be simplified as follows:

 $G = S [195.5 \times 10^{-6} \text{ PHK} + M]$ (6)

A.5.3.6 <u>Afterburners</u>: The major operating cost item for afterburners is fuel. Fuel requirements are a direct function of the gas volume, the enthalpy of the gas, and the difference between inlet and outlet gas temperatures. For most applications, the inlet gas temperature at the source ranges from 300° to 400°F. Outlet temperatures may vary from 1200° to 1500°F for direct flame afterburners and from 730° to 1200°F for catalytic afterburners.²/ The use of heat exchangers may bring about a 50% reduction in the temperature difference.⁷.⁸/ Table A-7 lists hourly fuel costs based on a natural-gas cost of \$0.60/million Btu. No credit was given for heat of combustion of particulate or other matter. These costs were developed from enthalpies (heat content) of the process gas at given temperatures.⁹/ Maintenance includes servicing the fan, repairing the refractory lining, washing and rinsing the catalyst, and rejuvenating the catalyst.¹⁰/

HOURLY FUEL COSTS

| Device | <u>Temperatur</u> <u>Inlet</u> | re, (°F) Outlet | Δ Temperature, (°F) | Fuel Cost, ^{<u>B</u>/ Dollars/acfm-Hr} |
|-----------------------------|-----------------------------------|--------------------|---------------------------|---|
| Direct flame (DF) | 380 | 1400 · | 1020 | 0,00057 |
| DF with heat exchanger | 1000 | 1 400 | 4 00 | 0.00023 |
| Catalytic afterburner (CAB) | 380 | 900 | 520 | 0.00028 |
| CAB with heat exchanger | 650 | 900 | 250 | 0.00014 |

These figures include the cost of heating an additional 50% excess air. It is assumed there is no heat content in the material or pollutant being consumed.

The equation for calculating the operation and maintenance costs (G) is as follows:

$$G = S \left[\frac{0.7457}{6356} \frac{PHK}{E} + HF + M \right]$$
(7)

where:

S = design capacity of the afterburner, acfm
P = pressure drop, inches of water (see Table A-6)
E = fan efficiency, assumed to be 60% (expressed as 0.60)
0.7457 = a constant (1 horsepower = 0.7457 kilowatt)
H = annual operating time (assumed 8,760 hr.)
K = power cost, dollars per kilowatt-hour (see Table A-6)
F = fuel cost, dollars per acfm/hr (see Table A-7)
M = maintenance cost, dollars/acfm (see Table A-5)

For computational purposes, the cost formula is simplified as follows:

$$G = S \left[195.5 \times 10^{-6} \text{ PHK} + \text{HF} + \text{M} \right]$$
 (8)

A.5.4 Capital Charges

Capital charge includes overhead expenses such as taxes, insurance, and interest incurred in the operation of a control device. Such costs frequently lose specific identity because of internal accounting practices. It is possible, however, by reasonable assumptions, to include capital charges in the annualized cost of control.

A.5.5 Annualization of Costs

Annualized capital costs are estimated by depreciating the capital investment (total installed cost) over the expected life of the control equipment and adding the capital charges (taxes, interest, and insurance). Adding the recurring maintenance and operation costs to this figure gives a total annualized cost of control. Total annualized cost estimates are shown in Section A.7.

A.5.6 Assumptions in Annualized Control Cost Elements

Annualized control costs will differ from installation to installation and from region to region, and certain simplifying assumptions have been necessary to develop the cost figures of this section. If more information for a given location is available, it is desirable to substitute this for the assumptions used here.

A.5.6.1 <u>Annualized Capital Cost Assumptions</u>: The simplifying assumptions for computing the total annualized capital cost are as follows:

1. Purchase and installation costs are depreciated over 15 years, a period assumed to be a feasible economic life for control devices.

2. The straight-line method of depreciation (6-2/3%/year) is used because it is the most common method used in accounting practices. This method has the simplicity of a constant annual writeoff.

3. Other costs called capital charges--which include interest, taxes, insurance, and other miscellaneous costs--are assumed to be equal to the amount of depreciation, or 6-2/3% of the initial capital cost of the control equipment installed. Therefore, depreciation plus these other annual charges amounts to 13-1/3% of the initial capital cost of the equipment.
A.5.6.2 <u>Operating Cost Assumptions</u>: The following assumptions were taken into account for computing operation and maintenance costs.

1. Power costs included in annual operating expense reflect electricity used by all systems directly associated with the control equipment. Electrical power requirements are computed on a constant usage basis at a specified gas volume.

2. For wet collectors, it is assumed that the liquor is recirculated in a closed system. Liquor consumption consists of the makeup liquor which must be added from time to time. Stack gas temperature influences the rate of liquor loss; this influence is partially accounted for by assuming a constant loss per cubic foot of stack gas volume. This assumption is necessary because of the extremely wide range of stack gas temperatures.

3. The costs for electricity and water are computed on the marginal rate classes for each size user, which assumes that any additional consumption will be priced at the lowest rate-highest volume class available. Except where specifically indicated, the typical values for the pressure drop and cost of electricity (see Table A-7) were assumed in all control cost calculations and illustrations.

4. The disposal cost and/or recovered value of collected effluents are not included in the operating cost calculations because of cost differences from process to process. Disposal cost figures for several major industrial categories are reported in Section A.8.

A.5.6.3 <u>Maintenance Cost Assumption</u>: It is assumed that a user of control equipment establishes a preventive (scheduled) maintenance program and carries it out to maintain equipment at its designed collection efficiency. Further, it is assumed that unscheduled maintenance, such as replacement of defective parts, is undertaken as required. The cost incurred for equipment modification or repair due to an operational accident is not included.

A.6 METHOD FOR ESTIMATING ANNUAL COST OF CONTROL FOR A SPECIFIC SOURCE

A.6.1 General

As previously indicated, it is beyond the scope of this Appendix to identify and assess the cost of control for a specific source. Such assessments can, however, be calculated by applying the steps outlined below.

A.6.2 Procedure

The following procedure can be used to determine the expected cost of control for any source.

Step 1. Describe the source (including characteristics of the process), the characteristics and consumption of fuel for combustion, and the total number of hours in operation annually. Emissions can be determined by making stack gas tests or can be estimated by making calculations using the emission factors.

Step 2. Select the applicable types of control equipment. Figure A-1 illustrates what must be considered in selecting the optimum type of control equipment.

Step 3. Specify pressure drops, efficiencies, construction material, energy and fuel requirements, and size limitations for the selected control equipment, taking into account any existing equipment.

Step 4. Determine the gas flow in acfm at the point of collector location. For wet collectors, this would be the water saturated gas volume. This should be done by taking measurements at maximum operating conditions.

Step 5. Determine the estimated total purchase cost for the specific selected device (curves found in Section A.7) at the required gas volume and control efficiency. For fabric filters, select the proper filter medium for the process.

Step 6. Multiply the cost found in Step 5 by the low, typical, and high installation cost factors (Table A-3), and add the result to the estimated total purchase cost to obtain the corresponding low, typical, and high total installed costs. Conditions affecting the cost of installation are listed in Table A-4.

Step 7. Calculate the total annual capital cost as follows:

Annualized capital cost = depreciation + capital charges = 0.133 x total investment cost*

Step 8. Compute the cost of electricity, maintenance, and liquor consumption.

Step 9. Compute low, medium, and high operating and maintenance costs from the appropriate formulas:

Dry centrifugal collectors

 $G = S [195.5 \times 10^{-6} \text{ PHK} + \text{M}]$

* Based on the assumptions in Section A.5.6.1.

Wet scrubbers

$$G = S \left[0.7457 \text{ HK} \left(Z + \frac{Qh}{1980} \right) + \text{ WHL} + M \right]$$

Electrostatic precipitator

G = S [JHK + M]

Fabric filters

G = S [195.5 x 10-6 PHK + M]

Afterburners

 $G = S [195.5 \times 10^{-6} \text{ PHK} + M + HF]$

where:

G = theoretical value for operating and maintenance costs

S = the design capacity of the collection device, acfm

P = pressure drop cf the gas, inches of water

H = annual operating time

K = power costs, dollars per kilowatt-hour

Q =liquor circulation, gal/acfm

- Z = total power input required for scrubbing efficiency, horsepower/ acfm

M = maintenance cost, dollars/acfm

W = liquor consumption, gal/hr/acfm

L = cost of liquor, dollars/gal

J = power requirement, kilowatts/acfm based on efficiency

F = fuel cost, dollars/hr/acfm

Step 10. Add the typical annualized capital cost to the typical operating and maintenance cost to yield the estimated total annualized cost of control.

Step 11. Because the above calculation is a point estimate, the range of costs should be investigated. For this, a variance is calculated and applied to the total estimated annual cost. The low cost variance (V_1) and high cost variance (V_h) of an equipment combination can be computed by using the square root of the sum of the squares. The formulas for these variances are as follows:

$$V_{1} = \sqrt{(C_{m} - C_{1})^{2} + (G_{m} - G_{1})^{2}}$$
$$V_{h} = \sqrt{(C_{h} - C_{m})^{2} + (G_{h} - G_{m})^{2}}$$

where:

 C_1 , C_m , and C_h are the low, typical, and high annual capital cost estimates, respectively, and G_1 , G_m , and G_h are the low, typical, and high operation and maintenance cost estimates. These formulas are taken from the usual definition of the standard error of a linear combination of statistically independent variables. They permit computation of the most probable, rather than the extreme, range of costs.

Step 12. The high cost variance (V_h) is added to the total estimated annual cost to yield the high cost limit.

Step 13. The low cost variance (V_1) is subtracted from this total estimated annual cost to yield the low cost limit.

A.6.3 Sample Calculations

The following calculations illustrate the method used to determine the total estimated annual cost of control. The following example shows the estimation of annualized cost for a 60,000 cfm, 90% (medium efficiency) wet collector.

Step 1. Annual operating time = 8,760 hr. (H)
Step 2. Wet collector (given)
Step 3. 90% efficiency (given)

Scrubbing power required - 0.0035 horsepower/acfm (Z)

Step 4. Actual gas flow = 60,000 acfm (given)

Step 5. Purchase cost = \$17,000 (from Section A.7.4 for wet collectors)

Step 6. Installation factors from Table A-3 are 50%, 100%, and 200%

| Installation f | factor | 50% 10 0% | 20 0% | | | |
|------------------------------------|------------------------------|--------------------|---------------|-----|--|--|
| Installation of | cost 8, | ,500 17,000 | 34,000 | | | |
| Purchase cost | 17, | ,000 <u>17,000</u> | <u>17,000</u> | | | |
| Total capital | cost \$25, | ,500 \$34,000 | \$51,000 | | | |
| Step 7. 0.133 x | ([Total capital | cost] = annual | capital cost | (C) | | |
| C _l = 0.133 x \$ | \$25,500 = \$3,400 | | | | | |
| C _m ≠ 0.133 x \$ | \$34,000 = \$4,530 | | | | | |
| C _h = 0.133 x \$ | \$51,000 = \$6,800 | | | | | |
| Step 8. Power o | cost, dollars/kil | Lowatt-hr (K) | | | | |
| Low | Typical | | High | | | |
| 0.005 | 0.011 | | 0.020 | | | |
| Maintenance cost, dollars/acfm (M) | | | | | | |
| Low | Typical | | <u>High</u> | | | |
| 0.02 | 0.04 | | 0.06 | | | |
| Liquor cost, l | 10 ⁻³ dollars/gal | (L) | | | | |
| Low | Typical | | High | | | |
| 0.35 | 0.50 | | 1.00 | | | |
| Heat r e quired | for circulation | in system, feet | t (h) | | | |
| Low | Typical | | High | | | |
| 1 | 30 | | 60 | | | |
| Liquor circula | ation, gallons/a | .cfm (Q) | | | | |

High

Makeup liquor rate, 10^{-3} gal/hr/acfm, (W) = 0.5

Step 9. Using the following formula to determine annual operating cost (G) $% \left(G\right) =0$

$$G = S\left[\left(Z + \frac{Qh}{1980}\right)(0.7457 \text{ HK}) + \text{WHL} + M\right]$$

The low, typical, and high operating and maintenance costs are as follows:

$$G_1 = \$8,200$$
 $G_m = \$18,100$ $G_h = \$35,900$

Step 10. From the steps 7 and 9,

$$C_m = $4,530$$
 $G_m = $18,100$

Then, the total estimated annual cost is as follows:

$$C_{m} + G_{m} = $22,600$$

Step 11. Using the square root of the sum of the squares of the differences, the high and low cost variances are as follows:

$$V_{1} = \sqrt{(C_{m} - C_{1})^{2} + (G_{m} - G_{1})^{2}}$$

$$V_{1} = \sqrt{(4,530 - 3,400)^{2} + (18,100 - 8,200)^{2}}$$

$$V_{1} = \$10,000$$

$$V_{h} = \sqrt{(C_{h} - C_{m})^{2} + (G_{h} - G_{m})^{2}}$$

$$V_{h} = \sqrt{(6,800 - 4,530)^{2} + (35,900 - 18,100)^{2}}$$

$$V_{h} = \$17,900$$

Step 12. From Step 10, the total estimated annual cost = \$22,600

. From Step 11, V₁ = \$10,000

Low cost limit = \$22,600 - \$10,000 = \$12,600

Step 13. Total estimated annual cost = \$22,600

From Step 11, $V_h = $17,900$

High cost limit = \$22,600 + \$17,900 = \$40,500

Step 14. The amount of particulate matter emitted may be calculated if the inlet conditions are known.

A.6.4 Annualized Cost Variation

The previous section illustrated the probable high and low cost limits for a single installation, taking into account the variation in costs for installation, maintenance, and operation. To compute the annualized cost for a given emission reduction system, one must take into account four variables: (1) collection efficiency of the system, (2) cost of installing the system, (3) cost of operation, and (4) maintenance cost. A more complete summary of the range of total annualized costs is shown in Table A-8 for a 60,000 acfm wet collector. This table illustrates cost figures for 81 possible combinations of each of the four variables, with each variable taking on three independent values -- low, typical, and high. It is constructed by the procedure outlined in Steps 1 through 10 in the previous section. The constants for computing these values are taken from Tables A-5 and A-6. Table A-8 shows that a low-efficiency 60,000 acfm wet collector with low installation, maintenance, and operation costs will cost approximately \$6,100/ year to operate (extreme upper left-hand corner). The most efficient (99% efficiency) wet collector, according to the table, will cost as high as \$137,400/yr to operate. The most likely costs for efficiencies of 75%, 90%, and 99% are \$11,300, \$22,700, and \$74,500, respectively. The type of data shown in Table A-8 is useful in developing cost-effectiveness relationships. Note that this table does not show the variances, V_1 and V_h ; these should be used only when the probable cost limits are desired.

| TABL | E | A- | 8 |
|------|---|----|---|
|------|---|----|---|

ILLUSTRATIVE PRESENTATION OF ANNUAL COSTS OF CONTROL FOR 60,000 ACFM WET SCRUBBER (DOLLARS) $E_1 = 75\%^{a,b/}$ $E_{h} = 99\%$ $E_{m} = 90\%$ ľ $\mathbf{I}_{\mathbf{h}}$ I₁ Ih I_m 1_h I_1 I_m I_m **e**/ <u>a</u>/ M₁ 15,200 35,500 37.800 42,300 6,100 6,800 8,100 11.800 13,000 01 M 7,300 8,000 13,000 16.400 36,700 39,000 43,500 9,300 14.200 44,700 Mh 8,500 9,200 10,500 14,200 15.400 17,600 37,900 40,200 20.300 23,700 71,100 73.300 77.900 Ml 9,500 10,100 11,500 21,500 0_m Mm 10,700 11.300 12,700 21,500 22.700 24,900 72.300 74,500 79,100 11,900 12,500 13,900 22,700 23,900 26,100 73,500 75,700 80,300 Mh Ml 20,300 36,900 40,300 130,500 135,000 18,300 18,900 38,100 128,200 0_h M 131,700 19,500 20,100 21,500 38,100 39,300 41,500 129,400 136,200 M 20,700 21,300 22,700 39,300 40,500 42,700 130,600 132,900 137,400

a/E = efficiency factor.

b/ Subscripts 1, m, and h indicate low, medium, and high ranges, respectively.

 \bar{c} / I = installation factor.

 \overline{d} / M = maintenance factor.

 \overline{e} / 0 = operating factor.

Note: A similar table can be generated to show the various control costs for any type of control equipment by specifying operating conditions and calculating each entry. This procedure provides complete information to aid in the assessment of existing controls or other control alternatives.

575

A.7 COST CURVES BY EQUIPMENT TYPE

A.7.1 General

The following sections contain a series of control cost curves (see Figures A-5 through A-24). For each type of control equipment, a series of curves is presented: (1) purchase cost curves, (2) installed cost curves, and (3) annualized cost curves.

The estimated purchase cost curves show the dollar amounts charged by manufacturers for basic control equipment, exclusive of transportation charges to the installation site. This basic control equipment includes built-in auxiliary parts of the control unit, such as instrumentation and solution pumps. The installed cost curves include the purchase costs, additional auxiliary equipment costs, and installation costs, as described in Section A.5.2. The annualized cost curves include elements discussed in Sections A.5.3 through A.5.6. The assumptions, sources of data, and the limitations used to develop this information are discussed in Sections A.3 and A.4.

A.7.2 Gravitational Collectors

In computing the cost of gravity collectors, three collection efficiencies were considered. These efficiencies were based on the assumption of essentially complete removal of $87_{-\mu}$, $50_{-\mu}$, and $25_{-\mu}$ particles, and are designated as low, medium, and high efficiencies, respectively. The low and medium efficiency collectors are simple expansion chambers, and the high efficiency collector is a multiple-tray settling chamber, commonly called a Howard separator.

In actual operation, the collection efficiency for a gravitational collector depends on the particle size distribution. In cleaning the flue gas from a stoker-fired coal furnace, for example, low-, medium-, and high-efficiency collectors would have particle removal efficiencies of approximately 64%, 75%, and 88%, respectively. In cleaning the flue gas from a pulverized-coal furnace, these same collectors, because of the smaller sized particles emitted by the combustion unit, would have approximate efficiencies of 21%, 34%, and 56%, respectively.

The purchase costs of gravitational collectors are shown for three different efficiencies in Figure A-5. These are approximate costs for typical installations. If it were necessary to include insulation or a corrosion-resistant lining, the costs would be higher. The total installed cost was also calculated for each efficiency and is shown in Figure A-6. The total installed cost is the sum of the purchase and installation costs.









Figure A-7 - Purchase Cost of Dry Centrifugal Collectors



Figure A-8 - Installed Cost of Dry Centrifugal Collectors



Figure A-9 - Annualized Cost of Operation of Dry Centrifugal Collectors



Figure A-10 - Purchase Cost of Wet Collectors



Figure A-11 - Installed Cost of Wet Collectors



Figure A-12 - Annualized Cost of Operation of Wet Collectors

580

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GAS VOLUME THROUGH COLLECTOR, 103 ocfm

Figure A-13 - Purchase Cost of High-Voltage Electrostatic Precipitators



Figure A-14 - Installed Cost of High-Voltage Electrostatic Precipitators



Figure A-16 - Purchase Cost of Low-Voltage Electrostatic Precipitators



Figure A-17 - Installed Cost of Low-Voltage Electrostatic Precipitators



Precipitators



- A HIGH-TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING. B MEDIUM-TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING.
- C-WOVEN NATURAL FIBERS. INTERMITTENTLY CLEANED - SINGLE COMPARTMENT.





Figure A-20 - Installed Cost of Fabric Filters



- A HIGH TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING. B MEDIUM-TEMPERATURE SYNTHETICS, WOVEN AND
- FELT. CONTINUOUS AUTOMATIC CLEANING, C-WOVEN NATURAL FIBERS, INTERMITTENTLY CLEANED SINGLE COMPARTMENT.





Figure A-22 - Purchase Cost of Afterburners



Figure A-23 - Installed Cost of Afterburners



The installation costs were assumed to range from 33% to 100% of the purchase cost (see Table A-3), and this range results in a cost band for each efficiency, as shown in the figure. No annualized cost curves are presented for these collectors because operation and maintenance costs, other than for removal and disposal of collected material, usually are negligible, except where corrosion may be a problem. Section A.8 provides specific information on the disposal of collected material.

A.7.3 Dry Centrifugal Collectors

The costs of purchasing, installing, and operating mechanical centrifugal collectors are given in Figures A-7, A-8, and A-9, respectively. The curves in these figures show costs for collectors that operate at nominal efficiencies of 50%, 70%, and 95% (see Section A.4). Costs are plotted for equipment sizes ranging from 10,000 to 1,000,000 acfm. The assumptions used in calculating annual operation and maintenance costs for dry centrifugal collectors are as follows:

- 1. Annual operating time = 8,760 hr.
- 2. Collector pressure drop = 3 in. of water
- 3. Power cost = \$0.011/kilowatt-hr
- 4. Maintenance cost = \$0.015/acfm

A.7.4 Wet Collectors

The costs of purchasing, installing, and operating wet collectors are given in Figures A-10, A-11, and A-12, respectively, as a function of equipment size. The curves in these figures show costs for collectors that operate at nominal efficiencies of 75%, 90%, and 99% (see Section A.4). The basic hardware costs for medium and high collection-efficiency equipment are reported by manufacturers to lie in the same cost range and both appear on the same curve in Figure A-10. The higher installed cost of a high collection-efficiency system in Figure A-11 results from the need for larger, more expensive auxiliary equipment (based on Table A-3). The assumptions used in calculating annual operating and maintenance costs for wet collectors are as follows:

- 1. Annual operating time = 8,760 hr.
- 2. Contact power requirements:

0.0013 horsepower/acfm for 75% efficiency

- 0.0035 horsepower/acfm for 90% efficiency
- 0.015 horsepower/acfm for 99% efficiency

- 3. Power cost = \$0.011/kilowatt-hr
- 4. Maintenance cost = \$0.04/acfm
- 5. Head required for liquor circulation in collection system = 30 ft.
- 6. Liquor circulation = 0.008 gal/acfm
- 7. Liquor consumption = 0.0005 gal/hr-acfm
- 8. Liquor cost = 0.0005/gal

A.7.5 High-Voltage Electrostatic Precipitators

The costs of purchasing, installing, and operating high-voltage electrostatic precipitators are given in Figures A-13, A-14, and A-15, respectively. The curves in these figures show costs for collectors that operate at nominal efficiencies of 90%, 95%, and 99.5%. These costs are plotted for equipment sizes ranging from 20,000 to 1,000,000 acfm. The assumptions used in calculating annual operation and maintenance costs for high-voltage electrostatic precipitators are as follows:

- 1. Annual operating time = 8,760 hr.
- 2. Electrical power requirements:

0.00019 kilowatt/acfm for low efficiency

0.00026 kilowatt/acfm for medium efficiency

0.00034 kilowatt/acfm for high efficiency

- 3. Power cost = \$0.011/kilowatt-hr
- 4. Maintenance cost = \$0.02/acfm

A.7.6 Low-Voltage Electrostatic Precipitators

The curves in Figures A-16, A-17, and A-18 indicate purchase cost, installed cost, and operation cost of low-voltage electrostatic precipitators for low and high collection efficiencies based on design gas velocities of 150 and 125 ft/min, respectively. Packaged modular low-voltage precipitators with flow rates of less than 1,500 acfm are used to collect oil mist from machining operations. Purchase cost of such a unit usually is less than \$1,200. The assumptions used in calculating annual operation and maintenance costs for low-voltage electrostatic precipitators are as follows:

- 1. Annual operating time = 8,760 hr.
- 2. Electrical power requirements:

0.000015 kilowatt/acfm for low efficiency

- 0.000040 kilowatt/acfm for high efficiency
- 3. Power cost = \$0.011/kilowatt-hr

4. Maintenance cost = \$0.02/acfm

A.7.7 Fabric Filters

Figures A-19, A-20, and A-21 show purchase cost, installed cost, and annualized cost of control for three different types of filters. Each of the three filters is designed with about the same efficiency--99.9%. Costs are plotted for equipment sizes ranging from 10,000 to 1,000,000 acfm.

The control costs curves represent the following different types of filter installations:

1. Curve A represents a fabric filter installation with hightemperature synthetic woven fibers (including fiberglass) and felted fibers cleaned continuously and automatically.

2. Curve B represents an installation using medium-temperature synthetic woven and felted fibers, such as Orlon or Dacron, cleaned continuously and automatically.

3. Curve C is the least expensive installation. Woven natural fibers are used in a single compartment. Filters are intermittently cleaned. This equipment is rarely designed for processes handling over 150,000 acfm.

These control cost curves do not include data for furnace hoods, ventilation ductwork and precoolers that may appear only in certain installations. The assumptions for calculating operating and maintenance costs are as follows:

1. Annual operating time = 8,760 hr.

2. Pressure drop of the gas through the three types of fabric filters = 4 in. of water

- 3. Power cost = \$0.05/acfm
- 4. Maintenance cost = \$0.05/acfm

A.7.8 Afterburners

Afterburners are separated into four categories: (1) direct flame, (2) catalytic, (3) direct flame with heat recovery, and (4) catalytic with heat recovery. Equipment and installation costs were obtained from both the literature and manufacturers of afterburners. Sufficient data were received on catalytic afterburners to define the narrow purchase cost range shown in Figure A-22. The figure shows that purchase costs of direct flame afterburners have a wider range than those of catalytic afterburners.

Figure A-23 shows the installation costs for afterburners. Heat exchangers are considered accessory equipment and appear as part of the installation cost. Installation costs may range from 10% to 100% of the purchase costs, although in some situations they may be as high as 400%. Differences in installation costs are due to the differences in burner locations relative to the emission source, and differences in structural supports, ductwork, and foundations. Installation costs for the addition of equipment to existing plant facilities will be higher than similar costs for new plants. Other factors accounting for different installation fees are the degree of instrumentation required, engineering fees in manufacturers' bids, startup tests and adjustments, heat exchangers, auxiliary fans, and utilities. The assumptions for calculating operation and maintenance costs are as follows:

1. Annual operating time = 8,760 hr.

2. Fuel cost:

\$0.57/1,000 acfm-hr for direct flame afterburner with no heat recovery

\$0.23/1,000 acfm-hr for direct flame afterburner with heat

recovery

\$0.28/1,000 acfm-hr for catalytic afterburner with no heat recovery

\$0.14/1,000 acfm-hr for catalytic afterburner with heat

recovery

3. Maintenance cost:

\$0.06/acfm for direct flame afterburner

\$0.20/acfm for catalytic afterburner

- 4. Pressure drop through all afterburner types = 1 in. of water
- 5. Power cost = \$0.011/kilowatt-hr

Cost comparisons presented in Figure A-24 show that the direct flame afterburner without a heat exchanger is the most expensive. The lower curve in Figure A-24 shows that the annualized cost of a direct flame afterburner with heat recovery is lower than the cost of a catalytic afterburner without heat recovery.

A.8 DISPOSAL OF COLLECTED PARTICULATE EMISSIONS

A.8.1 General

The installation of any pollution control system designed to collect particulate matter demands a decision regarding the disposal of the collected particulate material. This section discusses the relevant factors and illustrates the economic consequences of disposal of the collected material.

In the past, pollution control equipment often was installed either to reduce a severe nuisance or to recover valuable material. Such equipment not only prevented valuable material from escaping to the atmosphere, but also reduced costly cleaning of the plant grounds and facilities.

As industrial plants become more crowded together and as the public desires a higher quality of air, more emphasis will be placed on intensive control activities. This emphasis will increase the demand for more effective air pollution control. Generally, most air pollution control systems collect material that has little economic worth.

Basically, the alternatives for handling collected particulate material are as follows:

- 1. Return the material to the process.
- 2. Sell the material directly as collected.
- 3. Convert the material to a salable product.
- 4. Discard the material in the most economical manner.

The process of selecting an alternative should take into account the following questions:

- 1. Can the material be used within the company?
- 2. Is there a profitable market for the material?
- 3. What is the most economical method of disposal?
- 4. Is there land available for a landfill?
- 5. Is there a source of water available for:
 - a. A wet pipeline system
 - b. Disposal at sea
 - c. Transportation by barge

6. Is there space available for a settling basin or filtering system?

7. Is there process-related equipment presently available for transporting or treating the collected material?

8. Is there access to a municipal waste treatment system?

9. Can technology and/or markets be developed for utilization of the waste material?

A.8.2 Elements of Disposal Systems

After examining feasible solutions to the disposal problem, the least costly alternative that is most compatible with other operating factors in the plant should be chosen. The decision should result from consideration of each of the four functional elements of the disposal system described below and their relationships to the manufacturing process.

1. <u>Temporary storage</u>, which allows gathering sufficient quantities of the collected material to make final disposal more economical. The unit cost of disposal usually is lower for greater quantities. Temporary storage may be convenient at many points in the overall disposal scheme, such as in the hopper or settling chamber of a pollution control device, or in a silo some distance from the plant.

2. Transportation that moves the collected material from the particulate control device to some location where disposal is relatively economical. In most cases, transportation displaces the material to a location where accumulation minimizes any potential interference with plant activities. Any single disposal system may require more than one method of transporting the material. For example, a conveyor system may be used at the control device, a truck may be used to transport the material to a landfill area, and a bulldozer may be used to push it to its final disposal location.

3. <u>Treatment that changes physical and/or chemical characteristics</u> for easier disposal. Such treatment may simplify operations and reduce costs for handling and disposal of wastes. Frequently, for easier transport, particulate matter is made into a slurry by adding water to it. This permits the use of a pipeline, which is often the most economical method for transporting wastes over long distances. Slurries from wet-scrubbing pollution control systems frequently are treated in an opposite manner: the water is removed and the particulate matter is concentrated by filtration or sedimentation. This permits the ultimate disposal of a solid waste, rather than a sludge or a slurry. The method of treatment should be selected with a view to minimizing contamination of the environment. Examples of such treatment methods are the wetting of fine dust to prevent air pollution, the neutralization and filtration of slurries to prevent contamination of receiving waters, and the proper burial of solid material in a sanitary landfill.

4. Final disposition, which pertains to discarding the unusable <u>material</u>. Material which cannot be sold, converted, or reused ultimately can be discarded in landfills; or sometimes it can be disposed of in lagoons or the sea.

The following list shows some examples of the four functional elements for both wet and dry disposal systems.

- A. Storage
 - (1) Slurry of suspended particulate matter in water
 - (a) Settling basin
 - (b) Lagoon
 - (c) Tank
 - (2) Dry collected particulates
 - (a) Mound
 - (b) Rail car
 - (c) Bin
 - (d) Silo

- B. Transportation
 - (1) Slurry of suspended particulates in water
 - (a) Barge
 - (b) Pipeline
 - (c) Truck
 - (d) Rail
 - (2) Dry collected particulates
 - (a) Truck
 - (b) Rail
 - (c) Front-end loader
 - (d) Conveying system
 - (e) Barge

C. Treatment

- (1) Slurry of suspended particulate in water<u>ll</u>/
 - (a) Sedimentation
 - (b) Filtration
 - (c) Flotation
 - (d) Thickening; wet combustion
 - (e) Lagoons and drying beds
 - (f) Vacuum filtration
 - (g) Centrifugation; incineration
 - (h) Neutralization

- (2) Dry collected material
 - (a) Compressing
 - (b) Wetting
- D. Final Disposition
 - (1) Landfill
 - (a) Public or private disposal sites
 - (b) Quarry
 - (c) Evacuated coal mine
 - (2) Lagoon
 - (3) Dump at sea

The arrangement of these elements in an overall disposal scheme is shown in Figure A-25. This flow diagram shows the movement of the collected material through various stages toward final disposal.

Environmental factors such as space, utilities, disposal facilities, and the desired form of collected waste material usually have an important bearing on the selection of a disposal system compatible with a specific type of particulate pollution control equipment. Therefore, a specific type of particulate pollution control equipment may not always call for the same waste disposal system.

A.8.3 Disposal Cost for Discarded Material

Table A-9 describes various disposal systems and the related costs within specific industries. Each system listed is specifically designed to cope with the disposal problem and available facilities of the individual plant shown. Therefore, drawing general conclusions about the relative costs of systems listed in the table would be erroneous. The disposal costs shown include capital charges and costs for labor and material. The disposal cost/ton will be higher the smaller the quantity of material, because capital charges for investment in facilities will remain the same regardless of quantity.

Fly ash, a residue from the combustion of coal and residual oil, probably is the most common material collected in emission control systems.



Figure A-25 - Flow Diagram for Disposal of Collected Particulate Material from Air Pollution Control Equipment

TABLE A-9

COSTS OF SPECIFIC DISPOSAL SYSTEMS

| Ind stry | Collected Material | Treatment | Transport | Storage | Final <u>Pisposal</u> | Cost estimate, <u>(Graiars/ton)</u> |
|---|-------------------------------------|-----------------------------|--------------------------------------|--------------------------------------|---------------------------------|--|
| inwer generation | Fly ash | Sedimentation | Pipeline | Settling pond | Landfill (sediment) | ?. 7 . |
| Hower generation | Fly as h | - | Truck | Mound | Landfill | |
| Aver generation | Fly ash | - | Truck | Mound | City dump, | :.10 |
| Rower generation | Fly ash | Form pellets | Vacuum sys- stem, truck, barge | Transfer bins, storage silo | Landfill or dump at sea | 2.00 |
| Fower generation | Fly Ash | Forma slurry | Fipeline | Settling pond | Landfil) (sediment) | 3.00 |
| River generation | Fly ast. | Wetted | Pheumatic pipeline truck | Storage silc | Landfill | 2.00 |
| Rower generation for chemical plant | Fly ash | Sedimentation | Pipeline | - | Lagoon | 1,60 |
| Power generation for chemical plant | Fly ash | - | דדינכא | Silos | Landfill | 0.90 |
| Chemical | - | Slurry (100,000 gal/day) | Barge | Tank | Dump at sea | 3. JC |
| Chemical | Weak acid (large Vilume) | - | Berge | Tank | Damp et. sea | 0.00 |
| Rower generation for pulp and paper | Fly ash | Sedimentation | Pipeline | - | Lagoon | 2.30 |
| Bray iron Swindry | Cupola dust | Water clarification | Sediment by truck | Dempster dump | Lendfill | 1.40 |
| Fetroleum refining | Nondewatered sludge | - | Centract hauling | - | Landfill | £ .75 |
| Fetro)eum refining | Dewatered sludge | - | Contract hauling | - | Candfill | 2,70 |
| Petroleum refining | Sludge, filter coke, oily solids | • | Truck | - | In-plant landfill | 20,00 |
| Fetroleum refining | Oily solids | - | Barge | - | Dump at sea | r.50 |
| Petroleum refining | Catalyst fines | - | Contract hauling | - | Landfill | 2,75 |
| Rintland cement | Waste dust | Slight wetting | Conveyor, truck | Bins | Landfill | 1.05 |
| Comps and detergents | Suspended solids | | Pipeline | • | Municipal treatment plant | 12. 2 .2 |

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An estimated 20 million tons of fly ash was produced in the United States in 1965. Only 3% of this total was sold as a marketable product. $\frac{12}{}$ If the cost for discarding the remaining 97% of the fly ash as unusable waste were \$1.00/ton or more, this would represent a total cost of \$20 million or more. Based on the data in Table A-9, a cost of \$1.00/ton is a typical unit cost.

In certain situations, the disposal cost of fly ash can be a major portion of the total annualized cost for a complete pollution control system (including disposal facilities). For example, the disposal costs can be as high as 80% of the total annualized cost for an emission control system with older electrostatic precipitators which are no longer depreciated. The disposal cost still can be as high as 50% for similar systems with newly installed electrostatic precipitators, which usually have high depreciation charges.

Table A-10 shows a summary of fly ash disposal costs for material collected from electrostatic precipitators and mechanical collectors installed in electric utilities and is taken from a recent survey. 13/ This survey analyzed the costs of disposal, the sales, and the uses of fly ash collected by 54 electric utilities and reported an average disposal cost of \$0.74/ton. Analysis of the data for individual utilities revealed that disposal cost is partly a function of geographical location. The average disposal cost/ton in the heavily-populated East is higher than that reported elsewhere.

TABLE A-10

| | Disposal Costs, Dollars/Ton | | |
|--------------------------------------|-----------------------------|--------|--------------|
| Type and Collection Method | Low | Medium | <u>High</u> |
| Fly ash (mechanical collector) | \$0.15 | \$0.59 | \$1.67 |
| Fly ash (electrostatic precipitator) | 0.12 | 0.77 | 1.74 |
| Bottom ash | 0.15 | 1.04 | 4. 76 |

COST OF ASH DISPOSAL BY ELECTRIC UTILITIES

A.8.4 Return of Collected Material to the Process

In some process operations, collected material is sufficiently valuable to warrant its return to the process. In these situations, the value of the recovered material can partially or wholly pay for the collection equipment. In many applications, however, the cost for the high efficiency control systems necessary to achieve desired ambient air quality will be greater than the revenue returned for recovery of the material collected. This is illustrated by the hypothetical example in Figure A-26.

The figure shows a linear relationship between collection efficiency and value of material recovered. It also shows a curvilinear relationship between collection efficiency and related equipment costs. Up to the breakeven point D (which corresponds to an efficiency of about 97%), the recovery value of material collected is greater than the cost to achieve the recovery. Equipment designed for efficiencies greater than 97%, according to the curve, would have a higher cost than the potential recovery value.

If profit were the only control incentive, 85% collection efficiency would achieve the maximum profit, as illustrated by the profit line AB. If, however, emission standards made 97% collection efficiency necessary, no profit would be achieved at the break-even point D. For collection efficiency greater than 97%, equipment costs would exceed recovery costs. At 99% efficiency, for example, control equipment would cost the amount shown by FH, and the value recovered would be the amount GH. The difference FG would represent an expense and can be considered as the net control cost.

A survey conducted in 1956 shows that, out of 383 kilns, a total of 349 return collected dust to the process. $\frac{14}{}$ Not only does recovered dust, in such situations, have value as a raw material, but its recovery also reduces disposal costs and decreases other related costs for the preparation of raw materials used in the process.

A.8.5 Recovery of Material for Sale

Although material collected by air pollution control equipment may be unsuitable for return to a process within the plant, it may be suitable for another manufacturing activity. Hence, it may be treated and sold to another firm that can use the material. Untreated pulverized fly ash, for example, which cannot be reused in a furnace, can be sold as a raw material to a cement manufacturer. It also can be used as a soil conditioner, or as an asphalt filler, or as landfill material. For such uses, pulverized fly ash requires no treatment and can be sold for as much as \$1.00/ton. Pulverized fly ash which is treated can yield an even more valuable product. A limited number of utilities, for example, sinter pulverized fly ash to produce a lightweight aggregate which can be used to manufacture bricks and lightweight building blocks.

At the present time, however, the sale of raw or treated collected process material usually does not offer an opportunity to offset control costs to a significant extent.



Figure A-26 - Theoretical Effect of Dust Value on Control Cost

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APPENDIX B

MINOR SOURCES

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In addition to the data compiled on major industrial particulate pollutant sources discussed in Chapters 5-23, information of various types has been accumulated on several minor sources. Table B-1 presents emission factors and other assorted facts for these sources.

TABLE B-1

EMISSION FACTORS FOR MINOR SOURCES

| | Production | Control | Emission Factor Range | Average Emission Factor | |
|---|-----------------------|-----------|-----------------------------|-------------------------------|--|
| Source of Particulate | (tons/yr) | Device | (lb/ton) | (lb/ton) | |
| CHEMICAL FROCESS INDUSTRY | | | | | |
| Phenolic resin handling4/ | | | | 48 | |
| Pigment process±/ | | د ۲ | | | |
| Grinder | | water | | 0.33* | |
| | | Jspray } | | | |
| Blender | | and oil | | 1.9* | |
| <u>.</u> | c | [filters] | | | |
| PVC Manufacturing=/ | 1.1 × 10° | FF | | 0.35* | |
| Polypropylene | - · | | | | |
| manufacturing ² / | 3.2×10^{5} | | | 3.0 | |
| Rubber process1/ | 2.7 x 10 ⁰ | | | | |
| Mixer | | baghouse | | 0.13* | |
| Grinder | | cyclones | | ~ 20 | |
| | | | | 1.4* | |
| FOOD INDUSTRY | | | | | |
| Coffee roasting Roaster ³ / | 1.5 x 10 ⁶ | | | | |
| Direct fired | | cyclone | | 7.6 | |
| | | | | 2.2* | |
| Indirect fired | | cyclone | | 4.2 | |
| | | -• | | 1.2* | |

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TABLE B-1 (Continued)

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| Source of Particulate | Production (tons/yr) | Control Device | Emission Factor Range (lb/ton) | Average Emission Factor (lb/ton) |
|--|-------------------------------|-------------------|---|---|
| Coffee roasting (concluded) Stoner and cooler | | cyclone | | 1.4 0.4* |
| Instant Coffee | | | | 0,1 |
| Spray dryer | | cyclone + | | |
| 2/ | | wet scrubbe: | r | 1.4* |
| Roaster±/ Coffee/tea processing ¹ / | 7. x 10 ⁴ ‡ | cyclone | | 1.9* |
| Roaster Citrus plants1/ | | cyclone | | 3.1* |
| Peel dryer Orange pulp dryer | | | 1.8 - 9.6 | 5.0* 75.3 |
| MINERAL PRODUCTS INDUSTRY | | | | |
| Alexandra, much | 1 | | | |
| menufocturing1/ | 08111 | e sealmenta | .10n | *ונ ה |
| Blast grit and roofing ¹ / Granule manufacturing | | champer | | 0.11. |
| Dryer | | cyclone | | 0.42* |
| Screens | | cyclone | | 4.l* |
| Calcium carbide | | | | |
| manufacturing ³ / | 9.2 x 10 ⁵ | | | |
| Coke dryer | | cyclone + | | |
| | | spray drye | r | 0.2* |
| Electric furnace hood | | | | 1.7 |
| Furnace room vents | | | | 2.6 |
| Main stack | | impingemen | nt | |
| 2/ | | scrubber | | 2.0* |
| Concrete batching / | | | | 5.2 |
| Fiberglas manufacturing=/ | | | | |
| Melting furnace | | | | |
| Regenerative | | | 1 - 4 | 3 |
| Recuperative | | | 0.5 - 1 | l |
| Forming line | | | 23.5 - 100 | 62 |
| Curing oven | | | 3.4 - 14 | 6.9 |
| Frit manufacturing | | | | |
| Rotary melter=/ | | | | 17 |
| Reverberatory furnace2/ | | | 5.9 - 45.5 | 16.5 |

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TABLE B-1 (Continued)

| | Source of Particulate | Production (tons/yr) | Control Device | Emission Factor Range (lb/ton) | Average Emission Factor (lb/ton) |
|---|--|-------------------------|-------------------|---|---|
| | MINERAL PRODUCTS INDUSTRY (Concluded) | | | | |
| | Glass manufacturing | | | | _ |
| | Furnace <u>2</u> / | | | | 2 |
| | Reverberatory furnace±/ | | | 1 - 1 0 | 3 |
| | Furnace ¹ | | | 1.5 - 7.9 | 3 |
| | Furnaces=/ | | | 0.02 - 1.1 | 0.31 |
| | Ground brick plant=/ | | | | 150 |
| | Guinden]/ | | 202 | 0.14 0.04 | A 19¥ |
| | Trim sau4/ | | EDF . | 15/350 + 2 | 0.15* |
| | Gensum manufacturing ² | | | 10/000 10 | |
| | Drver | | नग | | 22 |
| • | 51902 | | cvclone + | - | |
| | | | ESP | 4 - 40 (2) | C*, 0.2* |
| | Grinder | | FF | | l |
| | | | | | neg.* |
| | Calciner | | \mathbf{FF} | | 90 |
| | | | | | C.1* |
| | Conveyor | | FF | | 0.7 |
| | ן ר | | | | neg.* |
| | Magnesite plant ^{±/} | 5 | | | 430 |
| | Perlite manufacturing | 4.1 x 10° | | | |
| | furnace | | | | 21 |
| | Plaster of Paris | | | | 0.04 |
| | manui acturing=/ | | ESP (z) | 7 0 0 5 | 0.9* |
| | Book wool menufectuming3/ | | (3) | 1.8 - 9.5 | 0.C* |
| | Cupole | | | 16 09 | 216 |
| | Reverberatory furnace | | | 10 - 20 | 4 9 |
| | Blow chamber | | | 4 - 56 | 21.6 |
| | Curing oven | | | 1.5 - 5.9 | 3.6 |
| | Cooler | | | 0.4 - 5.5 | 2.4 |
| | Cupols1/ | | | | 32.4 |
| | | | | | |

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TABLE B-1 (Concluded)

| Source of Particulate | Production (tons/yr) | Control Device | Emission Factor Range (lb/ton) | Average Emission Factor (1b/ton) |
|---|-------------------------|-------------------|---|---|
| MISCELLAVEOUS | | | | |
| Electric arc welding $\frac{1}{2}$ | | | | 0.01 - 0.02 lb/lb |
| Soldering ^{1/} | | | | electrode 0.005 1b/1b |
| Plywood manufacturing ^{5/} Dryer Mercury smelting <u>6</u> / | | | | solder 0.51 40.0 |
| | | | | |

* Controlled emission factor based on indicated control device.

+ Tea production only.

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