

**SUPPLEMENT NO. 3
FOR
COMPILATION
OF AIR POLLUTANT
EMISSION FACTORS
SECOND EDITION**

**U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina
July 1974**

**INSTRUCTIONS
FOR INSERTING SUPPLEMENT NO. 3
INTO
COMPILATION OF AIR POLLUTANT EMISSION FACTORS**

1. Replace page iii-iv with new page iii-iv.
2. Replace page v-vi with new page v-vi.
3. Replace page ix-x with new page ix-x.
4. Replace page xi-xii with new page xi-xii.
5. Replace page xiii-xiv with new page xiii-xiv.
6. Replace page xv - xvi with new page xv-xvi.
7. Replace page 1-2 dated 4/73 with new page 1-2 dated 5/74.
8. Replace page 1.1-3 and 1.1-4 with new page 1.1-3 and 1.1-4.
9. Replace pages 1.4-1 through 1.4-3 dated 4/73 with new pages 1.4-1 through 1.4-3 dated 5/74.
10. Replace page 1.5-1 and 1.5-2 with new page 1.5-1 and 1.5-2.
11. Replace page 1.6-1 and 1.6-2 dated 4/73 with new pages 1.6-1 through 1.6-3 dated 5/74.
12. Insert new pages dated 2.5-1 and 2.5-2 dated 5/74 after page 2.4-2 in parent report.
13. Replace pages 7.5-3 through 7.5-6 with new pages 7.5-3 through 7.5-6.
14. Replace pages 7.6-1 and 7.6-2 dated 2/72 with new pages 7.6-1 through 7.6-5 dated 5/74.
15. Replace pages 7.11-1 and 7.11-2 dated 2/72 with new pages 7.11-1 through 7.11-4 dated 5/74.
16. Replace pages 9.1-1 and 9.1-2 with new pages 9.1-1 and 9.1-2.
17. Replace pages 10.1-1 through 10.2-2 dated 2/72 with new pages 10.1-1 through 10.3-2 dated 5/74.

PREFACE

This document reports data available on those atmospheric emissions for which sufficient information exists to establish realistic emission factors. The information contained herein is based on Public Health Service Publication 999-AP-42, *Compilation of Air Pollutant Emission Factors*, by R. L. Duprey, and on a revised and expanded version of *Compilation of Air Pollutant Emission Factors* that was published by the Environmental Protection Agency in February 1972. The scope of this second edition has been broadened to reflect expanding knowledge of emissions.

Chapters and sections of this document have been arranged in a format that permits easy and convenient replacement of material as information reflecting more accurate and refined emission factors is published and distributed. To speed dissemination of emission information, chapters or sections that contain new data will be issued—separate from the parent report—whenever they are revised.

To facilitate the addition of future materials, the punched, loose-leaf format was selected. This approach permits the document to be placed in a three-ring binder or to be secured by rings, rivets, or other fasteners; future supplements or revisions can then be easily inserted. The lower left- or right-hand corner of each page of the document bears a notation that indicates the date the information was issued.

NOTE: Those who obtained AP-42 by purchase or through special order and completed the request for future supplements are hereby advised of a change in the distribution procedure. The availability of these supplements will now be indicated in the publication *Air Pollution Technical Publications of the Environmental Protection Agency*, which is available from the Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711. This listing of publications, normally published in January and July, contains instructions for obtaining the desired documents.

Comments and suggestions regarding this document should be directed to the attention of Director, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, N. C. 27711.

ACKNOWLEDGMENTS

Because this document is a product of the efforts of many individuals, it is impossible to acknowledge each individual who has contributed. Special recognition is given, however, to Mr. Richard Gerstle and the staff of Resources Research, Inc., who provided a large part of the efforts that went into this document. Their complete effort is documented in their report for contract number CPA-22-69-119.

Environmental Protection Agency employees M. J. McGraw, A. J. Hoffman, J. H. Southerland, and R. L. Duprey are also acknowledged for their efforts in the production of this work. Bylines identify the contributions of individual authors who revised specific sections and chapters.

Issuance	Release Date
<i>Compilation of Air Pollutant Emission Factors</i>	4/73
<i>Supplement No. 1</i>	7/73
<i>Section 4.3 Storage of Petroleum Products</i>	
<i>Section 4.4 Marketing and Transportation of Petroleum Products</i>	
<i>Supplement No. 2</i>	9/73
<i>Introduction</i>	
<i>Section 3.1.1 Average Emission Factors for Highway Vehicles</i>	
<i>Section 3.1.2 Light-Duty, Gasoline-Powered Vehicles</i>	
<i>Supplement No. 3</i>	7/74
<i>Introduction</i>	
<i>Section 1.4 Natural Gas Combustion</i>	
<i>Section 1.5 Liquified Petroleum Gas Consumption</i>	
<i>Section 1.6 Wood/Bark Waste Combustion in Boilers</i>	
<i>Section 2.5 Sewage Sludge Incineration</i>	
<i>Section 7.6 Lead Smelting</i>	
<i>Section 7.11 Secondary Lead Smelting</i>	
<i>Section 10.1 Chemical Wood Pulping</i>	
<i>Section 10.2 Pulpboard</i>	
<i>Section 10.3 Plywood Veneer and Layout Operations</i>	

CONTENTS

	Page
LIST OF FIGURES	xiii
LIST OF TABLES	xiv
ABSTRACT	xvii
INTRODUCTION	1
1. EXTERNAL COMBUSTION SOURCES	1.1-1
1.1 BITUMINOUS COAL COMBUSTION	1.1-1
1.1.1 General	1.1-1
1.1.2 Emissions and Controls	1.1-1
1.1.2.1 Particulates	1.1-1
1.1.2.2 Sulfur Oxides	1.1-2
1.1.2.3 Nitrogen Oxides	1.1-2
1.1.2.4 Other Gases	1.1-2
References for Section 1.1	1.1-4
1.2 ANTHRACITE COAL COMBUSTION	1.2-1
1.2.1 General	1.2-1
1.2.2 Emissions and Controls	1.2-1
References for Section 1.2	1.2-3
1.3 FUEL OIL COMBUSTION	1.3-1
1.3.1 General	1.3-1
1.3.2 Emissions	1.3-1
References for Section 1.3	1.3-3
1.4 NATURAL GAS COMBUSTION	1.4-1
1.4.1 General	1.4-1
1.4.2 Emissions and Controls	1.4-1
References for Section 1.4	1.4-3
1.5 LIQUEFIED PETROLEUM GAS CONSUMPTION	1.5-1
1.5.1 General	1.5-1
1.5.2 Emissions	1.5-1
References for Section 1.5	1.5-1
1.6 WOOD WASTE COMBUSTION IN BOILERS	1.6-1
1.6.1 General	1.6-1
1.6.2 Firing Practices	1.6-1
1.6.3 Emissions	1.6-1
References for Section 1.6	1.6-2
2. SOLID WASTE DISPOSAL	2.1-1
2.1 REFUSE INCINERATION	2.1-2
2.1.1 Process Description	2.1-2
2.1.2 Definitions of Incinerator Categories	2.1-2
2.1.3 Emissions and Controls	2.1-5
References for Section 2.1	2.1-6
2.2 AUTOMOBILE BODY INCINERATION	2.2-1
2.2.1 Process Description	2.2-1
2.2.2 Emissions and Controls	2.2-1
References for Section 2.2	2.2-2

CONTENTS—(Continued)

	Page
2.3 CONICAL BURNERS	2.3-1
2.3.1 Process Description	2.3-1
2.3.2 Emissions and Controls	2.3-1
References for Section 2.3	2.3-3
2.4 OPEN BURNING	2.4-1
2.4.1 General	2.4-1
2.4.2 Emissions	2.4-1
References for Section 2.4	2.4-2
2.5 SEWAGE SLUDGE INCINERATION	2.5-1
2.5-1 Process Description	2.5-1
2.5-2 Emissions and Controls	2.5-1
References for Section 2.5	2.5-2
3. INTERNAL COMBUSTION ENGINE SOURCES	3.1.1-1
DEFINITIONS USED IN CHAPTER 3	3.1.1-1
3.1 HIGHWAY VEHICLES	3.1.1-3
3.1.1 Average Emission Factors for Highway Vehicles	3.1.1-5
3.1.2 Light-Duty, Gasoline-Powered Vehicles	3.1.2-1
3.1.3 Light-Duty, Diesel-Powered Vehicles	3.1.3-1
3.1.4 Heavy-Duty, Gasoline-Powered Vehicles	3.1.4-1
3.1.5 Heavy-Duty, Diesel-Powered Vehicles	3.1.5-1
3.1.6 Gaseous-Fueled Vehicles	3.1.6-1
3.1.7 Motorcycles	3.1.7-1
3.2 OFF-HIGHWAY, MOBILE SOURCES	3.2.1-1
3.2.1 Aircraft	3.2.1-1
3.2.2 Locomotives	3.2.2-1
3.2.3 Inboard-Powered Vessels	3.2.3-1
3.2.4 Outboard-Powered Vessels	3.2.4-1
3.2.5 Small, General Utility Engines	3.2.5-1
3.3 OFF-HIGHWAY, STATIONARY SOURCES	3.3.1-1
3.3.1 Stationary Gas Turbines	3.3.1-1
3.3.2 Heavy-Duty, General Utility, Gaseous Fueled Engines	3.3.2-1
4. EVAPORATION LOSS SOURCES	4.1-1
4.1 DRY CLEANING	4.1-1
4.1.1 General	4.1-1
4.1.2 Emissions and Controls	4.1-1
References for Section 4.1	4.1-2
4.2 SURFACE COATING	4.2-1
4.2.1 Process Description	4.2-1
4.2.2 Emissions and Controls	4.2-1
References for Section 4.2	4.2-2
4.3 PETROLEUM STORAGE	4.3-1
4.3.1 General	4.3-1
4.3.2 Emissions	4.3-1
References for Section 4.3	4.3-1
4.4 GASOLINE MARKETING	4.4-1
4.4.1 General	4.4-1
4.4.2 Emissions and Controls	4.4-1
References for Section 4.4	4.4-2
5. CHEMICAL PROCESS INDUSTRY	5.1-1
5.1 ADIPIC ACID	5.1-1
5.1.1 Process Description	5.1-1
5.1.2 Emissions	5.1-1
References for Section 5.1	5.1-2

CONTENTS--(Continued)

	Page
6.5	FERMENTATION 6.5-1
6.5.1	Process Description 6.5-1
6.5.2	Emissions 6.5-1
	References for Section 6.5 6.5-2
6.6	FISH PROCESSING 6.6-1
6.6.1	Process Description 6.6-1
6.6.2	Emissions and Controls 6.6-1
	References for Section 6.6 6.6-2
6.7	MEAT SMOKEHOUSES 6.7-1
6.7.1	Process Description 6.7-1
6.7.2	Emissions and Controls 6.7-1
	References for Section 6.7 6.7-2
6.8	NITRATE FERTILIZERS 6.8-1
6.8.1	General 6.8-1
6.8.2	Emissions and Controls 6.8-1
	References for Section 6.8 6.8-2
6.9	ORCHARD HEATERS 6.9-1
6.9.1	General 6.9-1
6.9.2	Emissions 6.9-1
	References for Section 6.9 6.9-4
6.10	PHOSPHATE FERTILIZERS 6.10-1
6.10.1	Normal Superphosphate 6.10-1
6.10.1.1	General 6.10-1
6.10.1.2	Emissions 6.10-2
6.10.2	Triple Superphosphate 6.10-2
6.10.2.1	General 6.10-2
6.10.2.2	Emissions 6.10-2
6.10.3	Ammonium Phosphate 6.10-2
6.10.3.1	General 6.10-2
6.10.3.2	Emissions 6.10-3
	References for Section 6.10 6.10-3
6.11	STARCH MANUFACTURING 6.11-1
6.11.1	Process Description 6.11-1
6.11.2	Emissions 6.11-1
	References for Section 6.11 6.11-1
6.12	SUGAR CANE PROCESSING 6.12-1
6.12.1	General 6.12-1
6.12.2	Emissions 6.12-1
	References for Section 6.12 6.12-2
7.	METALLURGICAL INDUSTRY 7.1-1
7.1	PRIMARY ALUMINUM PRODUCTION 7.1-1
7.1.1	Process Description 7.1-1
7.1.2	Emissions and Controls 7.1-2
	References for Section 7.1 7.1-8
7.2	METALLURGICAL COKE MANUFACTURING 7.2-1
7.2.1	Process Description 7.2-1
7.2.2	Emissions 7.2-1
	References for Section 7.2 7.2-3
7.3	COPPER SMELTERS 7.3-1
7.3.1	Process Description 7.3-1
7.3.2	Emissions and Controls 7.3-1
	References for Section 7.3 7.3-2
7.4	FERROALLOY PRODUCTION 7.4-1
7.4.1	Process Description 7.4-1

CONTENTS--(Continued)

	Page
7.4.2 Emissions	7.4-1
References for Section 7.4	7.4-2
7.5 IRON AND STEEL MILLS	7.5-1
7.5.1 General	7.5-1
7.5.1.1 Pig Iron Manufacture	7.5-1
7.5.1.2 Steel-Making Processes	7.5-1
7.5.1.3 Scarfing	7.5-1
References for Section 7.5	7.5-6
7.6 LEAD SMELTING	7.6-1
7.6.1 Process Description	7.6-1
7.6.2 Emissions and Controls	7.6-3
References for Section 7.6	7.6-5
7.7 ZINC SMELTING	7.7-1
7.7.1 Process Description	7.7-1
7.7.2 Emissions and Controls	7.7-1
References for Section 7.7	7.7-2
7.8 SECONDARY ALUMINUM OPERATIONS	7.8-1
7.8.1 Process Description	7.8-1
7.8.2 Emissions	7.8-1
References for Section 7.8	7.8-2
7.9 BRASS AND BRONZE INGOTS	7.9-1
7.9.1 Process Description	7.9-1
7.9.2 Emissions and Controls	7.9-1
References for Section 7.9	7.9-2
7.10 GRAY IRON FOUNDRY	7.10-1
7.10.1 Process Description	7.10-1
7.10.2 Emissions	7.10-1
References for Section 7.10	7.10-2
7.11 SECONDARY LEAD SMELTING	7.11-1
7.11.1 Process Description	7.11-1
7.11.2 Emissions and Controls	7.11-1
References for Section 7.11	7.11-1
7.12 SECONDARY MAGNESIUM SMELTING	7.12-1
7.12.1 Process Description	7.12-1
7.12.2 Emissions	7.12-1
References for Section 7.12	7.12-2
7.13 STEEL FOUNDRIES	7.13-1
7.13.1 Process Description	7.13-1
7.13.2 Emissions	7.13-1
References for Section 7.13	7.13-3
7.14 SECONDARY ZINC PROCESSING	7.14-1
7.14.1 Process Description	7.14-1
7.14.2 Emissions	7.14-1
References for Section 7.14	7.14-2
8. MINERAL PRODUCTS INDUSTRY	8.1-1
8.1 ASPHALTIC CONCRETE PLANTS	8.1-1
8.1.1 Process Description	8.1-1
8.1.2 Emissions and Controls	8.1-4
References for Section 8.1	8.1-5
8.2 ASPHALT ROOFING	8.2-1
8.2.1 Process Description	8.2-1
8.2.2 Emissions and Controls	8.2-1
References for Section 8.2	8.2-2

CONTENTS—(Continued)

	Page
8.3 BRICKS AND RELATED CLAY PRODUCTS	8.3-
8.3.1 Process Description	8.3-1
8.3.2 Emissions and Controls	8.3-1
References for Section 8.3	8.3-4
8.4 CALCIUM CARBIDE MANUFACTURING	8.4-1
8.4.1 Process Description	8.4-1
8.4.2 Emissions and Controls	8.4-1
References for Section 8.4	8.4-2
8.5 CASTABLE REFRACTORIES	8.5-1
8.5.1 Process Description	8.5-1
8.5.2 Emissions and Controls	8.5-1
References for Section 8.5	8.5-2
8.6 PORTLAND CEMENT MANUFACTURING	8.6-1
8.6.1 Process Description	8.6-1
8.6.2 Emissions and Controls	8.6-1
References for Section 8.6	8.6-2
8.7 CERAMIC CLAY MANUFACTURING	8.7-1
8.7.1 Process Description	8.7-1
8.7.2 Emissions and Controls	8.7-1
References for Section 8.7	8.7-2
8.8 CLAY AND FLY-ASH SINTERING	8.8-1
8.8.1 Process Description	8.8-1
8.8.2 Emissions and Controls	8.8-1
References for Section 8.8	8.8-2
8.9 COAL CLEANING	8.9-1
8.9.1 Process Description	8.9-1
8.9.2 Emissions and Controls	8.9-1
References for Section 8.9	8.9-2
8.10 CONCRETE BATCHING	8.10-1
8.10.1 Process Description	8.10-1
8.10.2 Emissions and Controls	8.10-1
References for Section 8.10	8.10-2
8.11 FIBER GLASS MANUFACTURING	8.11-1
8.11.1 Process Description	8.11-1
8.11.1.1 Textile Products	8.11-1
8.11.1.2 Wool Products	8.11-1
8.11.2 Emissions and Controls	8.11-1
References for Section 8.11	8.11-4
8.12 FRIT MANUFACTURING	8.12-1
8.12.1 Process Description	8.12-1
8.12.2 Emissions and Controls	8.12-1
References for Section 8.12	8.12-2
8.13 GLASS MANUFACTURING	8.13-1
8.13.1 Process Description	8.13-1
8.13.2 Emissions and Controls	8.13-1
References for Section 8.13	8.13-2
8.14 GYPSUM MANUFACTURING	8.14-1
8.14.1 Process Description	8.14-1
8.14.2 Emissions	8.14-1
References for Section 8.14	8.14-2
8.15 LIME MANUFACTURING	8.15-1
8.15.1 General	8.15-1
8.15.2 Emissions and Controls	8.15-1
References for Section 8.15	8.15-2

CONTENTS—(Continued)

	Page
8.16 MINERAL WOOL MANUFACTURING	8.16-1
8.16.1 Process Description	8.16-1
8.16.2 Emissions and Controls	8.16-1
References for Section 8.16	8.16-2
8.17 PERLITE MANUFACTURING	8.17-1
8.17.1 Process Description	8.17-1
8.17.2 Emissions and Controls	8.17-1
References for Section 8.17	8.17-2
8.18 PHOSPHATE ROCK PROCESSING	8.18-1
8.18.1 Process Description	8.18-1
8.18.2 Emissions and Controls	8.18-1
References for Section 8.18	8.18-2
8.19 SAND AND GRAVEL PROCESSING	8.19-1
8.19.1 Process Description	8.19-1
8.19.2 Emissions	8.19-1
References for Section 8.19	8.19-1
8.20 STONE QUARRYING AND PROCESSING	8.20-1
8.20.1 Process Description	8.20-1
8.20.2 Emissions	8.20-1
References for Section 8.20	8.20-2
9. PETROLEUM INDUSTRY	9.1-1
9.1 PETROLEUM REFINING	9.1-1
9.1.1 General	9.1-1
9.1.2 Crude Oil Distillation	9.1-1
9.1.2.1 Emissions	9.1-1
9.1.3 Converting	9.1-6
9.1.3.1 Catalytic Cracking	9.1-6
9.1.3.2 Hydrocracking	9.1-6
9.1.3.3 Catalytic Reforming	9.1-6
9.1.3.4 Polymerization, Alkylation, and Isomerization	9.1-6
9.1.3.5 Emissions	9.1-7
9.1.4 Treating	9.1-7
9.1.4.1 Hydrogen Treating	9.1-7
9.1.4.2 Chemical Treating	9.1-7
9.1.4.3 Physical Treating	9.1-8
9.1.4.4 Emissions	9.1-8
9.1.5 Blending	9.1-8
9.1.5.1 Emissions	9.1-8
9.1.6 Miscellaneous Operations	9.1-8
References for Chapter 9	9.1-8
10. WOOD PROCESSING	10.1-1
10.1 CHEMICAL WOOD PULPING	10.1-1
10.1.1 General	10.1-1
10.1.2 Kraft Pulping	10.1-1
10.1.3 Acid Sulfite Pulping	10.1-4
10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping	10.1-4
References for Section 10.1	10.1-6
10.2 PULPBOARD	10.2-1
10.2.1 General	10.2-1
10.2.2 Process Description	10.2-1
10.2.3 Emissions	10.2-1
References for Section 10.2	10.2-1

CONTENTS- (Continued)

	Page
10.3 PLYWOOD VENEER AND LAYOUT OPERATIONS	10.3-1
10.3.1 Process Description	10.3-1
10.3.2 Emissions	10.3-1
References for Section 10.3	10.3-2
APPENDIX	A-1
REFERENCES FOR APPENDIX	A-6

LIST OF FIGURES

Figure	Page
1.4-1 Lead Reduction Coefficient as Function of Boiler Load	1.4-2
3.1.1-1 Average Speed Correction Factors for All Model Years	3.1.1-7
3.3.2-1 Nitrogen Oxide Emissions from Stationary Internal Combustion Engines	3.3.2-2
5.9-1 Flow Diagram of Typical Nitric Acid Plant Using Pressure Process	5.9-2
5.17-1 Basic Flow Diagram of Contact-Process Sulfuric Acid Plant Burning Elemental Sulfur	5.17-2
5.17-2 Basic Flow Diagram of Contact-Process Sulfuric Acid Plant Burning Spent Acid	5.17-3
5.17-3 Sulfuric Acid Plant Feedstock Sulfur Conversion Versus Volumetric and Mass SO ₂ Emissions at Various Inlet SO ₂ Concentrations by Volume	5.17-6
5.18-1 Basic Flow Diagram of Modified Claus Process with Two Converter Stages Used in Manufacturing Sulfur	5.18-2
6.9-1 Types of Orchard Heaters	6.9-2
6.9-2 Particulate Emissions from Orchard Heaters	6.9-3
7.1-1 Schematic Diagram of Primary Aluminum Production Process	7.1-3
7.5-1 Basic Flow Diagram of Iron and Steel Processes	7.5-2
7.6-1 Typical Flowsheet of Pyrometallurgical Lead Smelting	7.6-2
7.11-1 Secondary Lead Smelter Processes	7.11-2
8.1-1 Batch Hot-Mix Asphalt Plant	8.1-2
8.1-2 Continuous Hot-Mix Asphalt Plant	8.1-3
8.3-1 Basic Flow Diagram of Brick Manufacturing Process	8.3-2
8.6-1 Basic Flow Diagram of Portland Cement Manufacturing Process	8.6-4
8.11-1 Typical Flow Diagram of Textile-Type Glass Fiber Production Process	8.11-2
8.11-2 Typical Flow Diagram of Wool-Type Glass Fiber Production Process	8.11-2
9.1-1 Basic Flow Diagram of Petroleum Refinery	9.1-2
10.1.2-1 Typical Kraft Sulfate Pulping and Recovery Process	10.1-2

LIST OF TABLES

Table	Page
1.1-1 Range of Collection Efficiencies for Common Types of Fly-Ash Control Equipment	1.1-2
1.1-2 Emission Factors for Bituminous Coal Combustion without Control Equipment	1.1-3
1.2-1 Emissions from Anthracite Coal Combustion without Control Equipment	1.2-2
1.3-1 Emission Factors for Fuel Oil Combustion	1.3-2
1.4-1 Emission Factors for Natural-Gas Combustion	1.4-2
1.5-1 Emission Factors for LPG Combustion	1.5-2
1.6-1 Emission Factors for Wood and Bark Combustion in Boilers with No Reinjection	1.6-2
2.1-1 Emission Factors for Refuse Incinerators without Controls	2.1-4
2.1-2 Collection Efficiencies for Various Types of Municipal Incineration Particulate Control Systems	2.1-5
2.2-1 Emission Factors for Auto Body Incineration	2.2-1
2.3-1 Emission Factors for Waste Incineration in Conical Burners without Controls	2.3-2
2.4-1 Emission Factors for Open Burning	2.4-1
2.5-1 Emission Factors for Sewage Sludge Incinerators	2.5-2
3.1.1-1 Average Emission Factors for Highway Vehicles Based on Nationwide Statistics	3.1.1-6
3.1.2-1 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxide Emission Factors for Light-Duty Vehicles at Low and High Altitude	3.1.2-2
3.1.2-2 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxide Emission Factors for Light-Duty Vehicles, State of California only	3.1.2-3
3.1.2-3 Light-Duty Vehicle Crankcase and Evaporative Hydrocarbon Emissions by Model Year for all Areas Except California	3.1.2-4
3.1.2-4 Light-Duty Vehicle Crankcase and Evaporative Hydrocarbon Emissions by Model Year for California	3.1.2-4
3.1.2-5 Carbon Monoxide, Exhaust Hydrocarbon, and Nitrogen Oxide Deterioration Factors for Light-Duty, Gasoline-Powered Vehicles in All Areas Except California	3.1.2-6
3.1.2-6 Carbon Monoxide, Exhaust Hydrocarbon, and Nitrogen Oxide Deterioration Factors for Light-Duty, Gasoline-Powered Vehicles in California	3.1.2-7
3.1.2-7 Sample Calculation of Weighted Light-Duty Vehicle Annual Travel	3.1.2-8
3.1.2-8 Particulate and Sulfur Oxide Emission Factors for Light-Duty, Gasoline-Powered Vehicles	3.1.2-8
3.1.3-1 Emission Factors for Light-Duty, Diesel-Powered Vehicles	3.1.3-2
3.1.4-1 Heavy-Duty, Gasoline-Powered Vehicle Exhaust Emission Factors for Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides	3.1.4-3
3.1.4-2 Exhaust Emission Deterioration Factors for Heavy-Duty, Gasoline-Powered Vehicles (California only), 1975 and Later Models	3.1.4-4
3.1.4-3 Sample Calculation of Weighted Heavy-Duty Vehicle Annual Travel	3.1.4-5
3.1.4-4 Sulfur Oxide and Particulate Emission Factors for Heavy-Duty, Gasoline-Powered Vehicles	3.1.4-5
3.1.5-1 Emission Factors for Heavy-Duty, Diesel-Powered Vehicles	3.1.5-2
3.1.6-1 Emission Factors by Model Year for Light-Duty Vehicles Using LPG, LPG/Dual Fuel, or CNG/Dual Fuel	3.1.6-2
3.1.6-2 Emission Factors for Heavy-Duty Vehicles Using LPG or CNG/Dual Fuel	3.1.6-2
3.1.7-1 Emission Factors for Motorcycles	3.1.7-2
3.2.1-1 Aircraft Classification	3.2.1-2
3.2.1-2 Typical Time in Mode for Landing-Takeoff Cycle	3.2.1-3
3.2.1-3 Emission Factors per Aircraft Landing-Takeoff Cycle	3.2.1-4
3.2.1-4 Modal Emission Factors	3.2.1-6
3.2.2-1 Average Locomotive Emission Factors Based on Nationwide Statistics	3.2.2-1
3.2.2-2 Emission Factors by Locomotive Engine Category	3.2.2-2
3.2.3-1 Fuel Consumption Rates for Steamships and Motor Ships	3.2.3-1

LIST OF TABLES—(Continued)

Table	Page
3.2.3-2 Emission Factors for Inboard Vessels	3.2.3-2
3.2.4-1 Average Emission Factors for Outboard Motors	3.2.4-1
3.2.5-1 Emission Factors for Small, General-Utility Engines	3.2.5-1
3.3.1-1 Emission Factors for Gas Turbines Using Distillate Fuel Oil	3.3.1-1
3.3.1-2 Emission Factors for Gas Turbines Using Natural Gas	3.3.1-2
3.3.2-1 Emission Factors for Heavy-Duty, General-Utility, Stationary Engines Using Gaseous Fuels	3.3.2-1
4.1-1 Hydrocarbon Emission Factors for Dry-Cleaning Operations	4.1-2
4.2-1 Gaseous Hydrocarbon Emission Factors for Surface-Coating Applications	4.2-1
4.3-1 Hydrocarbon Emission Factors for Evaporation Losses from the Storage of Petroleum Products	4.3-2
4.4-1 Emission Factors for Evaporation Losses from Gasoline Marketing	4.4-2
5.1-1 Emission Factors for an Adipic Acid Plant without Control Equipment	5.1-1
5.2-1 Emission Factors for Ammonia Manufacturing without Control Equipment	5.2-2
5.3-1 Emission Factors for Carbon Black Manufacturing	5.3-2
5.4-1 Emission Factors for Charcoal Manufacturing	5.4-1
5.5-1 Emission Factors for Chlor-Alkali Plants	5.5-2
5.6-1 Emission Factors for Explosives Manufacturing without Control Equipment	5.6-2
5.7-1 Emission Factors for Hydrochloric Acid Manufacturing	5.7-1
5.8-1 Emission Factors for Hydrofluoric Acid Manufacturing	5.8-1
5.9-1 Nitrogen Oxide Emissions from Nitric Acid Plants	5.9-3
5.10-1 Emission Factors for Paint and Varnish Manufacturing without Control Equipment	5.10-2
5.11-1 Emission Factors for Phosphoric Acid Production	5.11-2
5.12-1 Emission Factors for Phthalic Anhydride Plants	5.12-1
5.13-1 Emission Factors for Plastics Manufacturing without Controls	5.13-1
5.14-1 Emission Factors for Printing Ink Manufacturing	5.14-2
5.15-1 Particulate Emission Factors for Spray-Drying Detergents	5.15-1
5.16-1 Emission Factors for Soda-Ash Plants without Control	5.16-1
5.17-1 Emission Factors for Sulfuric Acid Plants	5.17-5
5.17-2 Acid Mist Emission Factors for Sulfuric Acid Plants without Controls	5.17-7
5.17-3 Collection Efficiency and Emissions Comparison of Typical Electrostatic Precipitator and Fiber Mist Eliminator	5.17-8
5.18-1 Emission Factors for Modified Claus Sulfur Plants	5.18-2
5.19-1 Emission Factors for Synthetic Fibers Manufacturing	5.19-1
5.20-1 Emission Factors for Synthetic Rubber Plants: Butadiene-Acrylonitrile and Butadiene-Styrene	5.20-1
5.21-1 Nitrogen Oxides Emission Factors for Terephthalic Acid Plants	5.21-1
6.1-1 Particulate Emission Factors for Alfalfa Dehydration	6.1-1
6.2-1 Emission Factors for Coffee Roasting Processes without Controls	6.2-1
6.3-1 Emission Factors for Cotton Ginning Operations without Controls	6.3-1
6.4-1 Particulate Emission Factors for Grain Handling and Processing	6.4-2
6.5-1 Emission Factors for Fermentation Processes	6.5-2
6.6-1 Emission Factors for Fish Meal Processing	6.6-1
6.7-1 Emission Factors for Meat Smoking	6.7-1
6.8-1 Emission Factors for Nitrate Fertilizer Manufacturing without Controls	6.8-2
6.9-1 Emission Factors for Orchard Heaters	6.9-4
6.10-1 Emission Factors for Production of Phosphate Fertilizers	6.10-1
6.11-1 Emission Factors for Starch Manufacturing	6.11-1
6.12-1 Emission Factors for Sugar Cane Processing	6.12-1
7.1-1 Raw Material and Energy Requirements for Aluminum Production	7.1-2
7.1-2 Representative Particle Size Distributions of Uncontrolled Effluents from Prebake and Horizontal-Stud Soderberg Cells	7.1-4
7.1-3 Emission Factors for Primary Aluminum Production Processes	7.1-5
7.2-1 Emission Factors for Metallurgical Coke Manufacture without Controls	7.2-2
7.3-1 Emission Factors for Primary Copper Smelters without Controls	7.3-2
7.4-1 Emission Factors for Ferroalloy Production in Electric Smelting Furnaces	7.4-2
7.5-1 Emission Factors for Iron and Steel Mills	7.5-4

LIST OF TABLES—(Continued)

Table		Page
7.6-1	Emission Factors for Primary Lead Smelting Processes without Controls	7.6-4
7.6-2	Efficiencies of Representative Control Devices Used with Primary Lead Smelting Operations	7.6-5
7.7-1	Emission Factors for Primary Zinc Smelting without Controls	7.7-1
7.8-1	Particulate Emission Factors for Secondary Aluminum Operations	7.8-1
7.9-1	Particulate Emission Factors for Brass and Bronze Melting Furnaces without Controls	7.9-2
7.10-1	Emission Factors for Gray Iron Foundries	7.10-1
7.11-1	Emission Factors for Secondary Lead Smelting Furnaces without Controls	7.11-2
7.11-2	Efficiencies of Particulate Control Equipment Associated with Secondary Lead Smelting Furnaces	7.11-3
7.11-3	Representative Particle Size Distribution from Combined Blast and Reverberatory Furnace Gas Stream.	7.11-3
7.12-1	Emission Factors for Magnesium Smelting	7.12-1
7.13-1	Emission Factors for Steel Foundries	7.13-2
7.14-1	Particulate Emission Factors for Secondary Zinc Smelting	7.14-2
8.1-1	Particulate Emission Factors for Asphaltic Concrete Plants	8.1-4
8.2-1	Emission Factors for Asphalt Roofing Manufacturing without Controls	8.2-1
8.3-1	Emission Factors for Brick Manufacturing without Controls	8.3-3
8.4-1	Emission Factors for Calcium Carbide Plants	8.4-1
8.5-1	Particulate Emission Factors for Castable Refractories Manufacturing	8.5-1
8.6-1	Emission Factors for Cement Manufacturing without Controls	8.6-3
8.6-2	Size Distribution of Dust Emitted from Kiln Operations without Controls	8.6-3
8.7-1	Particulate Emission Factors for Ceramic Clay Manufacturing	8.7-1
8.8-1	Particulate Emission Factors for Sintering Operations	8.8-2
8.9-1	Particulate Emission Factors for Thermal Coal Dryers	8.9-1
8.10-1	Particulate Emission Factors for Concrete Batching	8.10-1
8.11-1	Emission Factors for Fiber Glass Manufacturing without Controls	8.11-3
8.12-1	Emission Factors for Frit Smelters without Controls	8.12-2
8.13-1	Emission Factors for Glass Melting	8.13-1
8.14-1	Particulate Emission Factors for Gypsum Processing	8.14-1
8.15-1	Particulate Emission Factors for Lime Manufacturing without Controls	8.15-1
8.16-1	Emission Factors for Mineral Wool Processing without Controls	8.16-2
8.17-1	Particulate Emission Factors for Perlite Expansion Furnaces without Controls	8.17-1
8.18-1	Particulate Emission Factors for Phosphate Rock Processing without Controls	8.18-1
8.20-1	Particulate Emission Factors for Rock-Handling Processes	8.20-1
9.1-1	Emission Factors for Petroleum Refineries	9.1-3
10.1.2-1	Emission Factors for Sulfate Pulping	10.1-3
10.2-1	Particulate Emission Factors for Pulpboard Manufacturing	10.2-2
10.3-1	Emission Factors for Plywood Manufacturing	10.3-1
A-1	Nationwide Emissions for 1970	A-2
A-2	Distribution by Particle Size of Average Collection Efficiencies for Various Particulate Control Equipment	A-3
A-3	Thermal Equivalents for Various Fuels	A-4
A-4	Weights of Selected Substances	A-4
A-5	General Conversion Factors	A-5

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

INTRODUCTION

In the assessment of community air pollution, there is a critical need for accurate data on the quantity and characteristics of emissions from the numerous sources that contribute to the problem. The large number of individual sources and the diversity of source types make conducting field measurements of emissions on a source-by-source basis at the point of release impractical. The only feasible method of determining pollutant emissions for a given community is to make generalized estimates of typical emissions from each of the source types.

One of the most useful (and logical) tools for estimating typical emissions is the "emission factor," which is an estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity, such as combustion or industrial production, *divided by* the level of that activity (also expressed in terms of a temporal rate). In other words, the emission factor relates the quantity of pollutants emitted to some indicator (activity level) such as production capacity, quantity of fuel burned, or vehicle miles traveled. In most cases, these factors are simply given as statistical or estimated averages; that is, no empirical information on the various process parameters (temperature, reactant concentrations, etc.) is considered in their calculation. However, for a few cases, such as in the estimation of hydrocarbon emissions from petroleum storage tanks, precise empirical formulas relating emissions to such variables as tank diameter, liquid storage temperature, and wind velocity have been developed. Because of their superior precision, emission factors based on empirical formulas are more desirable to obtain and can usually be given the highest accuracy rating. Factors derived from statistical averages, however, if based on an adequate number of field measurements ("source tests"), can also be both precise and accurate within practical and useful limits.

An example should illustrate how the factors are to be used:

Suppose a sulfuric acid plant, with a production rate of 200 tons/day of 100 percent acid, operates at an overall SO₂ to SO₃ conversion efficiency of 97 percent. Using the formula given as a footnote to Table 5.17-1 on page 5.17-5 of this publication, the *uncontrolled* sulfur dioxide emissions can be calculated :

$$\begin{aligned}\text{SO}_2 \text{ emissions} &= [-13.65 (\% \text{ conversion efficiency}) + 1365] \times \text{production rate} \\ &= [-13.65 (97\%) + 1365] \text{ lb/ton acid} \times 200 \text{ tons acid/day} \\ &= 40 \text{ lb/ton acid} \times 200 \text{ tons acid/day} \\ &= 8000 \text{ lb/day (3632 kg/day)}\end{aligned}$$

The emission factors presented in this report have been estimated using a wide spectrum of techniques available for their determination. The preparation/revision of each factor section involves, first of all, the search for and obtainment of all the known written information on that source category from such sources as the Air Pollution Technical Information Center literature, Environmental Protection Agency technical reports (including emission test reports), and the National Emissions Data System point source file. After these data are reviewed,

organized, and analyzed, the process descriptions, process flowsheets, and other background portions of the section are prepared. Then, using the compiled information, representative emission factors are developed for each pollutant emitted by each point source of the process category. As stated above, these factors are usually obtained by simply averaging the respective numerical data obtained. When feasible, the ranges in the factors are presented for further clarity. Occasionally, enough data exist to permit the development of either empirical or theoretical formulas (or graphs) relating emissions factors to various process parameters such as stream temperature, sulfur content, or catalyst. In these cases, *representative* values of these process parameters are selected and substituted into the formulas or graphs that, in turn, yield representative emission factors which are then tabulated within. The pertinent formulas and graphical data are also included in the section to allow the estimation of emission factors when the process conditions differ from those selected by the author(s).

After the draft of a section is completed, it is circulated for technical review to various personnel routinely familiar with the emission aspects of the particular activity. After these review comments are obtained and evaluated, the final draft is written and submitted for editing and publication.

The limitations and applicability of emission factors must be understood. To give some notion of the accuracy of the factors for a specific process, each set of factors has been ranked according to the available data upon which it was based. Each rank was based on the weighting of the various information categories used to obtain the factor(s). These categories and associated numerical values were:

Measured emission data: 20 points; maximum.

Process data: 10 points; maximum.

Engineering analysis: 10 points; maximum.

The emission data category rated the amount of measured (source test) data available for the development of the factor. The process data category involved such considerations as the variability of the process and its resultant effect on emissions, as well as the amount of data available on these variables. Finally, the engineering analysis category was concerned with the data available upon which a material balance or related calculation could be made.

Depending on which information categories were employed to develop it, each set of factors was assigned a numerical score, ranging from 5 to 40. For example, if the factors developed for a certain process were based on a large number of source tests, a moderate amount of process data, and no engineering analysis work, the assigned score would be $20 + 5 = 25$.

Each numerical score was, in turn, converted to a letter rank as follows:

<u>Numerical Rank</u>	<u>Letter Rank</u>
5 or less	E (Poor)
6 to 15	D (Below average)
16 to 25	C (Average)
26 to 35	B (Above average)
36 to 40	A (Excellent)

These rankings are presented below the table titles throughout this publication.

The reader must be herein cautioned not to use these emission factors indiscriminately. That is, the factors generally will not permit the calculation of accurate emissions measurements from an individual installation. Only an on-site source test can provide data sufficiently accurate and precise to use in such undertakings as the design and purchase of control equipment or the initiation of a legal action. Factors are more valid when applied to a large number of processes, as, for example, when emission inventories are conducted as part of community or nationwide air pollution studies.

Table 1.1-2. EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: A

Furnace size, 10 ⁶ Btu/hr heat input ^a	Particulates ^b		Sulfur oxides ^c		Carbon monoxide		Hydro- carbons ^d		Nitrogen oxides		Aldehydes	
	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned
Greater than 100 ^e (Utility and large industrial boilers)												
Pulverized												
General	16A	8A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Wet bottom	13A ^f	6.5A	38S	19S	1	0.5	0.3	0.15	30	15	0.005	0.0025
Dry bottom	17A	8.5A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Cyclone	2A	1A	38S	19S	1	0.5	0.3	0.15	55	27.5	0.005	0.0025
10 to 100 ^g (large commercial and general industrial boilers)												
Spreader stoker ^h	13A ⁱ	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10 ^j (commercial and domestic furnaces)												
Spreader stoker	2A	1A	38S	19S	10	5	3	1.5	6	3	0.005	0.0025
Hand-fired units	20	10	38S	19S	90	45	20	10	3	1.5	0.005	0.0025

^a 1 Btu/hr = 0.252 kcal/hr.

^b The letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given.

Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 times 16, or 160

pounds of particulate per ton of coal (10 times 8, or 80 kg of particulates per MT of coal).

^c S equals the sulfur content (see footnote b above).

^d Expressed as methane.

^e References 1 and 3 through 7.

^f Without fly-ash reinjection.

^g References 1, 4, and 7 through 9.

^h For all other stokers use 5A for particulate emission factor.

ⁱ Without fly-ash reinjection. With fly-ash reinjection use 20 A. This value is not an emission factor but represents loading reaching the control equipment.¹

^j References 7, 9, and 10.

References for Section 1.1

1. Smith, W. S. Atmospheric Emissions from Coal Combustion. U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-24. April 1966.
2. Control Techniques for Particulate Air Pollutants. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication Number AP-51. January 1969.
3. Perry, H. and J. H. Field. Air Pollution and the Coal Industry. Transactions of the Society of Mining Engineers. 238:337-345, December 1967.
4. Heller, A. W. and D. F. Walters. Impact of Changing Patterns of Energy Use on Community Air Quality. J. Air Pol. Control Assoc. 15:426, September 1965.
5. Cuffe, S. T. and R. W. Gerstle. Emissions from Coal-Fired Power Plants: A Comprehensive Summary. U.S. DHEW, PHS, National Air Pollution Control Administration. Raleigh, N. C. PHS Publication Number 999-AP-35. 1967. p. 15.
6. Austin, H. C. Atmospheric Pollution Problems of the Public Utility Industry. J. Air Pol. Control Assoc. 10(4):292-294, August 1960.
7. Hangebrauck, R. P., D. S. Von Lehmden, and J. E. Meeker. Emissions of Polynuclear Hydrocarbons and Other Pollutants from Heat Generation and Incineration Processes. J. Air Pol. Control Assoc. 14:267-278, July 1964.
8. Hovey, H. H., A. Risman, and J. F. Cunnann. The Development of Air Contaminant Emission Tables for Nonprocess Emissions. J. Air Pol. Control Assoc. 16:362-366, July 1966.
9. Anderson, D. M., J. Lieben, and V. H. Sussman. Pure Air for Pennsylvania. Pennsylvania Department of Health. Harrisburg, Pa. November 1961. p. 91-95.
10. Communication with National Coal Association. Washington, D. C. September 1969.
11. Private communication with R.D. Stern, Control Systems Division, Environmental Protection Agency. Research Triangle Park, N.C. June 21, 1972.
12. Control Techniques for Sulfur Oxide Air Pollutants. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication Number AP-52. January 1969. p. xviii and xxii.
13. Air Pollution Aspects of Emission Sources: Electric Power Production. Environmental Protection Agency, Office of Air Programs. Research Triangle Park, N.C. Publication Number AP-96. May 1971.

1.4.1 General ^{1,2}

Natural gas has become one of the major fuels used throughout the country. It is used mainly for power generation, for industrial process steam and heat production, and for domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium, and carbon dioxide are also present. The average gross heating value of natural gas is approximately 1050 Btu/stdft³ (9350 kcal/Nm³), varying generally between 1000 and 1100 Btu/stdft³ (8900 to 9800 kcal/Nm³).

Because natural gas in its original state is a gaseous, homogenous fluid, its combustion is simple and can be precisely controlled. Common excess air rates range from 10 to 15 percent; however, some large units operate at excess air rates as low as 5 percent to maximize efficiency and minimize nitrogen oxide (NO_x) emissions.

1.4.2 Emissions and Controls ³⁻¹⁶

Even though natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide, and hydrocarbons to be produced. Moreover, because a sulfur-containing mercaptan is added to natural gas for detection purposes, small amounts of sulfur oxides will also be produced in the combustion process.

Nitrogen oxides are the major pollutants of concern when burning natural gas. Nitrogen oxide emissions are a function of the temperature in the combustion chamber and the rate of cooling of the combustion products. Emission levels generally vary considerably with the type and size of unit and are also a function of loading.

In some large boilers, several operating modifications have been employed for NO_x control. Staged combustion, for example, including off-stoichiometric firing and/or two-stage combustion, can reduce NO_x emissions by 30 to 70 percent. In off-stoichiometric firing, also called "biased firing," some burners are operated fuel-rich, some fuel-lean, while others may supply air only. In two-staged combustion, the burners are operated fuel-rich (by introducing only 80 to 95 percent stoichiometric air) with combustion being completed by air injected above the flame zone through second-stage "NO-ports." In staged combustion, NO_x emissions are reduced because the bulk of combustion occurs under fuel-rich, reducing conditions.

Other NO_x-reducing modifications include low excess air firing and flue gas recirculation. In low excess air firing, excess air levels are kept as low as possible without producing unacceptable levels of unburned combustibles (carbon monoxide, hydrocarbons, and smoke) and/or other operational problems. This technique can reduce NO_x emissions by 10 to 30 percent primarily because of the lack of availability of oxygen during combustion. Flue gas recirculation into the primary combustion zone, because the flue gas is relatively cool and oxygen deficient, can also lower NO_x emissions by 20 to 60 percent depending on the amount of gas recirculated. At present only a few systems have this capability, however.

Combinations of the above combustion modifications may also be employed to further reduce NO_x emissions. In some boilers, for instance, NO_x reductions as high as 70 to 90 percent have been produced as a result of employing several of these techniques simultaneously. In general, however, because the net effect of any of these combinations varies greatly, it is difficult to predict what the overall reductions will be in any given unit.

Emission factors for natural gas combustion are presented in Table 1.4-1. Flue gas cleaning equipment has not been utilized to control emissions from natural gas combustion equipment.

Table 1.4-1. EMISSION FACTORS FOR NATURAL-GAS COMBUSTION
EMISSION FACTOR RATING: A

Pollutant	Type of unit					
	Power plant		Industrial process boiler		Domestic and commercial heating	
	lb/10 ⁶ ft ³	kg/10 ⁶ m ³	lb/10 ⁶ ft ³	kg/10 ⁶ m ³	lb/10 ⁶ ft ³	kg/10 ⁶ m ³
Particulates ^a	5-15	80-240	5-15	80-240	5-15	80-240
Sulfur oxides (SO ₂) ^b	0.6	9.6	0.6	9.6	0.6	9.6
Carbon monoxide ^c	17	272	17	272	20	320
Hydrocarbons (as CH ₄) ^d	1	16	3	48	8	128
Nitrogen oxides (NO ₂) ^e	700 ^{f-h}	11,200 ^{f-h}	(120-230) ⁱ	(1920-3680) ⁱ	(80-120) ^j	(1280-1920) ^j

^aReferences 4,7,8,12.

^bReference 4 (based on an average sulfur content of natural gas of 2000 gr/10⁶ stdft³ (4600 g/10⁶ Nm³).

^cReferences 5, 8-12.

^dReferences 8, 9, 12.

^eReferences 3-9, 12-16.

^f Use 300 lb/10⁶ stdft³ (4800 kg/10⁶ Nm³) for tangentially fired units.

^gAt reduced loads, multiply this factor by the load reduction coefficient given in Figure 1.4-1.

^hSee text for potential NO_x reductions due to combustion modifications. Note that the NO_x reduction from these modifications will also occur at reduced load conditions.

ⁱ This represents a typical range for many industrial boilers. For large industrial units (> 100 MMBtu/hr) use the NO_x factors presented for power plants.

^j Use 80 (1280) for domestic heating units and 120 (1920) for commercial units.

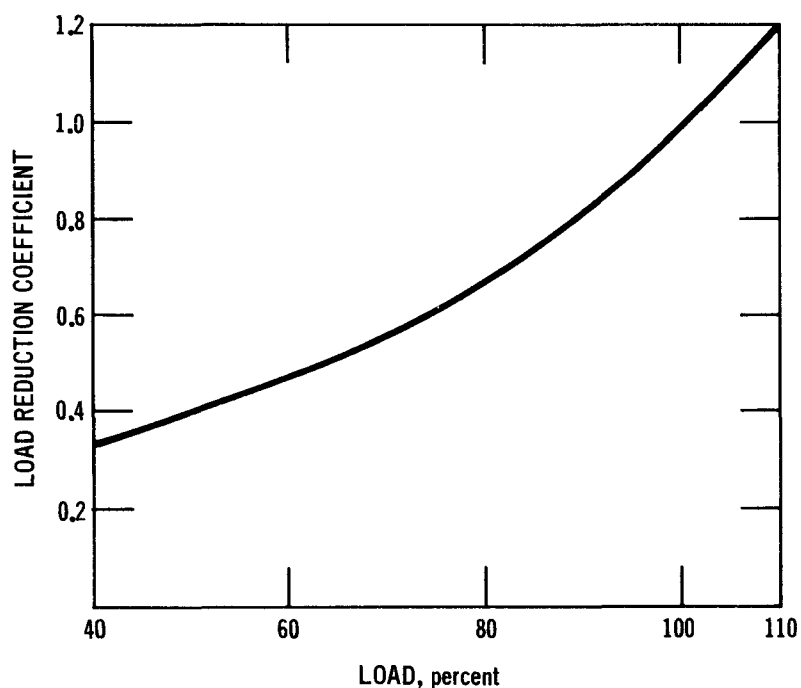


Figure 1.4-1. Load reduction coefficient as function of boiler load. (Used to determine NO_x reductions at reduced loads in large boilers.)

References for Section 1.4

1. High, D. M. et al. Exhaust Gases from Combustion and Industrial Processes. Engineering Science, Inc. Washington, D.C. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. EHSD 71-36, October 2, 1971.
2. Perry, J. H. (ed.). Chemical Engineer's Handbook. 4th Ed. New York, McGraw-Hill Book Co., 1963. p. 9-8.
3. Hall, E. L. What is the Role of the Gas Industry in Air Pollution? In: Proceedings of the 2nd National Air Pollution Symposium. Pasadena, California, 1952. p.54-58.
4. Hovey, H. H., A. Risman, and J. F. Cunnann. The Development of Air Contaminant Emission Tables for Non-process Emissions. New York State Department of Health. Albany, New York. 1965.
5. Bartok, W. et al. Systematic Field Study of NO_x Emission Control Methods for Utility Boilers. Esso Research and Engineering Co., Linden, N. J. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. CPA 70-90, December 31, 1971.
6. Bagwell, F. A. et al. Oxides of Nitrogen Emission Reduction Program for Oil and Gas Fired Utility Boilers. *Proceedings of the American Power Conference*. Vol. 32. 1970. p.683-693.
7. Chass, R. L. and R. E. George. Contaminant Emissions from the Combustion of Fuels, *J. Air Pollution Control Assoc.* 10:34-43, February 1960.
8. Hangebrauck, R. P., D. S. Von Lehmden, and J. E. Meeker. Emissions of Polynuclear Hydrocarbons and other Pollutants from Heat Generation and Incineration Processes. *J. Air Pollution Control Assoc.* 14:271, July 1964.
9. Dietzmann, H. E. A Study of Power Plant Boiler Emissions. Southwest Research Institute, San Antonio, Texas. Final Report No. AR-837. August 1972.
10. Private communication with the American Gas Association Laboratories. Cleveland, Ohio. May 1970.
11. Unpublished data on domestic gas-fired units. U.S. Dept. of Health, Education, and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio. 1970.
12. Barrett, R. E. et al. Field Investigation of Emissions from Combustion Equipment for Space Heating. Battelle-Columbus Laboratories, Columbus, Ohio. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0251. Publication No. EPA-R2-73-084. June 1973.
13. Blakeslee, C. E. and H. E. Burbock. Controlling NO_x Emissions from Steam Generators. *J. Air Pollution Control Assoc.* 23:37-42, January 1973.
14. Jain, L. K. et al. "State of the Art" for Controlling NO_x Emissions. Part 1. Utility Boilers. Catalytic, Inc., Charlotte, N. C. Prepared for U.S. Environmental Protection Agency under Contract No. 68-02-0241 (Task No. 2). September 1972.
15. Bradstreet, J. W. and R. J. Fortman. Status of Control Techniques for Achieving Compliance with Air Pollution Regulations by the Electric Utility Industry. (Presented at the 3rd Annual Industrial Air Pollution Control Conference. Knoxville, Tennessee. March 29-30, 1973.)
16. Study of Emissions of NO_x from Natural Gas-Fired Steam Electric Power Plants in Texas. Phase II. Vol. 2. Radian Corporation, Austin, Texas. Prepared for the Electric Reliability Council of Texas. May 8, 1972.

1.5.1 General¹

Liquefied petroleum gas, commonly referred to as LPG, consists mainly of butane, propane, or a mixture of the two, and of trace amounts of propylene and butylene. This gas, obtained from oil or gas wells as a by-product of gasoline refining, is sold as a liquid in metal cylinders under pressure and, therefore, is often called bottled gas. LPG is graded according to maximum vapor pressure with Grade A being predominantly butane, Grade F being predominantly propane, and Grades B through E consisting of varying mixtures of butane and propane. The heating value of LPG ranges from 97,400 Btu/gallon (6,480 kcal/liter) for Grade A to 90,500 Btu/gallon (6,030 kcal/liter) for Grade F. The largest market for LPG is the domestic-commercial market, followed by the chemical industry and the internal combustion engine.

1.5.2 Emissions¹

LPG is considered a “clean” fuel because it does not produce visible emissions. Gaseous pollutants such as carbon monoxide, hydrocarbons, and nitrogen oxides do occur, however. The most significant factors affecting these emissions are the burner design, adjustment, and venting.² Improper design, blocking and clogging of the flue vent, and lack of combustion air result in improper combustion that causes the emission of aldehydes, carbon monoxide, hydrocarbons, and other organics. Nitrogen oxide emissions are a function of a number of variables including temperature, excess air, and residence time in the combustion zone. The amount of sulfur dioxide emitted is directly proportional to the amount of sulfur in the fuel. Emission factors for LPG combustion are presented in Table 1.5-1.

References for Section 1.5

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.
2. Clifford, E.A. A Practical Guide to Liquefied Petroleum Gas Utilization. New York, Moore Publishing Co. 1962.

Table 1.5-1. EMISSION FACTORS FOR LPG COMBUSTION^a
EMISSION FACTOR RATING: C

Pollutant	Industrial process furnaces				Domestic and commercial furnaces			
	Butane		Propane		Butane		Propane	
	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters	lb/10 ³ gal	kg/10 ³ liters
Particulates	1.8	0.22	1.7	0.20	1.9	0.23	1.8	0.22
Sulfur oxides ^b	0.09S	0.01S	0.09S	0.01S	0.09S	0.01S	0.09S	0.01S
Carbon monoxide	1.6	0.19	1.5	0.18	2.0	0.24	1.9	0.23
Hydrocarbons	0.3	0.036	0.3	0.036	0.8	0.096	0.7	0.084
Nitrogen oxides ^c	12.1	1.45	11.2	1.35	(8 to 12) ^d	(1.0 to 1.5) ^d	(7 to 11) ^d	(0.8 to 1.3) ^d

^aLPG emission factors calculated assuming emissions (excluding sulfur oxides) are the same, on a heat input basis, as for natural gas combustion.

^bS equals sulfur content expressed in grains per 100 ft³ gas vapor; e.g., if the sulfur content is 0.16 grain per 100 ft³ (0.366 g/100 m³) vapor, the SO₂ emission factor would be 0.09 x 0.16 or 0.014 lb SO₂ per 1000 gallons (0.01 x 0.366 or 0.00366 kg SO₂/10³ liters) butane burned.

^cExpressed as NO₂.

^dUse lower value for domestic units and higher value for commercial units.

1.6.1 General ¹⁻³

Today, the burning of wood/bark waste in boilers is largely confined to those industries where it is available as a by-product. It is burned both to recover heat energy and to alleviate a potential solid waste disposal problem. Wood/bark waste may include large pieces such as slabs, logs, and bark strips as well as smaller pieces such as ends, shavings, and sawdust. Heating values for this waste range from 8000 to 9000 Btu/lb, on a dry basis; however, because of typical moisture contents of 40 to 75 percent, the as-fired heating values for many wood/bark waste materials range as low as 4000 to 6000 Btu/lb. Generally, bark is the major type of waste burned in pulp mills; whereas, a variable mixture of wood and bark waste, or wood waste alone, is most frequently burned in the lumber, furniture, and plywood industries.

1.6.2 Firing Practices ¹⁻³

A variety of boiler firing configurations are utilized for burning wood/bark waste. One common type in smaller operations is the Dutch Oven, or extension type of furnace with a flat grate. In this unit the fuel is fed through the furnace roof and burned in a cone-shaped pile on the grate. In many other, generally larger, operations, more conventional boilers have been modified to burn wood/bark waste. These units may include spreader stokers with traveling grates, vibrating grate stokers, etc., as well as tangentially fired or cyclone fired boilers. Generally, an auxiliary fuel is burned in these units to maintain constant steam when the waste fuel supply fluctuates and/or to provide more steam than is possible from the waste supply alone.

1.6.3 Emissions ^{1,2,4-8}

The major pollutant of concern from wood/bark boilers is particulate matter although other pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions. These emissions depend on a number of variables including (1) the composition of the waste fuel burned, (2) the degree of fly-ash reinjection employed, and (3) furnace design and operating conditions.

The composition of wood/bark waste depends largely on the industry from whence it originates. Pulping operations, for instance, produce great quantities of bark that may contain more than 70 percent moisture (by weight) as well as high levels of sand and other noncombustibles. Because of this, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are well controlled. On the other hand, some operations such as furniture manufacture, produce a clean, dry (5 to 50 percent moisture) wood waste that results in relatively few particulate emissions when properly burned. Still other operations, such as sawmills, burn a variable mixture of bark and wood waste that results in particulate emissions somewhere in between these two extremes.

Fly-ash reinjection, which is commonly employed in many larger boilers to improve fuel-use efficiency, has a considerable effect on particulate emissions. Because a fraction of the collected fly-ash is reinjected into the boiler, the dust loading from the furnace, and consequently from the collection device, increases significantly per ton of wood waste burned. It is reported that full reinjection can cause a 10-fold increase in the dust loadings of some systems although increases of 1.2 to 2 times are more typical for boilers employing 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other non-combustibles can be successfully separated from the fly-ash before reinjection to the furnace.

Furnace design and operating conditions are particularly important when burning wood and bark waste. For example, because of the high moisture content in this waste, a larger area of refractory surface should be provided to dry the fuel prior to combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions

do not exist, or when sufficient secondary air is not available, the combustion temperature is lowered, incomplete combustion occurs, and increased particulate, carbon monoxide, and hydrocarbon emissions will result.

Emission factors for wood waste boilers are presented in Table 1.6-1. For boilers where fly-ash reinjection is employed, two factors are shown: the first represents the dust loading reaching the control equipment; the value in parenthesis represents the dust loading after controls assuming about 80 percent control efficiency. All other factors represent uncontrolled emissions.

Table 1.6-1. EMISSION FACTORS FOR WOOD AND BARK WASTE COMBUSTION IN BOILERS
EMISSION FACTOR RATING: B

Pollutant	Emissions	
	lb/ton	kg/MT
Particulates ^a		
Bark ^{b,c}		
With fly-ash reinjection ^d	75 (15)	37.5 (7.5)
Without fly-ash reinjection	50	25
Wood/bark mixture ^{b,e}		
With fly-ash reinjection ^d	45 (9)	22.5 (4.5)
Without fly-ash reinjection	30	15
Wood ^{f,g}	5-15	2.5-7.5
Sulfur oxides (SO ₂) ^{h,i}	1.5	0.75
Carbon monoxide ^j	2-60	1-30
Hydrocarbons ^k	2-70	1-35
Nitrogen oxides (NO ₂) ^l	10	5

^aThese emission factors were determined for boilers burning gas or oil as an auxiliary fuel, and it was assumed all particulates resulted from the waste fuel alone. When coal is burned as an auxiliary fuel, the appropriate emission factor from Table 1.1-2 should be used in addition to the above factor.

^bThese factors based on an as-fired moisture content of 50 percent.

^cReferences 2, 4, 9.

^dThis factor represents a typical dust loading reaching the control equipment for boilers employing fly-ash reinjection. The value in parenthesis represents emissions after the control equipment assuming an average efficiency of 80 percent.

^eReferences 7, 10.

^fThis waste includes clean, dry (5 to 50 percent moisture) sawdust, shavings, ends, etc., and no bark. For well designed and operated boilers use lower value and higher values for others. This factor is expressed on an as-fired moisture content basis assuming no fly-ash reinjection.

^gReferences 11-13.

^hThis factor is calculated by material balance assuming a maximum sulfur content of 0.1 percent in the waste. When auxiliary fuels are burned, the appropriate factors from Tables 1.1-2, 1.3-1, or 1.4-1 should be used in addition to determine sulfur oxide emissions.

ⁱReferences 1, 5, 7.

^jThis factor is based on engineering judgment and limited data from references 11 through 13. Use lower values for well designed and operated boilers.

^kThis factor is based on limited data from references 13 through 15. Use lower values for well designed and operated boilers.

^lReference 16.

References for Section 1.6

1. Steam, Its Generation and Use, 37th Ed. New York, Babcock and Wilcox Co., 1963. p. 19-7 to 19-10 and 3-A4.
2. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/1-73-002. September 1973.

3. C-E Bark Burning Boilers. Combustion Engineering, Inc., Windsor, Connecticut. 1973.
4. Barron, Jr., Alvah. Studies on the Collection of Bark Char Throughout the Industry. TAPPI. 53(8):1441-1448, August 1970.
5. Kreisinger, Henry. Combustion of Wood-Waste Fuels. Mechanical Engineering. 61:115-120, February 1939.
6. Magill, P. L. et al. (eds.). Air Pollution Handbook. New York, McGraw-Hill Book Co., 1956. p. 1-15 and 1-16.
7. Air Pollutant Emission Factors. Final Report. Resources Research, Inc., Reston, Virginia. Prepared for U.S. Environmental Protection Agency, Durham, N.C. under Contract No. CPA-22-69-119. April 1970. p. 2-47 to 2-55.
8. Mullen, J. F. A Method for Determining Combustible Loss, Dust Emissions, and Recirculated Refuse for a Solid Fuel Burning System. Combustion Engineering, Inc., Windsor, Connecticut.
9. Source test data from Alan Lindsey, Region IV, U.S. Environmental Protection Agency, Atlanta, Georgia. May 1973.
10. Effenberger, H. K. et al. Control of Hogged-Fuel Boiler Emissions: A Case History. TAPPI. 56(2):111-115, February 1973.
11. Source test data from the Oregon Department of Environmental Quality, Portland, Oregon. May 1973.
12. Source test data from the Illinois Environmental Protection Agency, Springfield, Illinois. June 1973.
13. Danielson, J. A. (ed.). Air Pollution Engineering Manual. U.S. Department of Health, Education, and Welfare, PHS, National Center for Air Pollution Control, Cincinnati, Ohio. Publication No. 999-AP-40. 1967. p. 436-439.
14. Droege, H. and G. Lee. The Use of Gas Sampling and Analysis for the Evaluation of Teepee Burners. Bureau of Air Sanitation, California Department of Public Health. (Presented at the 7th Conference on Methods in Air Pollution Studies, Los Angeles. January 1967.)
15. Junge, D. C. and R. Kwan. An Investigation of the Chemically Reactive Constituents of Atmospheric Emissions from Hog-Fuel Boilers in Oregon. PNWIS-APCA Paper No. 73-AP-21. November 1973.
16. Galeano, S. F. and K. M. Leopold. A Survey of Emissions of Nitrogen Oxides in the Pulp Mill. TAPPI. 56(3):74-76, March 1973.

2.5.1 Process Description ¹⁻³

Incineration is becoming an important means of disposal for the increasing amounts of sludge being produced in sewage treatment plants. Incineration has the advantages of both destroying the organic matter present in sludge, leaving only an odorless, sterile ash, as well as reducing the solid mass by about 90 percent. Disadvantages include the remaining, but reduced, waste disposal problem and the potential for air pollution. Sludge incineration systems usually include a sludge pretreatment stage to thicken and dewater the incoming sludge, an incinerator, and some type of air pollution control equipment (commonly wet scrubbers).

The most prevalent types of incinerators are multiple hearth and fluidized bed units. In multiple hearth units the sludge enters the top of the furnace where it is first dried by contact with the hot, rising, combustion gases, and then burned as it moves slowly down through the lower hearths. At the bottom hearth any residual ash is then removed. In fluidized bed reactors, the combustion takes place in a hot, suspended bed of sand with much of the ash residue being swept out with the flue gas. Temperatures in a multiple hearth furnace are 600°F (320°C) in the lower, ash cooling hearth; 1400 to 2000°F (760 to 1100°C) in the central combustion hearths, and 1000 to 1200°F (540 to 650°C) in the upper, drying hearths. Temperatures in a fluidized bed reactor are fairly uniform, from 1250 to 1500°F (680 to 820°C). In both types of furnace an auxiliary fuel may be required either during startup or when the moisture content of the sludge is too high to support combustion.

2.5.2 Emissions and Controls ^{1,2,4-7}

Because of the violent upwards movement of combustion gases with respect to the burning sludge, particulates are the major emissions problem in both multiple hearth and fluidized bed incinerators. Wet scrubbers are commonly employed for particulate control and can achieve efficiencies ranging from 95 to 99+ percent.

Although dry sludge may contain from 1 to 2 percent sulfur by weight, sulfur oxides are not emitted in significant amounts when sludge burning is compared with many other combustion processes. Similarly, nitrogen oxides, because temperatures during incineration do not exceed 1500°F (820°C) in fluidized bed reactors or 1600 to 2000°F (870 to 1100°C) in multiple hearth units, are not formed in great amounts.

Odors can be a problem in multiple hearth systems as unburned volatiles are given off in the upper, drying hearths, but are readily removed when afterburners are employed. Odors are not generally a problem in fluidized bed units as temperatures are uniformly high enough to provide complete oxidation of the volatile compounds. Odors can also emanate from the pretreatment stages unless the operations are properly enclosed.

Emission factors for sludge incinerators are shown in Table 2.5-1. It should be noted that most sludge incinerators operating today employ some type of scrubber.

Table 2.5-1. EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS
EMISSION FACTOR RATING: B

Pollutant	Emissions ^a			
	Uncontrolled ^b		After scrubber	
	lb/ton	kg/MT	lb/ton	kg/MT
Particulate ^c	100	50	3	1.5
Sulfur dioxide ^d	1	0.5	0.8	0.4
Carbon monoxide ^e	Neg	Neg	Neg	Neg
Nitrogen oxides ^d (as NO ₂)	6	3	5	2.5
Hydrocarbons ^d	1.5	0.75	1	0.5
Hydrogen chloride gas ^d	1.5	0.75	0.3	0.15

^aUnit weights in terms of dried sludge.

^bEstimated from emission factors after scrubbers.

^cReferences 6-9.

^dReference 8.

^eReferences 6, 8.

References for Section 2.5

1. Calaceto, R. R. Advances in Fly Ash Removal with Gas-Scrubbing Devices. *Filtration Engineering*. 1(7):12-15, March 1970.
2. Balakrishnam, S. et al. State of the Art Review on Sludge Incineration Practices. U.S. Department of the Interior, Federal Water Quality Administration, Washington, D.C. FWQA-WPC Research Series.
3. Canada's Largest Sludge Incinerators Fired Up and Running. *Water and Pollution Control*. 107(1):20-21, 24, January 1969.
4. Calaceto, R. R. Sludge Incinerator Fly Ash Controlled by Cyclonic Scrubber. *Public Works*. 94(2):113-114, February 1963.
5. Schuraytz, I. M. et al. Stainless Steel Use in Sludge Incinerator Gas Scrubbers. *Public Works*. 103(2):55-57, February 1972.
6. Liao, P. Design Method for Fluidized Bed Sewage Sludge Incinerators. PhD. Thesis. University of Washington, Seattle, Washington, 1972.
7. Source test data supplied by the Detroit Metropolitan Water Department, Detroit, Michigan. 1973.
8. Source test data from Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 1972.
9. Source test data from Dorr-Oliver, Inc., Stamford, Connecticut. 1973.

Emissions from open hearths consist of particulates and small amounts of fluorides when fluoride-bearing ore, fluorspar, is used in the charge. The particulates are composed primarily of iron oxides, with a large portion (45 to 50 percent) in the 0 to 5 micrometer size range. The quantity of dust in the off-gas increases considerably when oxygen lancing is used (see Table 7.5-1).

The devices most commonly used to control the iron oxide and fluoride particulates are electrostatic precipitators and high-energy venturi scrubbers, both of which effectively remove about 98 percent of the particulates. The scrubbers also remove nearly 99 percent of the gaseous fluorides and 95 percent of the particulate fluorides.

7.5.1.2.2 Basic Oxygen Furnaces^{2,3}—The basic oxygen process, also called the Linz-Donawitz (LD) process, is employed to produce steel from a furnace charge composed of approximately 70 percent molten blast-furnace metal and 30 percent scrap metal by use of a stream of commercially pure oxygen to oxidize the impurities, principally carbon and silicon.

The reaction that converts the molten iron into steel generates a considerable amount of particulate matter, largely in the form of iron oxide, although small amounts of fluorides may be present. Probably as the result of the tremendous agitation of the molten bath by the oxygen lancing, the dust loadings vary from 5 to 8 grains per standard cubic foot (11 to 18 grams/standard cubic meter) and high percentages of the particles are in the 0 to 5 micrometer size range.

In addition, tremendous amounts of carbon monoxide (140 lb/ton of steel and more) are generated by the reaction. Combustion in the hood, direct flaring, or some other means of ignition is used in the stack to reduce the actual carbon monoxide emissions to less than 3 lb/ton (1.5 kg/MT).

The particulate control devices used are venturi scrubbers and electrostatic precipitators, both of which have overall efficiencies of 99 percent. Furthermore, the scrubbers are 99 percent efficient in removing gaseous fluorides (see Table 7.5-1).

7.5.1.2.3 Electric Arc Furnaces^{2,3}—Electric furnaces are used primarily to produce special alloy steels or to melt large amounts of scrap for reuse. Heat is furnished by direct-arc electrodes extending through the roof of the furnace. In recent years, oxygen has been used to increase the rate of uniformity of scrap-melt-down and to decrease power consumption.

The particulates, primarily oxides of iron, manganese, aluminum, and silicon, that evolve when steel is being processed in an electric furnace result from the exposure of molten steel to extremely high temperatures. The quantity of these emissions is a function of the cleanliness and composition of the scrap metal charge, the refining procedure used (with or without oxygen lancing), and the refining time. As with open hearths, many of the particulates (40 to 75 percent) are in the 0 to 5 micrometer range. Additionally, moderate amounts of carbon monoxide (15 to 20 lb/ton) are emitted.

Particulate control devices most widely used with electric furnaces are venturi scrubbers, which have a collection efficiency of approximately 98 percent, and bag filters, which have collection efficiencies of 99 percent or higher.

7.5.1.3 Scarfing³—Scarfing is a method of surface preparation of semi-finished steel. A scarfing machine removes surface defects from the steel billets and slabs, before they are shaped or rolled, by applying jets of oxygen to the surface of the steel, which is at orange heat, thus removing a thin upper layer of the metal by rapid oxidation.

Emissions from scarfing operations consist of iron oxide fumes. The rate at which particulates are emitted is dependent on the condition of the billets or slabs and the amount of metal removal required (Table 7.5-1). Emission control techniques for the removal of fine particles vary among steel producers, but one of the most commonly used devices is the electrostatic precipitator, which is approximately 94 percent efficient.

Table 7.5-1. EMISSION FACTORS FOR IRON AND STEEL MILLS^{a,b}
EMISSION FACTOR RATINGS: A (PARTICULATES AND CARBON MONOXIDE)
C (FLUORIDES)

Type of operation	Total particulates		Carbon monoxide		Fluorides ^{c,d}		
	lb/ton	kg/MT	lb/ton	kg/MT	Gaseous (HF) lb/ton	Particulates (CaF ₂) lb/ton	kg/MT
Pig iron production							
Blast furnaces ^e							
Ore charge, uncontrolled	110	55	—	—	—	—	—
Agglomerates charge, uncontrolled	40	20	—	—	—	—	—
Total, uncontrolled ^f	165 (130 to 200)	82.5 (65 to 100)	1750 (1400 to 2100)	875 (700 to 1050)	—	—	—
Settling chamber or dry cyclone	60	30	—	—	—	—	—
Plus wet scrubber	15	7.5	—	—	—	—	—
Plus venturi or electrostatic precipitator	1.5	0.75	—	—	—	—	—
Sintering ^g							
Windbox, uncontrolled ^h	20	10	—	—	—	—	—
Dry cyclone	2.0	1.0	—	—	—	—	—
Dry cyclone plus electrostatic precipitator	1.0	0.5	—	—	—	—	—
Dry cyclone plus wet scrubber	0.04	0.02	—	—	—	—	—
Discharge, uncontrolled	22	11	44	22	—	—	—
Dry cyclone	2.2	1.1	44	22	—	—	—
Dry cyclone plus electrostatic precipitator	0.11	0.055	44	22	—	—	—
Steel production							
Open hearth ⁱ							
No oxygen lance, uncontrolled	8.3 (5.8 to 12.0)	4.15 (2.9 to 6.0)	—	—	0.100	0.030	0.015
Venturi scrubber	0.17	0.085	—	—	0.011	0.0055	0.0008
Electrostatic precipitator	0.17	0.085	—	—	0.100	0.006	0.0003
Oxygen lance, uncontrolled	17.4 (9.3 to 22.0)	8.7 (4.65 to 11.0)	—	—	0.100	0.030	0.015

Table 7.5-1 (continued). EMISSION FACTORS FOR IRON AND STEEL MILLS^{a,b}
EMISSION FACTOR RATINGS: A (PARTICULATES AND CARBON MONOXIDE)
C (FLUORIDES)

Type of operation	Total particulates		Carbon monoxide		Fluorides ^{c,d}		
	lb/ton	kg/MT	lb/ton	kg/MT	Gaseous (HF) lb/ton	Particulates (CaF ₂) lb/ton	Particulates (CaF ₂) kg/MT
Venturi scrubber	0.17	0.085	—	—	0.011	0.0015	0.0008
Electrostatic precipitator	0.35	0.175	—	—	0.100	0.0006	0.0003
Basic oxygen, uncontrolled ^j	51 (32 to 86)	25.5 (16 to 43)	139 (104 to 237)	69.5 (52.0 to 118.5)	Neg	0.200	0.100
Venturi scrubber	0.51	0.255	—	—	—	0.002	0.001
Electrostatic precipitator	0.51	0.255	—	—	—	0.002	0.001
Spray chamber	15.3	7.65	—	—	—	0.060	0.030
Electric arc ^k							
No oxygen lance ^l , uncontrolled	9.2 (7.0 to 10.6)	4.6 (3.5 to 5.3)	18	9	0.012	0.238	0.119
Venturi scrubber	0.18	0.09	18	9	0.0018	0.011	0.0055
Electrostatic precipitator	0.28 to 0.74	0.14 to 0.37	18	9	0.012	0.011	0.0055
Baghouse	0.09	0.045	18	9	0.012	0.0024	0.0012
Oxygen lance ^m , uncontrolled	11	5.5	18	9	0.012	0.238	0.119
Venturi scrubber	0.22	0.11	18	9	0.0018	0.011	0.0055
Electrostatic precipitator	0.33 to 0.88	0.165 to 0.44	18	9	0.012	0.011	0.0055
Baghouse	0.11	0.055	18	9	0.012	0.0024	0.0012
Scarfing ⁿ , uncontrolled	≤ 1	≤ 0.5	—	—	—	—	—
Electrostatic precipitator	≤ 0.06	≤ 0.03	—	—	—	—	—
Venturi scrubber	≤ 0.02	≤ 0.01	—	—	—	—	—

^g Reference 3.

^a Emission factors expressed as units per unit weight of metal produced.

^b Numbers in parentheses after uncontrolled values are ranges. Controlled factors are calculated using average uncontrolled factors and observed equipment efficiencies.

^c Reference 4.

^d Value included in "Total Particulates" figure.

^e References 2, 3, and 5.

^f These factors should be used to estimate particulate and carbon monoxide emissions from the entire blast furnace operation. The total particulate factors for ore charging and agglomerates charging apply only to those operations.

^h Approximately 3 pounds of sulfur dioxide per ton (1.5 kg/MT) of sinter is produced at windbox.

ⁱ References 2, 3, 5, and 6.

^j References 2 through 10.

^k Values are for carbon type electric arc furnaces. For alloy type furnaces, multiply given values by 2.80.

^l References 2 through 5.

^m References 3 and 4.

ⁿ Factors are based on operating experience and engineering judgment.

References for Section 7.5

1. Bramer, Henry C. Pollution Control in the Steel Industry. Environmental Science and Technology. p. 1004-1008, October 1971.
2. Celenza, C.J. Air Pollution Problems Faced by the Iron and Steel Industry. Plant Engineering. p. 60-63, April 30, 1970.
3. Compilation of Air Pollutant Emission Factors (Revised). Environmental Protection Agency, Office of Air Programs. Research Triangle Park, N.C. Publication Number AP-42. 1972.
4. Personal communication between Ernest Kirkendall, American Iron and Steel Institute, and John McGinnity, Environmental Protection Agency, Durham, N.C. September 1970.
5. Particulate Pollutant Systems Study, Vol. I. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C., under Contract Number CPA 22-69-104. May 1971.
6. Walker, A.B. and R.F. Brown. Statistics on Utilization, Performance, and Economics of Electrostatic Precipitation for Control of Particulate Air Pollution. (Presented at 2nd International Clean Air Congress, International Union of Air Pollution Prevention Association, Washington, D.C. December 1970.)
7. Source Testing Report - EPA Task 2. Midwest Research Institute, Kansas City. Prepared for Environmental Protection Agency, Office of Air Program, Research Triangle Park, N.C., under Contract Number 68-02-0228. February 1972.
8. Source Testing Report - EPA Test 71-MM-24. Engineering Science, Inc., Washington, D.C. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C., under Contract Number 68-02-0225. March 1972.
9. Source Testing Report - EPA Task 2. Rust Engineering Co., Birmingham, Ala. Prepared for Environmental Protection Agency, Office of Air Program, Research Triangle Park, N.C., under Contract Number CPA 70-132. April 1972.
10. Source Testing Report - EPA Task 4. Roy F. Weston, Inc., West Chester, Pa. Prepared for Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C., under Contract Number 68-02-0231.

7.6.1 Process Description ¹⁻³

Lead is usually found in nature as a sulfide ore containing small amounts of copper, iron, zinc, and other trace elements. It is normally concentrated at the mine from an ore of 3 to 8 percent lead to an ore concentrate of 55 to 70 percent lead, containing from 13 to 19 percent free and uncombined sulfur by weight.

Normal practice for the production of lead metal from this concentrate involves the following operations (see Figure 7.6-1):

1. Sintering, in which the concentrate lead and sulfur are oxidized to produce lead oxide and sulfur dioxide. (Simultaneously, the charge material, comprised of concentrates, recycle sinter, sand, and other inert materials, is agglomerated to form a dense, permeable material called sinter.)
2. Reducing the lead oxide contained in the sinter to produce molten lead bullion.
3. Refining the lead bullion to eliminate any impurities.

Sinter is produced by means of a sinter machine, a continuous steel-pallet conveyor belt moved by gears and sprockets. Each pallet consists of perforated or slotted grates, beneath which are situated windboxes connected to fans that provide a draft on the moving sinter charge. Depending on the direction of this draft, the sinter machine is either of the updraft or downdraft type. Except for the draft direction, however, all machines are similar in design, construction, and operation.

The sintering reaction is autogenous and occurs at a temperature of approximately 1000°C:



Operating experience has shown that system operation and product quality are optimum when the sulfur content of the sinter charge is between 5 and 7 percent by weight. To maintain this desired sulfur content, sulfide-free fluxes such as silica and limestone, plus large amounts of recycled sinter and smelter residues are added to the mix. The quality of the product sinter is usually determined by its hardness (Ritter Index), which is inversely proportional to the sulfur content. Hard quality sinter (low sulfur content) is preferred because it resists crushing during discharge from the sinter machine. Conversely, undersized sinter will usually result from insufficient desulfurization and is recycled for further processing.

Of the two kinds of sintering machines used, the updraft design is superior for many reasons. First, the sinter bed height is more permeable (and, hence, can be greater) with an updraft machine, thereby permitting a higher production rate than that of a downdraft machine of similar dimensions. Secondly, the small amounts of elemental lead that form during sintering will solidify at their point of formation with updraft machines; whereas, in downdraft operation, the metal tends to flow downward and collect on the grates or at the bottom of the sinter charge, thus causing increased pressure drop and attendant reduced blower capacity. In addition, the updraft system exhibits the capability of producing sinter of higher lead content and requires less maintenance than the downdraft machine. Finally, and most important from an air pollution control standpoint, updraft sintering can produce a single strong SO₂ effluent stream from the operation, by use of weak gas recirculation. This, in turn, permits the more efficient and economical use of such control methods as sulfuric acid recovery plants.

Lead reduction is carried out in a blast furnace, basically a water-jacketed shaft furnace supported by a refractory base. Tuyeres, through which combustion air is admitted under pressure, are located near the bottom and are evenly spaced on either side of the furnace.

The furnace is charged with a mixture of sinter (80 to 90 percent of charge), metallurgical coke (8 to 14 percent of the charge), and other materials, such as limestone, silica, litharge, slag-forming constituents, and various recycled and clean-up materials. In the furnace the sinter is reduced to lead bullion; most of the impurities are

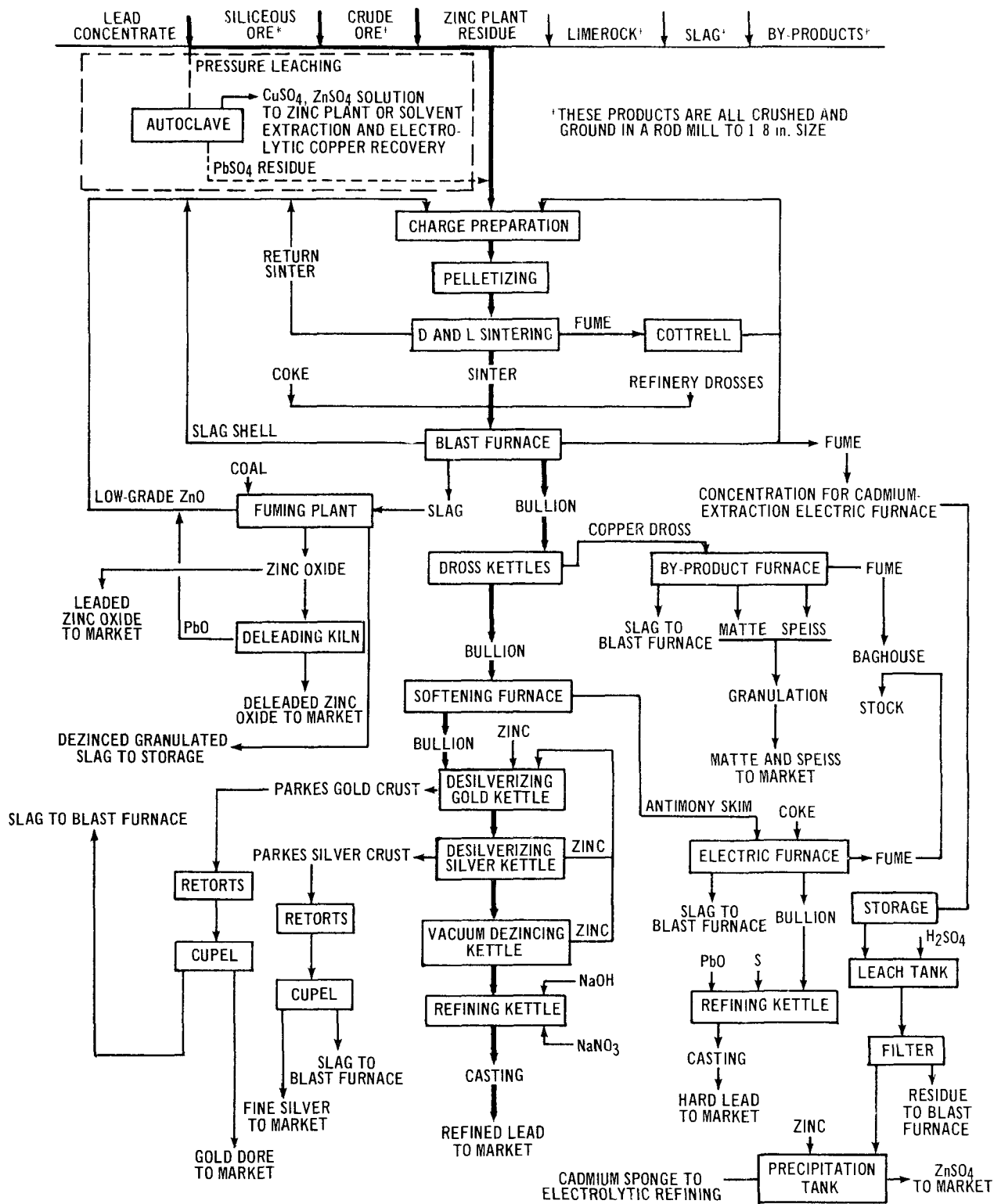


Figure 7.6-1. Typical flowsheet of pyrometallurgical lead smelting.²

eliminated in the slag. Solid products from the blast furnace generally separate into four layers: speiss (basically arsenic and antimony, the lightest material); matte (composed of copper sulfide and other metal sulfides); slag (primarily silicates); and lead bullion. The first three layers are combined as slag, which is continually collected from the furnace and either processed at the smelter for its metal content or shipped to treatment facilities.

A certain amount of SO_2 is also generated in blast furnaces due to the presence of small quantities of residual lead sulfide and lead sulfates in the sinter feed. The quantity of these emissions is a function of not only the residual sulfur content in the sinter, but of the amount of sulfur that is captured by copper and other impurities in the slag.

Rough lead bullion from the blast furnace usually requires preliminary treatment (drossing) in steel cast-iron kettles before undergoing refining operations. First, the bullion is cooled to 700 to 800°F; copper and small amounts of sulfur, arsenic, antimony, and nickel are removed from solution and collect on the surface as a dross. This dross, in turn, is treated in a reverberatory-type furnace where the copper and other metal impurities are further concentrated before being routed to copper smelters for their eventual recovery. Drossed lead bullion is further treated for copper removal by the addition of sulfur-bearing material and zinc and/or aluminum to lower the copper content to approximately 0.01 percent.

The final phase of smelting, the refining of the bullion in cast-iron kettles, occurs in five steps:

1. Removal of antimony, tin, and arsenic;
2. Removal of precious metals via the Parke's Process, in which zinc metal combines with gold and silver to form an insoluble intermetallic at operating temperatures;
3. Vacuum removal of zinc;
4. Bismuth removal using the Betterson Process, which involves the addition of calcium and magnesium, which in turn, form an insoluble compound with the bismuth that is skimmed from the kettle; and
5. Removal of remaining traces of metal impurities by addition of NaOH and NaNO_3 .

The final refined lead, commonly of 99.99 to 99.999 percent purity, is then cast into 100-pound pigs before shipment.

7.6.2 Emissions and Controls ^{1,2}

Each of the three major lead smelting operations generates substantial quantities of particulates and/or sulfur dioxide.

Nearly 85 percent of the sulfur present in the lead ore concentrate is eliminated in the sintering operation. In handling these process offgases, either a single weak stream is taken from the machine hood at less than 2 percent SO_2 or two streams are taken—one weak stream (<0.5 percent SO_2) from the discharge end of the machine and one strong stream (5 to 7 percent SO_2) taken from the feed end. Single stream operation is generally used when there is little or no market for the recovered sulfur, so that the uncontrolled weak SO_2 stream is emitted to the atmosphere. Where there is a potential sulfur market, however, the strong stream is sent to a sulfuric acid plant, and the weak stream is vented after particulate removal.

When dual gas stream operation is used with updraft sinter machines, the weak gas stream can be recirculated through the bed to mix with the strong gas stream, resulting in a single stream with an SO_2 concentration of about 6 percent. This technique has the overall effect of decreasing machine production capacity, but does permit a more convenient and economical recovery of the SO_2 via sulfuric acid plants and other control methods.

Without weak gas recirculation, the latter portion of the sinter machine acts as a cooling zone for the sinter and consequently assists in the reduction of dust formation during product discharge and screening. However,

when recirculation is used, the sinter is usually discharged in a relatively hot state (400 to 500°C), with an attendant increase in particulate formation. Methods for reducing these dust quantities include recirculation of off-gases through the sinter bed, relying upon the filtering effect of the latter, or ducting the gases from the discharge through a particulate collection device directly to the atmosphere. Because reaction activity has ceased in the discharge area in these cases, these latter gases contain little SO₂.

The particulate emissions from sinter machines consist of from 5 to 20 percent of the concentrated ore feed. When expressed in terms of product weight, these emissions are an estimated 106.5 kg/MT (213 lb/ton) of lead produced. This value, along with other particulate and SO₂ factors, appears in Table 7.6-1.

**Table 7.6-1. EMISSION FACTORS FOR PRIMARY LEAD
SMELTING PROCESSES WITHOUT CONTROLS^a
EMISSION FACTOR RATING: B**

Process	Particulates		Sulfur dioxide	
	kg/MT	lb/ton	kg/MT	lb/ton
Ore crushing ^b	1.0	2.0	—	—
Sintering (updraft) ^c	106.5	213.0	275.0	550.0
Blast furnace ^b	180.5	361.0	22.5	45.0
Dross reverberatory furnace ^b	10.0	20.0	Neg	Neg
Materials handling ^b	2.5	5.0	—	—

^aOre crushing emission factors expressed as kg/MT (lb/ton) of crushed ore; all other emission factors expressed as kg/MT (lb/ton) of lead product.

^bReference 2.

^cReferences 1, 4, 5, and 6.

^dReferences 1, 2, and 7.

Typical material balances from domestic lead smelters indicate that about 10 to 20 percent of the sulfur in the ore concentrate fed to the sinter machine is eliminated in the blast furnace. However, only *half* of this amount (about 7 percent of the total) is emitted as SO₂; the remainder is captured by the slag. The concentration of this SO₂ stream can vary from 500 to 2500 ppm by volume, depending on the amount of dilution air injected to oxidize the carbon monoxide and cool the stream before baghouse treatment for particulate removal.

Particulate emissions from blast furnaces contain many different kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic, and other metals-containing compounds associated with lead ores. These particles readily agglomerate, are primarily submicron in size, difficult to wet, cohesive, and will bridge and arch in hoppers. On the average, this dust loading is quite substantial (see Table 7.6-1).

Virtually no sulfur dioxide emissions are associated with the various refining operations. However, a small amount of particulates is generated by the dross reverberatory furnace (10 kg/MT of lead).

Finally, minor quantities of particulates are generated by ore crushing and materials handling operations. These emission factors are also presented in Table 7.6-1.

Methods used to control emission from lead smelter operations fall into two broad categories—particulate and sulfur dioxide control techniques. The most commonly employed high-efficiency particulate control devices are fabric filters and electrostatic precipitators, which, in turn, often follow centrifugal collectors and tubular coolers (pseudogravity collectors). Three of the six lead smelters presently operating in the United States use single absorption sulfuric acid plants for control of sulfur dioxide emissions from sinter machines and, occasionally, blast furnaces. Other technically feasible SO₂ control methods are elemental sulfur recovery plants and

dimethylaniline (DMA) and ammonia absorption processes. These methods and their representative control efficiencies are listed in Table 7.6-2.

**Table 7.6-2. EFFICIENCIES OF REPRESENTATIVE CONTROL DEVICES
USED WITH PRIMARY LEAD SMELTING OPERATIONS**

Control device or method	Control device efficiency range	
	Particulates	Sulfur dioxide
Centrifugal collector (e.g., cyclone) ^a	80 to 90	—
Electrostatic precipitator ^a	95 to 99	—
Fabric filter ^a	95 to 99	—
Tubular cooler (associated with waste heat boiler) ^a	70 to 80	—
Sulfuric acid plant (single contact) ^{b,c}	99.5 to 99.9	96 to 97
Elemental sulfur recovery plant ^{b,d}	—	90
Dimethylaniline (DMA) absorption process ^{b,e}	—	95 to 98.8
Ammonia absorption process ^{b,f}	—	92 to 95.2

^aReference 2.

^bReference 1.

^cHigh particulate control efficiency due to action of acid plant gas precleaning system. Range of SO₂ efficiencies based on inlet and outlet concentrations of 5 to 7 percent and 2000 ppm, respectively.

^dCollection efficiency for a two-stage, uncontrolled Claus-type plant. Refer to Section 5.18 for more information.

^eRange of SO₂ efficiencies based on inlet and outlet concentrations of 4 to 6 percent and 500 to 3000 ppm, respectively.

^fRange of SO₂ efficiencies based on inlet and outlet concentrations of 1.5 to 2.5 percent and 1200 ppm, respectively.

References for Section 7.6

1. Darwin, Charles and Frederick Porter. Background Information for Proposed New Source Performance Standards for Primary Copper, Zinc, and Lead Smelters. (Draft). Emission Standards and Engineering Division, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 1973.
2. Handbook of Emissions, Effluents, and Control Practices for Stationary Particulate Pollution Sources. Midwest Research Institute, Kansas City, Missouri. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. under Contract Number CPA 22-69-104. November 1970.
3. Worchester, A. and D. H. Beilstein. Lead—Progress and Prognosis: The State of the Art: Lead Recovery. (Presented at 10th Annual Meeting of Metallurgical Society of AIME. New York. Paper No. A71-87. March 1971.)
4. Trip report memorandum. T. J. Jacobs to Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C. Subject: Plant visit to St. Joe Minerals Corporation Lead Smelter at Herculaneum, Missouri. October 21, 1971.
5. Trip report memorandum. T. J. Jacobs to Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C. Subject: Plant visit to Amax Lead Company of Missouri Lead Smelter at Boss, Missouri. October 28, 1971.
6. Personal communication from R. B. Paul, Plant Manager, American Smelting and Refining Company Lead Smelter at Glover, Missouri, to Regional Administrator, EPA Region VII, Kansas City, Missouri. April 3, 1973.
7. Source Testing Report: Emissions from a Primary Lead Smelter Blast Furnace. Midwest Research Institute, Kansas City, Missouri. Prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C. Report No. 72-MM-14. May 1972.

7.11.1 Process Description ¹⁻³

In the secondary smelting, refining, and alloying of lead, the three types of furnace most commonly used are reverberatory, blast or cupola, and pot. The grade of metal to be produced—soft, semisoft, or hard—dictates the type of furnace to be used.

Used for the production of semisoft lead, the reverberatory furnace reclaims this metal from a charge of lead scrap, battery plates, oxides, drosses, and lead residues. The furnace consists of an outer shell built in the shape of a rectangular box lined with refractory brick. To provide heat for melting, the charge gas or oil-fired burners are usually placed at one end of the furnace, and the material to be melted is charged through an opening in the shell.

The charge is placed in the furnace in such a manner as to keep a small mound of unmelted material on top of the bath. Continuously, as this mound becomes molten at the operating temperature (approximately 1250°C), more material is charged. Semisoft lead is tapped off periodically as the level of the metal rises in the furnace. The amount of metal recovered is about 50 to 60 kilograms per square meter of hearth area per hour.

A similar kind of furnace—the revolving (rotary) reverberatory—is used at several European installations for the recovery of lead from battery scrap and lead sulfate sludge. Its charge makeup and operating characteristics are identical to the reverberatories used in the United States, except that the furnace slowly revolves as the charge is heated.

The blast (cupola) furnace, used to produce “hard” lead, is normally charged with the following: rerun slag from previous runs (4.5 percent); cast-iron scrap (4.5 percent); limestone (3 percent); coke (5.5 percent); and drosses from pot furnace refining, oxides, and reverberatory slag (82.5 percent). Similar to an iron cupola, the furnace consists of a steel sheet lined with refractory material. Air, under high pressure, is introduced at the bottom through tuyeres to permit combustion of the coke, which provides the heat and a reducing atmosphere.

As the charge material melts, limestone and iron form an oxidation-retardant flux that floats to the top, and the molten lead flows from the furnace into a holding pot at a nearly continuous rate. The rest (30 percent) of the tapped molten material is slag, 5 percent of which is retained for later rerun. From the holding pot, the lead is usually cast into large ingots called “buttons” or “sows.”

Pot-type furnaces are used for remelting, alloying, and refining processes. These furnaces are usually gas fired and range in size from 1 to 45 metric tons capacity. Their operation consists simply of charging ingots of lead or alloy material and firing the charge until the desired product quality is obtained.

Refining processes most commonly employed are those for the removal of copper and antimony to produce soft lead, and those for the removal of arsenic, copper, and nickel to produce hard lead.

Figure 7.11-1 illustrates these three secondary lead smelting processes.

7.11.2 Emissions and Controls ^{1,2}

The emissions and controls from secondary lead smelting processes may be conveniently considered according to the type of furnace employed.

With the reverberatory furnaces, the temperature maintained is high enough to oxidize the sulfides present in the charge to sulfur dioxide and sulfur trioxide, which, in turn, are emitted in the exit gas. Also emitted are such particulates (at concentrations of 16 to 50 grams per cubic meter) as oxides, sulfides, and sulfates of lead, tin,

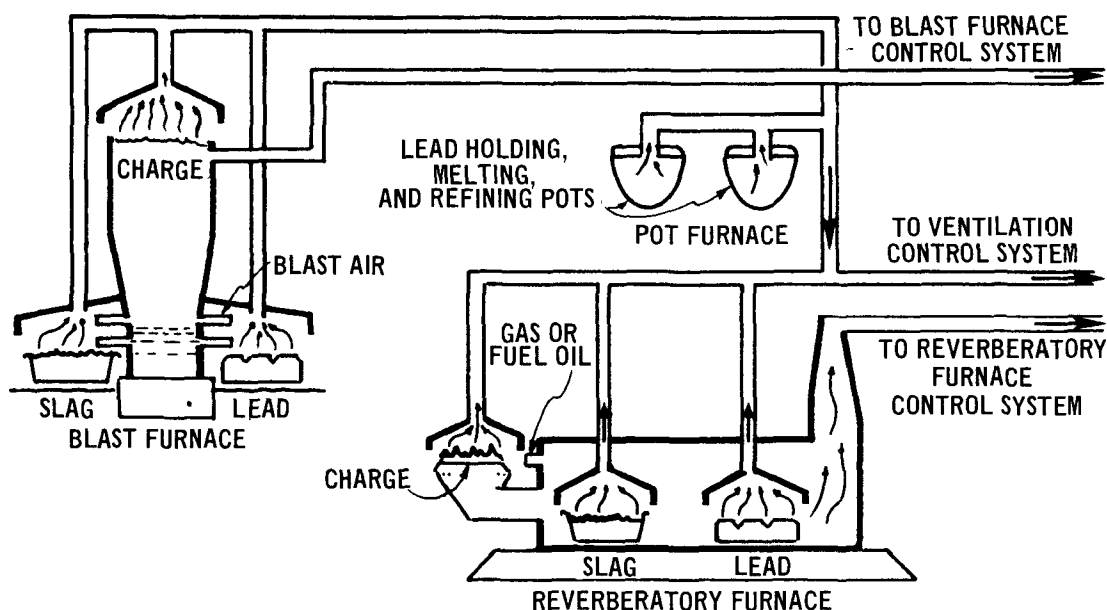


Figure 7.11-1. Secondary lead smelter processes.⁴

arsenic, copper, and antimony. The particles are nearly spherical and tend to agglomerate. Emission factors for reverberatory furnaces are presented in Table 7.11-1.

The most practical control system for a reverberatory furnace consists of a gas settling/cooling chamber and a fabric filter. This system effects a particulate removal of well in excess of 99 percent. Because of the potential presence of sparks and flammable material, a great deal of care is taken to control the temperature of the gas stream. In turn, the type of filter cloth selected depends upon stream temperature and such parameters as gas

**Table 7.11-1. EMISSION FACTORS FOR SECONDARY LEAD SMELTING FURNACES
WITHOUT CONTROLS^a
EMISSION FACTOR RATING: B**

Furnace type	Particulates		Sulfur dioxide	
	kg/MT	lb/ ton	kg/MT	lb/ton
Reverberatory ^b	73.5 (28.0 to 156.5) ^c	147 (56 to 313)	40.0 (35.5 to 44.0)	80 (71 to 88)
Blast (cupola) ^d	96.5 (10.5 to 190.5)	193 (21.0 to 381.0)	26.5 (9.0 to 55.0)	53.0 (18 to 110)
Pot ^e	0.4	0.8	Neg	Neg
Rotary reverberatory ^f	35.0	70.0	NA ^g	NA ^g

^aAll emission factors expressed in terms of kg/MT and lb/ton of metal charged to furnace.

^bReferences 2, 5 through 7.

^cNumbers in parentheses represent ranges of values obtained.

^dReferences 2, 7 through 9.

^eReference 7.

^fReference 3.

^gNA—no data available to make estimates.

stream corrosivity and the permeability and abrasion (or stress)-resisting characteristics of the cloth. In any case, the filtering velocity seldom exceeds 0.6 m/min. Table 7.11-2 offers a listing of control devices and their efficiencies.

**Table 7.11-2. EFFICIENCIES OF PARTICULATE CONTROL EQUIPMENT
ASSOCIATED WITH SECONDARY LEAD SMELTING FURNACES**

Control device	Furnace type	Particulate control efficiency
Fabric filter ^a	Blast	98.4
	Reverberatory	99.2
Dry cyclone plus fabric filter ^a	Blast	99.0
Wet cyclone plus fabric filter ^b	Reverberatory	99.7
Settling chamber plus dry cyclone plus fabric filter ^c	Reverberatory	99.8
Venturi scrubber plus demister ^d	Blast	99.3

^aReference 2.

^bReference 5.

^cReference 6.

^dReference 8.

Combustion air from the tuyeres passing through the blast furnace charge conveys metal oxides, bits of coke, and other particulates present in the charge. The particulate is roughly 7 percent by weight of the total charge (up to 44 g/m³). In addition to particulates, the stack gases also contain carbon monoxide. However, the carbon monoxide and any volatile hydrocarbons present are oxidized to carbon dioxide and water in the upper portion of the furnace, which effectively acts as an afterburner.

Fabric filters, preceded by radiant cooling columns, evaporative water coolers, or air dilution jets, are also used to control blast furnace particulates. Overall efficiencies exceeding 95 percent are common (see Table 7.11-2). Representative size distributions of particles in blast and reverberatory furnace streams are presented in Table 7.11-3.

Compared with the other furnace types, pot furnace emissions are low (see Table 7.11-1). However, to maintain a hygienic working environment, pot furnace off gases, usually along with emission streams from other furnaces, are directed to fabric filter systems.

**Table 7.11-3. REPRESENTATIVE PARTICLE SIZE DISTRIBUTION
FROM A COMBINED BLAST AND REVERBERATORY
FURNACE GAS STREAM^a**

Size range, μm	Fabric filter catch, wt %
0 to 1	13.3
1 to 2	45.2
2 to 3	19.1
3 to 4	14.0
4 to 16	8.4

^aReference 1.

^bThese particles are distributed log-normally, according to the following frequency distribution:

$$f(D) = 1.56 \exp \left[\frac{-(\log D - 0.262)^2}{0.131} \right]$$

References for Section 7.11

1. Nance, J. T. and K. O. Luedtke. Lead Refining. In: Air Pollution Engineering Manual. 2nd Ed. Danielson, J. A. (ed.). Office of Air and Water Programs, U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. AP-42. May 1973. p. 299-304.
2. Williamson, John E., Joel F. Nenzell, and Wayne E. Zwiacher. A Study of Five Source Tests on Emissions from Secondary Lead Smelters. County of Los Angeles Air Pollution Control District. Environmental Protection Agency Order No. 2PO-68-02-3326. February 11, 1972.
3. Restricting Dust and Sulfur Dioxide Emissions from Lead Smelters (translated from German). Kommission Reinhaltung der Luft. Reproduced by U.S. DHEW, PHS. Washington, D.C. VDI Number 2285. September 1961.
4. Background Information for Proposed New Source Performance Standards: Secondary Lead Smelters and Refineries. Volume I, Main Text. Environmental Protection Agency, Office of Air and Water Programs, Office of Air Quality Planning and Standards. Research Triangle Park, N.C. June 1973.
5. Source Testing Report: Secondary Lead Plant Stack Emission Sampling. Battelle Columbus Laboratories, Columbus, Ohio. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. Report Number 72-CI-8. July 1972.
6. Source Testing Report: Secondary Lead Plant Stack Emission Sampling. Battelle Columbus Laboratories, Columbus, Ohio. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. Report Number 72-CI-7. August 1972.
7. Particulate Pollutant Systems Study, Vol. I. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. May 1971.
8. Source Testing Report: Secondary Lead Plant Stack Emission Sampling. Battelle Columbus Laboratories, Columbus, Ohio. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. Report Number 71-CI-33. August 1972.
9. Source Testing Report: Secondary Lead Plant Stack Emission Sampling. Battelle Columbus Laboratories, Columbus, Ohio. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. Report Number 71-CI-34. July 1972.

9. PETROLEUM INDUSTRY

9.1 PETROLEUM REFINING

Revised by William M. Vataavuk

9.1.1 General

Although a modern refinery is a complex system of many processes, the entire operation can be divided into four major steps: separating, converting, treating, and blending. The crude oil is first separated into selected fractions (e.g. gasoline, kerosene, fuel, oil, etc.). Because the relative volumes of each fraction produced by merely separating the crude may not conform to the market demands for each fraction, some of the less valuable products, such as heavy naptha, are converted to products with a greater sale value, such as gasoline. This conversion is accomplished by splitting (cracking), uniting (polymerization), or rearranging (reforming) the original molecules. The final step is the blending of the refined base stocks with each other and with various additives to meet final product specifications. The various unit operations involved at petroleum refineries will be briefly discussed in the following sections. A generalized petroleum refinery flow sheet is shown in Figure 9.1-1.

9.1.2 Crude Oil Distillation¹⁻⁶

Crude oil is a mixture of many different hydrocarbons, some of them combined with small amounts of impurities. Crude oils vary considerably in composition and physical properties, but primarily consist of three families of hydrocarbons: paraffins, saturated hydrocarbons having the empirical formula C_nH_{2n+2} ; napthenes, ring-structure saturated hydrocarbons with the formula C_nH_{2n} ; and aromatics, characterized by a benzene ring, C_6H_6 , in the molecular structure. In addition to carbon and hydrogen, significant amounts of sulfur, oxygen, and nitrogen can be present in crude petroleum.

Separation of these hydrocarbon constituents into their respective fractions is performed by simple distillation in crude topping or skimming units. Crude oil is heated in pipe stills and passed to fractionating towers or columns for vaporization and preparation. Heavy fractions of the crude oil, which do not vaporize in the topping operation, are separated by steam or vacuum distillation. The heavy residuum products are reduced to coke and more valuable volatile products via destructive distillation and coking. Depending on the boiling range of the stock and its stability with respect to heat and product specifications, solvent extraction and/or absorption techniques can also be used. The distillation fractions - "straight run products" - usually include refinery gas, gasoline, kerosene, light fuel oil, diesel oils, gas oil, lube distillate, and heavy bottoms, the amount of each being determined by the type and composition of the crude oil. Some of these products are treated to remove impurities and used as base stocks or sold as finished products; the remainder are used as feedstock for other refinery units.

9.1.2.1 Emissions—The main source of emissions from crude oil preparation processes is the barometric condenser on the vacuum distillation column. This condenser, while maintaining a vacuum on the tower, often allows noncondensable light hydrocarbons and hydrogen sulfide to pass through to the atmosphere. The quantity of these emissions is a function of the unit size, type of feedstock, and the cooling water temperature. Vapor recovery systems reduce these emissions to negligible amounts (see Table 9.1-1).

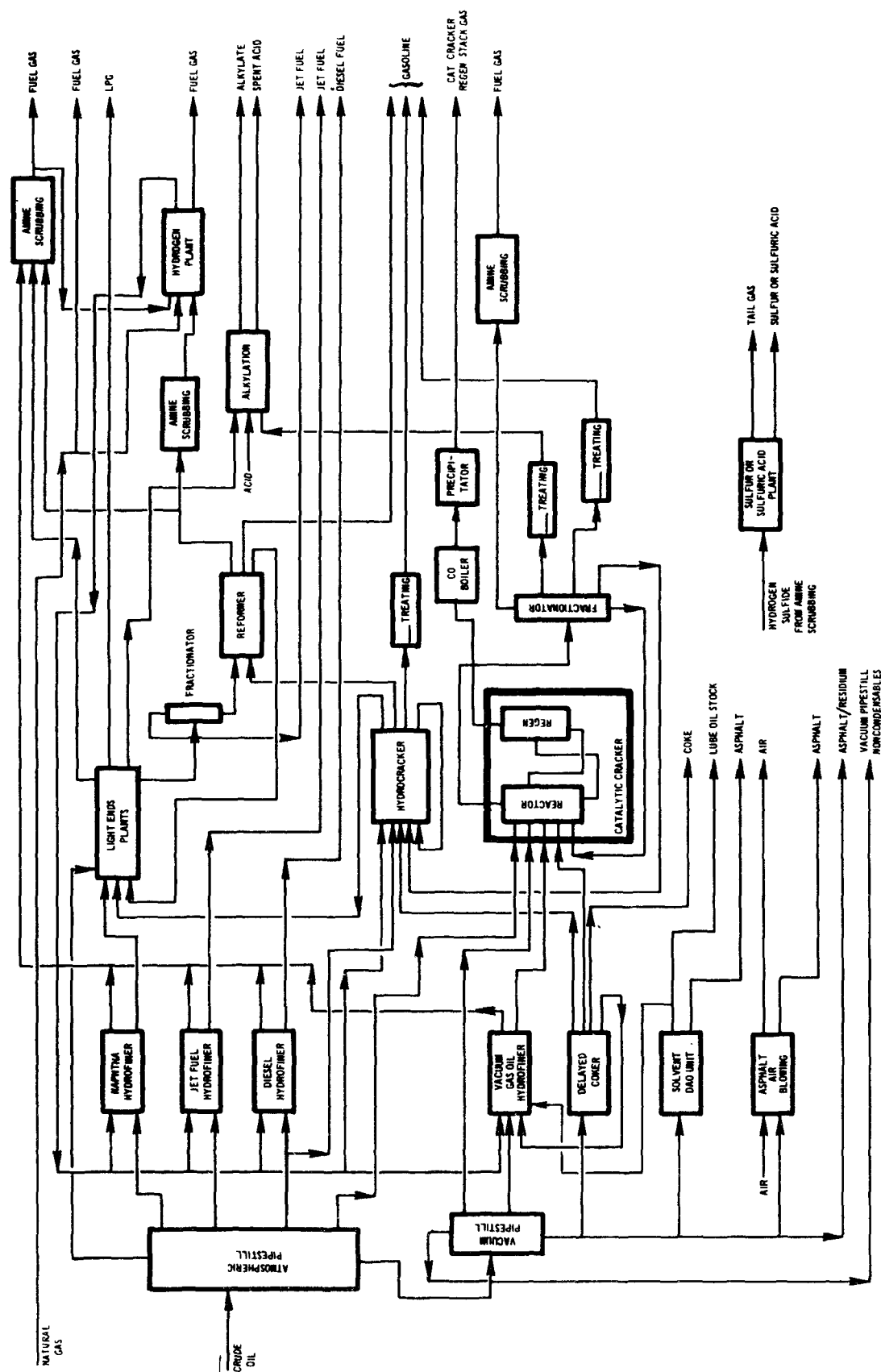


Figure 9.1-1. Basic flow diagram of petroleum refinery. (Emission factor data for sulfur or sulfuric acid plants are available in sections 5.18 and 5.17, respectively.)

10. WOOD PROCESSING

Wood processing involves the conversion of raw wood to either pulp, pulpboard, or one of several types of wallboard including plywood, particleboard, or hardboard. This section presents emissions data for chemical wood pulping as well as for pulpboard and plywood manufacturing. The burning of wood waste in boilers and conical burners is not included as it is discussed in Chapters 1 and 2 of this publication.

10.1 CHEMICAL WOOD PULPING

Revised by Thomas Lahre

10.1.1 General¹

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The principal processes used in chemical pulping are the kraft, sulfite, neutral sulfite semichemical (NSSC), dissolving, and soda; the first three of these display the greatest potential for causing air pollution. The kraft process accounts for about 65 percent of all pulp produced in the United States; the sulfite and NSSC processes, together, account for less than 20 percent of the total. The choice of pulping process is determined by the product being made, by the type of wood species available, and by economic considerations.

10.1.2 Kraft Pulping

10.1.2.1 Process Description^{1,2}—The kraft process (see Figure 10.1.2-1) involves the cooking of wood chips under pressure in the presence of a cooking liquor in either a batch or a continuous digester. The cooking liquor, or “white liquor,” consisting of an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers together.

When cooking is completed, the contents of the digester are forced into the blow tank. Here the major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter where unreacted chunks of wood are removed. The pulp is then washed and, in some mills, bleached before being pressed and dried into the finished product.

It is economically necessary to recover both the inorganic cooking chemicals and the heat content of the spent “black liquor,” which is separated from the cooked pulp. Recovery is accomplished by first concentrating the liquor to a level that will support combustion and then feeding it to a furnace where burning and chemical recovery take place.

Initial concentration of the weak black liquor, which contains about 15 percent solids, occurs in the multiple-effect evaporator. Here process steam is passed countercurrent to the liquor in a series of evaporator tubes that increase the solids content to 40 to 55 percent. Further concentration is then effected in the direct contact evaporator. This is generally a scrubbing device (a cyclonic or venturi scrubber or a cascade evaporator) in which hot combustion gases from the recovery furnace mix with the incoming black liquor to raise its solids content to 55 to 70 percent.

The black liquor concentrate is then sprayed into the recovery furnace where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are discharged to the smelt dissolving tank to form a solution called “green liquor.” The green liquor is then conveyed to a causticizer where slaked lime (calcium hydroxide) is added to convert the solution back to white liquor, which can be reused in subsequent cooks. Residual lime sludge from the causticizer can be recycled after being dewatered and calcined in the hot lime kiln.

Many mills need more steam for process heating, for driving equipment, for providing electric power, etc., than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, and in some cases, bark and wood waste are commonly employed.

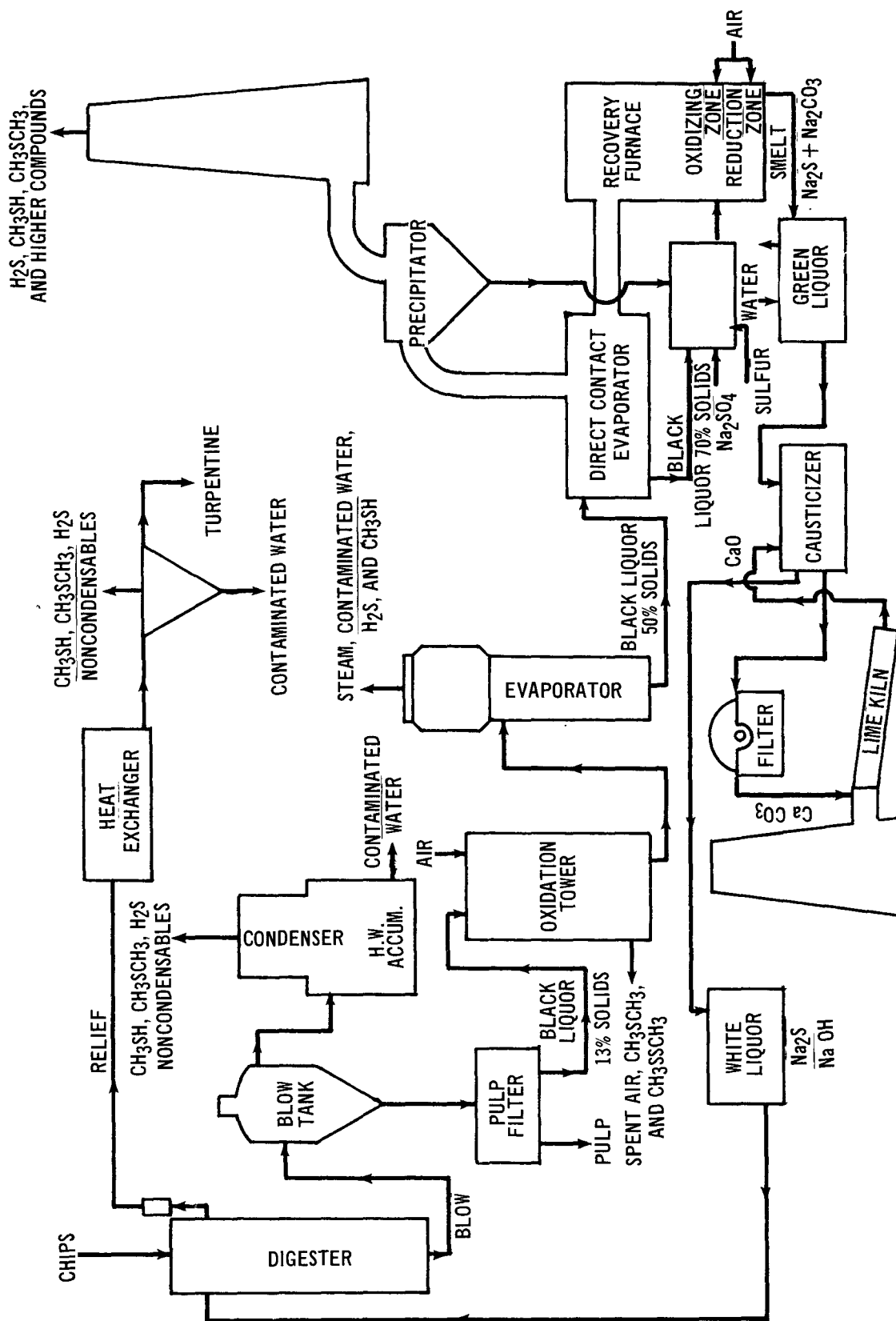


Figure 10.1.2-1. Typical kraft sulfate pulping and recovery process.

10.1.2.2. Emission and Controls¹⁻⁶—Particulate emissions from the kraft process occur primarily from the recovery furnace, the lime kiln, and the smelt dissolving tank. These emissions consist mainly of sodium salts but include some calcium salts from the lime kiln. They are caused primarily by the carryover of solids plus the sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills where either a cyclonic scrubber or cascade evaporator serves as the direct contact evaporator, further control is necessary as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostatic precipitator is employed after the direct contact evaporator to provide an overall particulate control efficiency of 85 to ≥ 99 percent. In a few mills, however, a venturi scrubber is utilized as the direct contact evaporator and simultaneously provides 80 to 90 percent particulate control. In either case auxiliary scrubbers may be included after the precipitator or the venturi scrubber to provide additional control of particulates.

Particulate control on lime kilns is generally accomplished by scrubbers. Smelt dissolving tanks are commonly controlled by mesh pads but employ scrubbers when further control is needed.

The characteristic odor of the kraft mill is caused in large part by the emission of hydrogen sulfide. The major source is the direct contact evaporator in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. The lime kiln can also be a potential source as a similar reaction occurs involving residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensable off-gasses from the digesters and multiple-effect evaporators.

The kraft-process odor also results from an assortment of organic sulfur compounds, all of which have extremely low odor thresholds. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignin. These compounds are emitted from many points within a mill; however, the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally employed in kraft mills, control of reduced sulfur compounds can be accomplished by process modifications and by optimizing operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Noncondensable odorous gases vented from the digester/blow tank system and multiple-effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Optimum operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen residual and turbulence, significantly reduces emissions of reduced sulfur compounds from this source. In addition, the use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions. The effect of any of these modifications on a given mill's emissions will vary considerably.

Several new mills have incorporated recovery systems that eliminate the conventional direct contact evaporators. In one system, preheated combustion air rather than flue gas provides direct contact evaporation. In the other, the multiple-effect evaporator system is extended to replace the direct contact evaporator altogether. In both of these systems, reduced sulfur emissions from the recovery furnace/direct contact evaporator reportedly can be reduced by more than 95 percent from conventional uncontrolled systems.

Sulfur dioxide emissions result mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs 50 to 80 percent of these emissions; further scrubbing, if employed, can reduce them another 10 to 20 percent.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Some nitrogen oxides are also emitted from the recovery furnace and lime kilns although the amounts are relatively small. Indications are that nitrogen oxides emissions from each of these sources are on the order of 1 pound per air-dried ton (0.5 kg/air-dried MT) of pulp produced.^{5,6}

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels used are coal, oil, natural gas, or bark/wood waste. Emission factors for boilers are presented in Chapter 1.

Table 10.1.2-1 presents emission factors for a conventional kraft mill. The most widely used particulate controls devices are shown along with the odor reductions resulting from black liquor oxidation and incineration of noncondensable off-gases.

10.1.3 Acid Sulfite Pulping

10.1.3.1 Process Description^{1,7,14-16}—The production of acid sulfite pulp proceeds similarly to kraft pulping except that different chemicals are used in the cooking liquor. In place of the caustic solution used to dissolve the lignin in the wood, a sulfurous-acid base is employed. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium, or ammonium is used.

Because of the variety of bases employed in the cooking liquor, numerous schemes for heat and/or chemical recovery have evolved. In calcium-base systems, which are used mostly in older mills, chemical recovery is not practical, and the spent liquor is usually discarded. In ammonium-base operations, heat can be recovered from the spent liquor through combustion, but the ammonium base is consumed in the process. In sodium- or magnesium-base operations (the latter being utilized most frequently in newer sulfite mills) heat, sulfur, and base recovery are all feasible.

When recovery is practiced, the spent liquor proceeds through a multiple-effect evaporator and recovery furnace arrangement similar to that found in the kraft process. The combustion gases from the furnace pass through absorbing (sulfiting) towers where sulfur dioxide is recovered (as bisulfite) for use in subsequent cooks. In magnesium- or sodium-base operations, moreover, the base can also be recovered by feeding the inorganic residue from the furnace (either as smelt or collected ash) into the absorbing tower to react with the sulfur dioxide.

10.1.3.2 Emission and Controls^{1,3,7,14-16}—Significant quantities of particulate emissions will be generated only if sodium-, magnesium-, or calcium-base liquors are burned. When ammonium-base liquor is burned, few particulates will result because the combustion products are mostly nitrogen, water vapor, and sulfur dioxide. In magnesium-base recovery systems, high particulate control is necessary because most of the base is swept out of the furnace in the form of magnesium oxide fumes. No particulate emissions will result from these systems, of course, when the spent liquor is not combusted.

The major gaseous pollutant is sulfur dioxide. Major potential sources, in probable order of importance, include the digester/blow tank system, absorbing towers, and multiple-effect evaporators. Because the vented gases from these systems are either scrubbed or fed into the absorbing tower to minimize sulfur losses, actual emissions to the atmosphere will depend on the degree of efficiencies desired.

The characteristic “kraft” odor is not emitted from acid sulfite mills because volatile reduced sulfur compounds are not products of the lignin-bisulfite reaction.

No factors for sulfite pulping are presented because of the variety of pulping schemes employed and lack of adequate emissions data.

10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping

10.1.4.1 Process Description^{1,7,14,17}—In this process, the wood chips are cooked in a neutral solution of sodium sulfite and sodium bicarbonate. The sulfite ion reacts with the lignin in the wood, and the sodium bicarbonate

Table 10.1.2-1. EMISSION FACTORS FOR SULFATE PULPING^a
(unit weights of air-dried unbleached pulp)
EMISSION FACTOR RATING: A

Source	Type control	Particulates ^b		Sulfur dioxide (SO ₂) ^c		Carbon monoxide ^d		Hydrogen sulfide (S ^{=e})		RSH, RSR, RSSR (S ^{=e,f})	
		lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Digester relief and blow tank	Untreated ^g	—	—	—	—	—	—	0.1	0.05	1.5	0.75
Brown stock washers	Untreated	—	—	0.01	0.005	—	—	0.02	0.01	0.2	0.1
Multiple effect evaporators	Untreated ^g	—	—	0.01	0.005	—	—	0.1	0.05	0.4	0.2
Recovery boiler and direct contact evaporator	Untreated ^h	150	75	5	2.5	2 - 60	1 - 30	12 ⁱ	6 ⁱ	1 ⁱ	0.5 ⁱ
	Venturi scrubber ^j	47	23.5	5	2.5	2 - 60	1 - 30	12 ⁱ	6 ⁱ	1 ⁱ	0.5 ⁱ
	Electrostatic precipitator	8	4	5	2.5	2 - 60	1 - 30	12 ⁱ	6 ⁱ	1 ⁱ	0.5 ⁱ
	Auxiliary scrubber	3 - 15 ^k	1.5 - 7.5 ^k	3	1.5	2 - 60	1 - 30	12 ⁱ	6 ⁱ	1 ⁱ	0.5 ⁱ
Smelt dissolving tank	Untreated	5	2.5	0.1	0.05	—	—	0.04	0.02	0.4	0.2
Lime kilns	Mesh pad	1	0.5	0.1	0.05	—	—	0.04	0.02	0.4	0.2
	Untreated	45	22.5	0.3	0.15	10	5	0.5	0.25	0.25	0.125
	Scrubber	3	1.5	0.2	0.1	10	5	0.5	0.25	0.25	0.125
Turpentine condenser	Untreated	—	—	—	—	—	—	0.01	0.005	0.5	0.25
Miscellaneous sources ^l	Untreated	—	—	—	—	—	—	—	—	0.5	0.25

^aFor more detailed data on specific types of mills, consult Reference 1.

^bReferences 1, 7, 8.

^cReferences 1, 7, 9, 10.

^dReferences 6, 11. Use higher value for overloaded furnaces.

^eReferences 1, 4, 7-10, 12, 13. These reduced sulfur compounds are usually expressed as sulfur.

^fRSH-methyl mercaptan, RSR-dimethyl sulfide; RSSR-dimethyl disulfide.

^gIf the noncondensable gases from these sources are vented to the lime kiln, recovery furnace, or equivalent, the reduced sulfur compounds are destroyed.

^hThese factors apply when either a cyclonic scrubber or cascade evaporator is used for direct contact evaporation with no further controls.

ⁱThese reduced sulfur compounds (TRS) are typically reduced by 50 percent when black liquor oxidation is employed but can be cut by 90 to 99 percent when oxidation is complete and the recovery furnace is operated optimally.

^jThese factors apply when a venturi scrubber is used for direct contact evaporation with no further controls.

^kUse 15(7.5) when the auxiliary scrubber follows a venturi scrubber and 3(1.5) when employed after an electrostatic precipitator.

^lIncludes knotted vents, brownstock seal tanks, etc. When black liquor oxidation is included, a factor of 0.6(0.3) should be used.

acts as a buffer to maintain a neutral solution. The major difference between this process (as well as all semi-chemical techniques) and the kraft and acid sulfite processes is that only a portion of the lignin is removed during the cook, after which the pulp is further reduced by mechanical disintegration. Because of this, yields as high as 60 to 80 percent can be achieved as opposed to 50 to 55 percent for other chemical processes.

The NSSC process varies from mill to mill. Some mills dispose of their spent liquor, some mills recover the cooking chemicals, and some, which are operated in conjunction with kraft mills, mix their spent liquor with the kraft liquor as a source of makeup chemicals. When recovery is practiced, the steps involved parallel those of the sulfite process.

10.1.4.2 Emissions and Controls^{1,7,14,17}—Particulate emissions are a potential problem only when recovery systems are employed. Mills that do practice recovery, but are not operated in conjunction with kraft operations often utilize fluidized bed reactors to burn their spent liquor. Because the flue gas contains sodium sulfate and sodium carbonate dust, efficient particulate collection may be included to facilitate chemical recovery.

A potential gaseous pollutant is sulfur dioxide. The absorbing towers, digester/blow tank system, and recovery furnace are the main sources of this pollutant with the amounts emitted dependent upon the capability of the scrubbing devices installed for control and recovery.

Hydrogen sulfide can also be emitted from NSSC mills using kraft-type recovery furnaces. The main potential source is the absorbing tower where a significant quantity of hydrogen sulfide is liberated as the cooking liquor is made. Other possible sources include the recovery furnace, depending on the operating conditions maintained, as well as the digester/blow tank system in mills where some green liquor is used in the cooking process. Where green liquor is used, it is also possible that significant quantities of mercaptans will be produced. Hydrogen sulfide emissions can be eliminated if burned to sulfur dioxide prior to entering the absorbing systems.

Because the NSSC process differs greatly from mill to mill, and because of the scarcity of adequate data, no emission factors are presented.

References for Section 10.1

1. Hendrickson, E. R. et al. Control of Atmospheric Emissions in the Wood Pulping Industry. Vol. I. U.S. Department of Health, Education and Welfare, PHS, National Air Pollution Control Administration, Washington, D.C. Final report under Contract No. CPA 22-69-18. March 15, 1970.
2. Britt, K. W. Handbook of Pulp and Paper Technology. New York, Reinhold Publishing Corporation, 1964. p. 166-200.
3. Hendrickson, E. R. et al. Control of Atmospheric Emissions in the Wood Pulping Industry. Vol. III. U.S. Department of Health, Education, and Welfare, PHS, National Air Pollution Control Administration, Washington, D.C. Final report under Contract No. CPA 22-69-18. March 15, 1970.
4. Walther, J. E. and H. R. Amberg. Odor Control in the Kraft Pulp Industry. Chem. Eng. Progress. 66:73-80, March 1970.
5. Galeano, S. F. and K. M. Leopold. A Survey of Emissions of Nitrogen Oxides in the Pulp Mill. TAPPI. 56(3):74-76, March 1973.
6. Source test data from the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 1972.

7. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/1-73-002. September 1973.
8. Blosser, R. O. and H. B. Cooper. Particulate Matter Reduction Trends in the Kraft Industry. NCASI paper, Corvallis, Oregon.
9. Padfield, D. H. Control of Odor from Recovery Units by Direct-Contact Evaporative Scrubbers with Oxidized Black-Liquor. TAPPI. 56:83-86, January 1973.
10. Walther, J. E. and H. R. Amberg. Emission Control at the Kraft Recovery Furnaces. TAPPI. 55(3):1185-1188, August 1972.
11. Control Techniques for Carbon Monoxide Emissions from Stationary Sources. U.S. Department of Health Education and Welfare, PHS, National Air Pollution Control Administration, Washington, D.C. Publication No. AP-65. March 1970. p. 4-24 and 4-25.
12. Blosser, R. O. et al. An Inventory of Miscellaneous Sources of Reduced Sulfur Emissions from the Kraft Pulping Process. (Presented at the 63rd APCA Meeting. St. Louis. June 14-18, 1970.)
13. Factors Affecting Emission of Odorous Reduced Sulfur Compounds from Miscellaneous Kraft Process Sources. NCASI Technical Bulletin No. 60. March 1972.
14. Benjamin, M. et al. A General Description of Commercial Wood Pulping and Bleaching Processes. J. Air Pollution Control Assoc. 19(3):155-161, March 1969.
15. Whittle, D. J. Sulfite and Bisulfite Pulp Mill Recovery Systems. TAPPI. 54(7):1074-1088, July 1971.
16. Clement, J. L. and W. L. Sage. Ammonia-Base Liquor Burning and Sulfur Dioxide Recovery. TAPPI. 52(8):1449-1455, August 1969.
17. Galeano, S. F. and B. M. Dillard. Process Modifications for Air Pollution Control in Neutral Sulfite Semi-Chemical Mills. J. Air Pollution Control Assoc. 22(3):195-199, March 1972.

10.2 PULPBOARD

10.2.1 General¹

Pulpboard manufacturing involves the fabrication of fibrous boards from a pulp slurry. This includes two distinct types of product, paperboard and fiberboard. Paperboard is a general term that describes a sheet 0.012 inch (0.30 mm) or more in thickness made of fibrous material on a paper-forming machine.² Fiberboard, also referred to as particle board, is thicker than paperboard and is made somewhat differently.

There are two distinct phases in the conversion of wood to pulpboard: (1) the manufacture of pulp from raw wood and (2) the manufacture of pulpboard from the pulp. This section deals only with the latter as the former is covered under the section on the wood pulping industry.

10.2.2 Process Description¹

In the manufacture of paperboard, the stock is sent through screens into the head box, from which it flows onto a moving screen. Approximately 15 percent of the water is removed by suction boxes located under the screen. Another 50 to 60 percent of the moisture content is removed in the drying section. The dried board then enters the calendar stack, which imparts the final surface to the product.

In the manufacture of fiberboard, the slurry that remains after pulping is washed and sent to the stock chests where sizing is added. The refined fiber from the stock chests is fed to the head box of the board machine. The stock is next fed onto the forming screens and sent to dryers, after which the dry product is finally cut and fabricated.

10.2.3 Emissions¹

Emissions from the paperboard machine consist mainly of water vapor; little or no particulate matter is emitted from the dryers.³⁻⁵ Particulates are emitted, however, from the fiberboard drying operation. Additional particulate emissions occur from the cutting and sanding operations, but no data are available to estimate these emissions. Emission factors for pulpboard manufacturing are shown in Table 10.2-1.

**Table 10.2-1. PARTICULATE EMISSION FACTORS FOR
PULPBOARD MANUFACTURING^a
EMISSION FACTOR RATING: E**

Type of product	Emissions	
	lb/ton	kg/MT
Paperboard	Neg	Neg
Fiberboard ^b	0.6	0.3

^aEmission factors expressed as units per unit weight of finished product.

^bReference 1.

References for Section 10.2

1. Air Pollutant Emission Factors. Resources Research, Inc., Reston, Virginia. Prepared for National Air Pollution Control Administration, Washington, D.C. under Contract No. CPA-22-69-119. April 1970.
2. The Dictionary of Paper. New York, American Paper and Pulp Association, 1940.

3. Hough, G. W. and L. J. Gross. Air Emission Control in a Modern Pulp and Paper Mill. Amer. Paper Industry. 51:36, February 1969.
4. Pollution Control Progress. J. Air Pollution Control Assoc. 17:410, June 1967.
5. Private communication between I. Gellman and the National Council of the Paper Industry for Clean Air and Stream Improvement. New York, October 28, 1969.

10.3.1 Process Description¹

Plywood is a material made of several thin wood veneers bonded together with an adhesive. Its uses are many and include wall sidings, sheathing, roof-decking, concrete-formboards, floors, and containers.

During the manufacture of plywood, incoming logs are sawed to desired length, debarked, and then peeled into thin, continuous veneers of uniform thickness. (Veneer thicknesses of 1/45 to 1/5 inch are common.) These veneers are then transported to special dryers where they are subjected to high temperatures until dried to a desired moisture content. After drying, the veneers are sorted, patched, and assembled in layers with some type of thermosetting resin used as the adhesive. The veneer assembly is then transferred to a hot press where, under pressure and steam heat, the plywood product is formed. Subsequently, all that remains is trimming, sanding, and possibly some sort of finishing treatment to enhance the usefulness of the plywood.

10.3.2 Emissions^{2,3}

The main sources of emissions from plywood manufacturing are the veneer drying and sanding operations. A third source is the pressing operation although these emissions are considered minor.

The major pollutants emitted from veneer dryers are organics. These consist of two discernable fractions: (1) condensibles, consisting of wood resins, resin acids, and wood sugars, which form a blue haze upon cooling in the atmosphere, and (2) volatiles, which are comprised of terpenes and unburned methane—the latter occurring when gas-fired dryers are employed. The amounts of these compounds produced depends on the wood species dried, the drying time, and the nature and operation of the dryer itself. In addition, negligible amounts of fine wood fibers are also emitted during the drying process.

Sanding operations are a potential source of particulate emissions. It is estimated that about 1,000 pounds of sanderdust may result for every 10,000 square feet of plywood produced. Hence, even if only a fraction of this is discharged to the atmosphere, an air pollution problem may exist. Few data exist to determine the actual magnitude of these emissions although efficient cyclonic collectors reportedly remove large portions of this dust.

Emission factors for plywood veneer dryers without controls are given in Table 10.3-1.

Table 10.3-1. EMISSION FACTORS FOR PLYWOOD MANUFACTURING
EMISSION FACTOR RATING: B

Source	Organic compounds ^{a,b}			
	Condensible		Volatile	
	lb/10 ⁴ ft ²	kg/10 ³ m ²	lb/10 ⁴ ft ²	kg/10 ³ m ²
Veneer dryers	3.6	1.9	2.1	1.1

^aEmission factors expressed in pounds of pollutant per 10,000 square feet of 3/8-in. plywood produced (kilograms per 1,000 square meters on a 1-cm basis).

^bReferences 2 and 3.

References for Section 10.3

1. Hemming, C. B. Encyclopedia of Chemical Technology. 2nd Ed. Vol. 15. New York, John Wiley and Sons, 1968. p.896-907.
2. Monroe, F. L. et al. Investigation of Emissions from Plywood Veneer Dryers. Final Report. Washington State University, Pullman, Washington. Prepared for the Plywood Research Foundation and the U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. APTD-1144. February 1972.
3. Mick, Allen and Dean McCargar. Air Pollution Problems in Plywood, Particleboard, and Hardboard Mills in the Mid-Willamette Valley. Mid-Willamette Valley Air Pollution Authority, Salem Oregon. March 24, 1969