STUDY OF TECHNICAL AND COST INFORMATION

FOR

GAS CLEANING EQUIPMENT

IN THE

LIME

AND

SECONDARY NON-FERROUS METALLURGICAL INDUSTRIES

INDUSTRIAL GAS CLEANING INSTITUTE, INC.
RYE, NEW YORK

INDUSTRIAL GAS CLEANING INSTITUTE, INC.

Contract No. CPA 70-150

STUDY OF TECHNICAL AND COST INFORMATION FOR GAS CLEANING EQUIPMENT IN THE LIME AND SECONDARY NON-FERROUS METALLURGICAL INDUSTRIES

FINAL REPORT

(Submitted December 31, 1970)

by

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Prepared for

The National Air Pollution Control Administration

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INDUSTRIAL GAS CLEANING INSTITUTE, INC.

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MEMBERS

STATEMENT OF PURPOSES

The Industrial Gas Cleaning Institute, incorporated in 1960 in the State of New York, was founded to further the interests of manufacturers of air pollution control equipment, by

encouraging the general improvement of engineering and technical standards in the manufacture, installation, operation, and performance of equipment

disseminating information on air pollution; the effect of industrial gas cleaning on public health; and general economic; social, scientific, technical, and governmental matters affecting the industry, together with the views of the members thereon; and

promoting the industry through desirable advertising and publicity.

ACKNOWLEDGEMENT

The efforts of the IGCI Engineering Standards Committee in the preparation, editing and reviewing of this Report are gratefully acknowledged:

Harry Krockta, Chairman, The Ducon Company, Inc.
G. L. Brewer, UOP Air Correction Division
C. A. Gallaer, Buell Engineering Co., Inc.
N. D. Phillips, Fuller Co., Dracco Products
E. P. Stastny, Koppers Company, Inc.

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I. INTRODUCTION

The Industrial Gas Cleaning Institute (IGCI) is an association of manufacturers which was created primarily to serve manufacturers of industrial gas cleaning equipment; but like any organization with a worthwhile purpose, its efforts are beneficial to others.

Its activities to develop and improve standards help the entire gas cleaning industry. Its work with technical committees of other associations benefits other industries. Its cooperation with government agencies simplifies their tasks.

Under this contract, members of the IGCI collected and formalized information on air pollution control for processes in the lime and secondary non-ferrous smelting industries. The specific process areas covered are:

(1) Rotary Lime Kilns (other than those in paper mills)
(2) Brass and Bronze Reverberatory Furnaces
(3) Lead Cupolas
(4) Lead and Aluminum Sweating
(5) Lead Reverberatory Furnaces
(6) Zinc Calcination
(7) Aluminum Chlorination

Three specific kinds of information are included:

(1) Narrative descriptions of the processes in question, the associated air pollution control equipment, and the problems special to the processes.

(2) The preparation of specifications and cost estimates for equipment to serve each of the specified processes.

(3) A tabulation of the past installations, and all of the available test data for each of these industries after January 1, 1960.

All of the data has been collected and summarized, and should serve as a valuable guide to the air pollution abatement methods useful in these industries, and to the costs of air pollution abatement.

The industrial areas covered vary from well-defined processes for which good air pollution control systems are routinely available — for rotary lime kilns — to relatively obscure processes for which there is no established approach, as is true of zinc calcination in the secondary metals industry.

Good test data is available in some areas; however, for many small furnace applications, inexpensive fabric filters are supplied on the basis of good practical experience, and little test data has been accumulated.

Little relationship exists between the lime industry and the secondary smelting industries. These were lumped together in this contract as a matter of convenience in the overall NAPCA program. Lime producers use native limestone, oyster shells, and other calcium-rich natural materials to make quicklime. The product is sold for use in steel making, agriculture and basic chemical manufacture. Secondary smelters process scrap metals to reclaim valuable components which can be resold at a profit.

There is a close relationship between lime manufacture for the uses included in this contract and lime sludge reburning for paper mills. Lime sludge is produced in Kraft mills during the paper making process. This material is calcined or "burned" in a kiln similar to that used for agricultural or metallurgical lime, and requires similar air pollution control equipment. A number of member companies initially reported paper mill applications for inclusion in this report because of these similarities. These have been eliminated from this study.

There were also some points of confusion in the smelting industries because of similarities between secondary processes and similar primary smelting applications. This was true of the aluminum chlorination application, and particularly of zinc calcination. Most of the latter applications reported by members turned out to be primary production of zinc oxide. Again, reports were carefully screened to limit applications described to those actually within the definition of the program.

The industrial areas covered comprise a very limited section of the total air pollution control market. Of the 29 member companies, only nine were identified as actively involved in servicing these industries. Most of these companies had applications and experience with rotary lime kilns, while none were actively involved in zinc calcination process air pollution control. The limited experience of the member companies in secondary smelting (as opposed to utility power production or ferrous smelting, for example) appears to relate to the small size and diversity of the secondary smelting applications rather than to the lack of need for air pollution control equipment.

The program was carried out over a six month period beginning on July 1, 1970 and terminating with the submission of this report draft on December 31, 1970. Several milestones in the progress of the program were identified during the initial planning stages as follows:

Event	Date
Completion of Work Plan	July 31, 1970
Completion of Progress Reports:	
Progress Report No. 1	July 31, 1970
Progress Report No. 2	August 31, 1970
Progress Report No. 3	September 30, 1970
Progress Report No. 4	October 30, 1970
Final Report Draft Submission	November 30, 1970

Although the time period was shorter than optimum for a program involving coordination of the activities of a large group of companies, these steps were completed in the allotted time. This required careful planning of the details of the program and good cooperation of the member companies involved. Appendix I describes the program planning and execution in some detail.

II. SUMMARY OF TECHNICAL DATA

This study contains six process descriptions for the process areas covered. These descriptions combine published material and first-hand experience gained by the member companies in servicing the industries involved.

Ten equipment specifications were written for air pollution control equipment. Each of these described a typical installation and specified two levels of performance for each of three equipment sizes. In all, 60 price quotations were requested. In addition to the technical specifications for the air pollution control equipment, generally acceptable terms and conditions are specified. These specifications are based almost entirely on the experience of the member companies. They contain several significant items of technical interest for each application, including:

A. Gas flow vs. furnace size relationship

B. Gas conditions and properties at the collector inlet

C. Selected minimum quality conditions for some collectors

D. Efficiency levels and grain loadings for good collection (LA-Process Weight) and very good collection (High Efficiency).

Probably the most significant information presented is the cost figures generated in response to the specifications. These pertain to all 60 specifications, and give figures for the collection equipment only, the total equipment, and the complete turnkey installation. These quotations are based entirely on the background of the IGCI members in designing, building, and installing equipment of the types specified.

This cost data was presented in three ways for convenience in estimating costs at sizes other than those specified:

A. Graphically, on log - log plots of cost vs. furnace size

B. Algebraically by fitting a power formula to the cost — furnace size relationship, and

C. Algebraically in terms of cost per SCFM.

In addition to the first costs of equipment, the maintenance costs were estimated for each of the cases specified, and the operating horsepower was estimated. From these figures, the total annual cost method (or any other sound method) can be used to compare the economics of alternative equipment types for the general conditions of this study. Caution is recommended in using these numbers for specific applications rather than estimates tailored to the conditions of the installation in question.

The installations made by the IGCI member companies since January 1, 1960 were reported and are tabulated. A total of 153 installations were reported, as follows:

Rotary Lime Kilns	79
Brass/Bronze Reverberatory Furnaces	16
Lead Cupolas	11
Lead/Aluminum Sweating Furnaces	18
Lead Reverberatory Furnaces	17
Zinc Calcination Furnaces	6
Aluminum Chlorination Stations	6
	153

Of these, the distribution among equipment types was:

	Electrostatic Precipitators	Fabric Collectors	Wet Scrubbers	Mechanical Collectors
Rotary Lime Kilns	5	18	35	21
Brass/Bronze	–	9	6	1
Lead Cupolas	–	10	1	–
Sweating Furnaces	–	12	6	–
Lead Reverb.	–	17	–	–
Zinc Calcination	–	5	1	–
Aluminum Chlor.	–	–	6	–
	5	71	55	22

Relatively good test data was reported for the rotary lime kilns. However, little test information was available for the other applications.

III. TECHNICAL DATA

This section contains all of the data relative to process requirements, typical specifications, costs, and existing installations of air pollution control equipment. This information was generated by the members of the Industrial Gas Cleaning Institute who have been active in supplying equipment in the lime and secondary non-ferrous metals areas. Editing of this material was done only to bring it together in a consistent form for ease of reference.

A. GENERAL DESCRIPTION

The format used for presentation of the collected information was chosen to provide a reasonably smooth progression from general descriptive material to specific examples of equipment specification and price data for each of the industrial segments represented in the study. For each area, the following sequence is used in Section B.

1. Description of the process
    a. Manufacturing aspects
    b. Air pollution control equipment
2. Specifications and Costs
    a. Electrostatic precipitators
    b. Wet Scrubbers
    c. Fabric Collectors
3. Summary comments

The data is presented, in turn for each of the industrial process segments, and an overall summary is presented in Section C. Installations completed since January 1, 1960 by the IGCI member companies are tabulated in Section D.

Several points arose during the preparation of this material which merit some detailed comment. These involve:

1. Selection of applicable equipment types
2. Selection of companies best qualified to write narratives, specifications and prepare proposals

3. Selection of emission levels for equipment specifications and bids

4. Basis for preparing specifications and bid prices

These points will be covered in turn in the following paragraphs.

1. SELECTION OF APPLICABLE EQUIPMENT TYPES

In general the processes covered by this study are equipped (or should be equipped) with devices for the removal of particulate matter from the effluent discharged into the air. In some cases, there is also a requirement for removal of a noxious gas such as carbon monoxide from a lead smelting cupola. Usually the gaseous pollutant control devices are either built into the smelting furnace – as is the case for the cupola, or for smoke incinerators in reverberatory furnaces – or omitted altogether. For this reason, the air pollution control equipment considered in this study is limited to particulate collection *after* the gaseous emissions have been treated.

One exception is taken to this general rule. Aluminum chlorination stations produce a fume in which aluminum chlorides, oxides and hydroxides are emitted in a stream containing high concentrations of chlorine gas and hydrogen chloride gas. The gaseous constituents here are a major part of the air pollution problem, and they are abated by the addition of air pollution control equipment, rather than by modification of the process. In this case alone the requirements for abatement of gaseous constituents are taken into account in selecting applicable equipment types.

The emphasis on particulate control equipment in this study should not be interpreted as a bias on the part of the IGCI member companies toward particulate collection. Rather, it is an indication that the specific industrial areas covered are far more likely to require "add-on" equipment for collection of fumes and dusts than for control of gaseous emissions.

The members of the Industrial Gas Cleaning Institute work independently of each other in commercial application of their specific lines of equipment. For this reason, unanimity of opinion as to the types of equipment applicable to each of the industrial areas presented is limited to a few generalizations. These were formulated by the Engineering Standards Committee, which is the group selected by the president of IGCI to pass upon all public statements of position on technical matters. This group met in Rye, New York on August 18, 1970 and agreed upon the following:

(1) Mechanical dust collectors or cyclones would not alone be suitable collection devices for any of the specific applications covered. They are useful as *precleaners* in combination with other, more efficient collectors, and in such cases they would be considered as a part of *the dust collection system.*

(2) Electrostatic precipitators would ordinarily be suitable for collection of any of the particulate matter discharged from the subject processes if the operating conditions were chosen properly. However, the conventional single-stage precipitator is not competitive with fabric filtration or wet scrubbing on a small scale. For this reason, precipitators were listed as acceptable for only the largest application in this study, the rotary lime kiln. As development work is done on small electrostatic precipitators, the cost difference is likely to become less significant, and precipitators may find acceptance in some of the areas from which they are now excluded for reasons of high cost.

(3) For several application areas, fabric filters predominate over wet scrubbers on the basis of both cost and factors relating to the recovery of the particulate matter in dry form rather than wet. In these cases, the scrubbers may not be competitive for the average application but show cost or performance advantages in a specific circumstance. For this reason the scrubber is included for each of the areas.

(4) In the case of the aluminum chlorination station, both particulate collection and gas absorption are required to provide adequate air pollution control. This can be done only by a wet scrubber if the air pollution abatement job must be done by a single piece of equipment. Only wet scrubbing is indicated as an adequate approach, although installations involving combinations of equipment can be made with fabric filters or electrostatic precipitators.

The result of this selection is shown in Table 1, which lists the equipment types considered by the members of the Engineering Standards Committee as acceptable in each area.

2. SELECTION OF COMPANIES TO WRITE NARRATIVES, SPECIFICATIONS AND PREPARE BID PRICE PROPOSALS

The IGCI member companies furnish air pollution abatement

Table 1

DEFINITION OF COLLECTOR TYPES APPLICABLE TO

VARIOUS INDUSTRIAL AREAS

Collector Type	1. Lime Kiln	2. Brass Reverb.	3. Lead Cupola	4. Lead Sweat.	5. Lead Reverb.	6. Zinc Calcin.	4** Alum. Sweat.	7. Alum. Chlor.	2** Bronze Reverb.
Electrostatic Precipitator	Yes	No*	No*	No*	No*	***	No*	No	No*
Fabric Collector	Yes	Yes	Yes	Yes	Yes	***	Yes	No	Yes
Wet Scrubber	Yes	Yes	Yes	Yes	Yes	***	Yes	Yes	Yes

* Note that Electrostatic Precipitators are not applicable to these areas only because the sources are too small to make precipitator application economical under ordinary circumstances.

** These areas were subsequently combined with others, and eliminated from the list (Brass/Bronze and Lead/Aluminum).

*** This application is too limited to provide adequate equipment definition.

equipment for every segment of industry. However, it is unlikely that any one of the companies has covered all of the possible applications. In the limited area covered by this study, 16 Institute member companies indicated an interest in the industries covered, while 18 of the members indicated at least one past application at the beginning of the program*.

In order to assign the work on this project equitably among those members who have taken an active interest in the lime kiln or secondary metals area covered by this program, the members were surveyed for interest in participating in regard to each industrial segment, and on the number of applications of equipment made by each. The survey forms, etc. are included in Appendix I of this report. The results of these two surveys were used by the Engineering Standards Committee to select companies for participation in each area. The companies selected in each of the categories included three participants and two alternates wherever possible. In a few areas there were not five companies actively involved. The five companies are listed alphabetically in each category in Table 2.

Failure of a company to appear on this list does not necessarily indicate lack of interest or ability on the part of a particular supplier of equipment. The interest of each company in participating *in this program* was taken into account to a significant extent in selecting the companies to be involved.

A further reduction in the number of companies actually involved in preparation of the narratives, specifications and bid prices took place on the basis of availability of the member's time.

The specifications were drafted at a Seminar-Workshop session held in Detroit, Michigan on September 2 and 3, 1970. At this meeting, the basic requirements of the program were reviewed with representatives of the participating companies, and first draft specifications were prepared by groups shown in Table 3. The specification drafts prepared in Detroit were reviewed and edited by the Coordinating Engineer, and then distributed to selected companies for preparation of bid prices.

One person was selected to prepare the process description in each case, and a portion of the Detroit workshop was devoted to a technical interchange

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*It should be noted that the number here does not agree precisely with the number of companies who reported on installations during the project. Some distinctions, such as the exclusion of paper mill applications in this study, were originally overlooked.

Table 2

SELECTION OF PARTICIPANTS IN NARRATIVE AND SPECIFICATION WRITING

Lime Kiln	Brass/Bronze Reverb.	Lead Cupola	Lead/Alum. Sweat.	Lead Reverb.	Zinc Calcin.	Alum. Chlor.
American Standard	American Air Filter	American Air Filter	American Air Filter	Ducon	Buell	Fuller
Ducon	Ducon	Chemico	Buell	Fuller	Fuller	MikroPul
Fuller	Fuller	Fuller	Fuller	Research-Cottrell	Koppers	UOP
Research-Cottrell	Research-Cottrell	Research-Cottrell	Environeering			
Western Precip.	UOP					

Table 3

Participants in Specification Writing

Seminar and Workshop

Herbert R. Herington – IGCI Project Director

L. C. Hardison – IGCI Coordinating Engineer

Harry Krockta, Chairman – Engineering Standards Committee

Ralph R. Calaceto – MikroPul

E. R. Gibbs - Koppers

Raymond B. Hunter – American Air Filter Company

Morris Mennell – Koppers

Robert Peden – Western Precipitation

A. R. Pike – UOP Air Correction Division

William J. Rudy – Ducon Company

J. J. Sheehan – Buell Engineering Company

Harold Treichler – Fuller Company

Robert J. Wright – Fuller Company

between the participants. The individuals selected to prepare the narratives are listed in Table 4.

The narrative drafts were prepared subsequent to the Detroit Workshop and were then edited by the Coordinating Engineer and reviewed by all the participants in the industry group prior to the final draft.

3. SELECTION OF EMISSION LEVELS FOR EQUIPMENT SPECIFICATIONS AND BIDS

The degree of reduction in the amount of dust discharged into the air has a large influence over the design and the cost of wet scrubbing and electrostatic precipitation equipment. The cost of these increases sharply as efficiency requirements approach 100%. Costs of fabric filters, on the other hand, are not very sensitive to the efficiency level specified.

In order to make a reasonable comparison between the three alternatives, it is necessary to establish the required performance level. The local conditions surrounding a particular installation dictate the performance requirements which should be specified, and equipment should never be acquired without a thorough knowledge of the local requirements.

For the purposes of this project, two arbitrary levels of performance were established, and equipment costs prepared for each:

(a) Conformance with the present Los Angeles Air Pollution Control District process weight requirements, and

(b) Reduction to a low concentration of particulate matter which should show little or no visible color in the stack discharge.

It is emphasized that these are *arbitrary* performance levels chosen for illustrative purposes in this study. While the first efficiency level is acceptable throughout much of the United States, and the second level should be acceptable almost anywhere, no specifications for air pollution control equipment should be written without a good understanding of all of the local requirements.

Table 4

Participants in Process Narrative Writing

1. Rotary Lime Kilns
   William J. Rudy – The Ducon Company

2. Brass/Bronze Reverberatory Furnaces
   Raymond B. Hunter – American Air Filter Co.

3. Lead Cupola
   L. C. Hardison – Air Resources (for Research-Cottrell)

4. Lead/Aluminum Sweating Furnace
   Harold Treichler – Fuller Company

5. Lead Reverberatory Furnace
   L. C. Hardison – Air Resources (for Research-Cottrell)

6. Zinc Calcination
   Morris Mennell – Koppers

7. Aluminum Chlorination Station
   A. R. Pike – UOP Air Correction

The LA-Process Weight Specification is typical of many such ordinances throughout the country. It is based on an allowable emission of particulate matter which increases with process feed rate. However, the allowable emission rate in pounds per hour of particulate increases more slowly than does the feed rate to the process. Because the emission produced in most processes is proportional to the feed rate, the particulate collection efficiency must be higher for large processes than for small ones. The law also specifies an absolute maximum of 40 lb/hr of particulate matter, regardless of process size, so that very large process units must have very efficient collection devices. Most of the processes covered by this study are relatively small in terms of total feed rate, and the 40 lb/hr maximum emission level is not usually applicable for the lime kilns or secondary smelters.

A list of allowable emission rates under the LA-Process Weight regulation is given in Table 5. A more detailed version of Rule 54 of the Air Pollution Control District of Los Angeles County is given in Appendix III.

In general, this type of regulation is easy to interpret and leads to definite, clear-cut levels of performance required for air pollution control systems, provided the rate at which particulate matter is generated by the process and the process feed rate (or process weight) are known. The particulate emission rate is best obtained by direct measurement by a qualified source test engineer or company if the process is an existing one, or obtained from the manufacturer of the furnace or kiln if the installation is in the planning stage. The process weight is the sum of all of the feed materials to the process, excluding air and liquid or gaseous fuels. The process weight ordinarily exceeds the *rated product capacity* of the equipment because it includes output product, plus losses and byproducts.

The second specification included for each of the air pollution control systems covered by this report is called the "High Efficiency" case. This is taken as an arbitrary stack grain loading (concentration of particulate matter, measured in grains per actual cubic foot) which should produce an effluent with little or no visible opacity, excluding that due to water. This grain loading is based on the best judgment of the members of the IGCI Engineering Standards Committee. The levels specified are arbitrary, and while most member companies will guarantee performance to the grain loading specified, they will not ordinarily represent or guarantee freedom from visible emissions. (Exceptions to this rule exist. A manufacturer may have an identical installation known to produce a color-free effluent and be willing to guarantee performance on this basis.) Table 6 lists the values assigned by the Engineering Standards Committee to this "High Efficiency" case.

Table 5

LA-PROCESS WEIGHT AND ALLOWANCE EMISSION

*Process Wt/hr(lbs)	Maximum Weight Disch/hr(lbs)	*Process Wt/hr(lbs)	Maximum Weight Disch/hr(lbs)
50	.24	3400	5.44
100	.46	3500	5.52
150	.66	3600	5.61
200	.85	3700	5.69
250	1.03	3800	5.77
300	1.20	3900	5.85
350	1.35	4000	5.93
400	1.50	4100	6.01
450	1.63	4200	6.08
500	1.77	4300	6.15
550	1.89	4400	6.22
600	2.01	4500	6.30
650	2.12	4600	6.37
700	2.24	4700	6.45
750	2.34	4800	6.52
800	2.43	4900	6.60
850	2.53	5000	6.67
900	2.62	5500	7.03
950	2.72	6000	7.37
1000	2.80	6500	7.71
1100	2.97	7000	8.05
1200	3.12	7500	8.39
1300	3.26	8000	8.71
1400	3.40	8500	9.03
1500	3.54	9000	9.36
1600	3.66	9500	9.67
1700	3.79	10000	10.0
1800	3.91	11000	10.63
1900	4.03	12000	11.28
2000	4.14	13000	11.89
2100	4.24	14000	12.50
2200	4.34	15000	13.13
2300	4.44	16000	13.74
2400	4.55	17000	14.36
2500	4.64	18000	14.97
2600	4.74	19000	15.58
2700	4.84	20000	16.19
2800	4.92	30000	22.22
2900	5.02	40000	28.3
3000	5.10	50000	34.3
3100	5.18	60000	40.0
3200	5.27	or	
3300	5.36	more	

*See Definition in Rule 2(j).

Table 6

Definition of Outlet Grain Loadings For

High Efficiency Level Bids

	Outlet Loading gr/ACF
Rotary Lime Kilns	0.03
Brass Reverberatory Furnaces	0.01
Lead Cupolas	0.03
Lead Sweating Furnaces	0.03
Lead Reverberatory Furnaces	0.01
Zinc Calcination Furnaces	0.01
Aluminum Sweating Furnaces	0.03
Aluminum Chlorination Stations	0.02
Bronze Reverberatory Furnaces	0.03

This table shows these loadings in gr/ACF at the stack discharge because they correlate with the opacity of the plume better than gr/SCF. Most frequently, measurements of particulate loading are reported in gr/SCF and the conversion of this value to gr/ACF should not be overlooked. Also, it should be noted that very large diameter stacks are likely to show a more visible plume at the same grain loading than small stacks.

4. BASIS FOR PREPARING SPECIFICATIONS AND BID PRICES

Several simplicications were made in the preparation of the specifications which have some bearing on the results which are reported here. These should be kept in mind when using the prices, operating costs, etc.

The form of the specification for equipment may have an influence over the price quoted. Overly-restrictive specifications may add 5 - 10% to the equipment price without a corresponding increase in value received by the purchaser. In each of the cases presented in this report, prices are based on a specification which covers most of the conditions of purchase in an equitable way. Instead of writing each specification independently, the participants in the Detroit workshop agreed upon the general terms and conditions to be specified, and these conditions were made identical for each specification. The final specification in each case was made by inserting one page of descriptive material and one page of operating conditions pertaining to the specific application into the standard format. To avoid unnecessary repetition, a sample of the complete specification for one of the six applications is included as Appendix IV to this report. Only the pages pertinent to specific applications are contained in the body of the report.

Prices were requested in such a way as to indicate three bases:

(a) Air pollution control *device*. This includes only the flange-to-flange precipitator, fabric collector, or scrubber.

(b) Air pollution control *system* equipment. This includes major items such as fans, pumps, etc.

(c) Complete turnkey installation. This includes the design, all materials and equipment and startup.

In order to maintain a consistent approach to quoting in each area, the specifications were written around the air pollution control *device.* The process description was, however, made general enough to allow the members to quote on the auxiliary equipment, such as fans, pumps, solid handling devices, etc., and to quote on an approximate installation cost. A complete set of instructions for preparing specifications and for quoting are given in Appendix II and Appendix V.

Labor costs are a variable from one location to another, and it was not possible to establish the complex pattern of variations in turnkey prices which occurs as a function of local variations in hourly rate, productivity and availability of construction tradesmen. In order to provide a consistent basis for the preparation of price quotations, the cost indices given in Table 7 were used. This was taken from "Building Construction Cost Data, 1970".* This gives a construction cost index for 90 cities, using 100 to represent the national average. These figures are for the building trades, but they should be representative of field construction rates in general.

These figures do not take productivity differences into account and may understate the variations in cost from one city to another.

The participating companies were instructed to estimate the installation costs as though erection or installation of the system would be in Milwaukee, Wisconsin or another city relatively convenient to the participants point of shipment with a labor rate near 100. Readers are cautioned to take local labor rates *and productivity* into account when making first estimates of air pollution control system installed costs based on the data in this report. Table 8 shows the tabulated hourly rates for various construction trades (based on national averages) which may be useful for this purpose.*

B. NARRATIVE DESCRIPTIONS AND COSTS

The following sections include all of the descriptive and cost data developed by the participating member companies. A separate section is devoted to each of the application areas:

1. Rotary Lime Kilns (other than paper mill)
2. Brass/Bronze Reverberatory Furnaces
3. Lead Cupolas
4. Lead/Aluminum Sweating Furnaces

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*Godfrey, Robert Sturgis, "Building Construction Cost Data," Robert Snow Means Co., Inc., Box G, Duxbury, Mass. 02332

5. Lead Reverberatory Furnaces

6. Zinc Calcination Furnaces

7. Aluminum Chlorination Stations

Past installation data is collected in a separate section, with a discussion of the application pattern.

Table 7

CITY COST INDICES

Average 1969 Construction Cost & Labor Indexes						Historical Average	
	Index			Index		Year	Index
City	Labor	Total	City	Labor	Total	1969	100
Albany, N.Y.	98	100	Milwaukee, Wi.	103	108	1968	91
Albuquerque, N.M.	86	95	Minneapolis, Mn.	99	98	1967	86
Amarillo, Tx.	87	84	Mobile, Al.	94	90	1966	83
Anchorage, Ak.	131	148	Montreal, Cn.	77	89	1965	79
Atlanta, Ga.	88	94	Nashville, Tn.	79	82	1964	78
Baltimore, Md.	90	93	Newark, N.J.	122	109	1963	76
Baton Rouge, La.	83	88	New Haven, Ct.	102	100	1962	74
Birmingham, Al.	79	86	New Orleans, La.	89	95	1961	72
Boston, Ma.	106	103	New York, N.Y.	132	118	1960	71
Bridgeport, Ct.	104	102	Norfolk, Va.	73	77	1959	69
Buffalo, N.Y.	104	107	Oklahoma City, Ok.	82	88	1958	67
Burlington, Vt.	86	90	Omaha, Nb.	90	93	1957	65
Charlotte, N.C.	70	75	Philadelphia, Pa.	106	101	1956	63
Chattanooga, Tn.	81	84	Phoenix, Az.	101	97	1955	59
Chicago, Ill.	107	103	Pittsburgh, Pa.	110	106	1954	58
Cincinnati, Oh.	108	104	Portland, Me.	82	87	1953	57
Cleveland, Oh.	121	112	Portland, Or.	102	103	1952	55
Columbus, Oh.	106	99	Providence, R.I.	98	97	1951	53
Dallas, Tx.	86	89	Richmond, Va.	76	79	1950	49
Dayton, Oh.	100	103	Rochester, N.Y.	110	107	1949	48
Denver, Co.	94	91	Rockford, Ill.	109	109	1948	48
Des Moines, Ia.	93	96	Sacramento, Ca.	117	110	1947	43
Detroit, Mi.	117	111	St. Louis, Mo.	110	103	1946	35
Edmonton, Cn.	80	83	Salt Lake City, Ut.	93	95	1945	30
El Paso, Tx.	77	83	San Antonio, Tx.	82	82	1944	29
Erie, Pa.	98	99	San Diego, Ca.	111	107	1943	29
Evansville, In.	93	97	San Francisco, Ca.	124	109	1942	28
Grand Rapids, Mi.	103	99	Savannah, Ga.	72	77	1941	25
Harrisburg, Pa.	90	92	Scranton, Pa.	94	96	1940	24
Hartford, Ct.	104	100	Seattle, Wa.	104	99	1939	23
Honolulu, Hi.	99	109	Shreveport, La.	82	89	1938	23
Houston, Tx.	92	89	South Bend, In.	99	97	1937	23
Indianapolis, In.	97	98	Spokane, Wa.	101	100	1936	20
Jackson, Ms.	73	75	Springfield, Ma.	99	97	1935	20
Jacksonville, Fl.	78	79	Syracuse, N.Y.	105	103	1934	20
Kansas City, Mo.	94	93	Tampa, Fl.	81	84	1933	18
Knoxville, Tn.	82	82	Toledo, Oh.	105	105	1932	17
Las Vegas, Nv.	115	107	Toronto, Cn.	84	93	1931	20
Little Rock, Ar.	78	81	Trenton, N.J.	114	103	1930	22
Los Angeles, Ca.	113	102	Tulsa, Ok.	85	89	1929	23
Louisville, Ky.	92	93	Vancouver, Cn.	81	91	1928	23
Madison, Wi.	95	98	Washington, D.C.	98	94	1927	23
Manchester, N.H.	89	92	Wichita, Ks.	85	90	1926	23
Memphis, Tn.	83	82	Winnipeg, Cn.	62	82	1925	23
Miami, Fl.	98	94	Youngstown, Oh.	107	106	1924	23

Table 8

AVERAGE HOURLY LABOR RATES BY TRADE

Trade	1970	1969	1968	1967	1966
Common Building Labor	$5.00	$4.55	$4.10	$3.85	$3.65
Skilled Average	6.85	6.05	5.50	5.15	4.90
Helpers Average	5.15	4.65	4.20	4.00	3.85
Foremen (usually 35¢ over trade)	7.20	6.40	5.85	5.50	5.25
Bricklayers	7.15	6.40	5.85	5.55	5.35
Bricklayers Helpers	5.20	4.70	4.30	4.05	3.95
Carpenters	6.95	6.15	5.40	5.10	4.90
Cement Finishers	6.75	5.90	5.30	5.05	4.85
Electricians	7.50	6.45	5.95	5.60	5.45
Glaziers	6.25	5.50	5.10	4.75	4.60
Hoist Engineers	7.05	5.90	5.40	5.10	4.85
Lathers	6.60	5.95	5.45	5.20	5.05
Marble & Terrazzo Workers	6.45	5.60	5.25	5.05	4.90
Painters, Ordinary	6.20	5.45	5.05	4.75	4.50
Painters, Structural Steel	6.50	5.80	5.30	4.95	4.80
Paperhangers	6.30	5.60	5.15	4.75	4.55
Plasterers	6.60	5.95	5.50	5.15	5.00
Plasterers Helpers	5.30	4.85	4.45	4.15	4.00
Plumbers	7.75	6.90	6.15	5.75	5.55
Power Shovel or Crane Operator	7.20	6.20	5.65	5.35	5.05
Rodmen (Reinforcing)	7.30	6.35	5.80	5.45	5.15
Roofers, Composition	6.30	5.55	5.05	4.75	4.65
Roofers, Tile & Slate	6.35	5.60	5.10	4.85	4.80
Roofers Helpers (Composition)	4.75	4.45	4.00	3.75	3.55
Steamfitters	7.70	6.90	6.10	5.70	5.50
Sprinkler Installers	7.70	6.90	6.10	5.70	5.50
Structural Steel Workers	7.45	6.45	5.90	5.55	5.25
Tile Layers (Floor)	6.50	5.60	5.20	4.90	4.80
Tile Layers Helpers	5.25	4.80	4.35	4.15	4.05
Truck Drivers	5.15	4.60	4.30	3.95	3.65
Welders, Structural Steel	7.15	6.35	5.80	5.45	5.10

1. AIR POLLUTION CONTROL FOR ROTARY LIME KILNS

a. PROCESS DESCRIPTION

1) MANUFACTURING ASPECTS

On the basis of the best estimates available, 80-90% of lime production in the U. S. is in rotary kilns. The kiln is a furnace made of steel lined with refractory brick, and fired by any one of three available fuels; natural gas, pulverized coal or oil, or by a combination of these fuels.

The raw materials for lime manufacturing are essentially calcium carbonate (limestone) or calcium magnesium carbonate (dolomite or dolomitic limestone), with varied amounts of impurities. If the magnesium-carbonate is less than 5%, the limestone is referred to as high calcium. If the magnesium-carbonate content is 30-40%, it is referred to as dolomitic limestone. Lime is produced by heating sized limestone to decompose the carbonate releasing CO_2 and leaving the calcium oxide as the product. During the heating process, moisture and volatile organic matter are driven off. Then at higher temperatures decomposition of the carbonate begins. Rotary lime kilns are basically heat exchangers and conveyors. The flow of stone and combustion products is counter-current through the kiln. Figure 1 indicates the basic flow of solids and combustion products through a kiln and the associated air pollution control equipment.

EQUIPMENT

Rotary kilns are of two basic types; the "long rotary kiln" and the "short rotary kiln with external pre-heater". (In this report, the specification was based on the "long rotary kiln".) Long rotary kilns generally have exit gases in the 1100 - 1400°F temperature range, while short rotary kilns with pre-heaters generally run between 1700 and 2100° F. For the short rotary kilns acceptable feed sizes are more limited than for the long rotary kilns. Space requirements for the pre-heater systems are less.

Pre-heater equipped kilns are particularly successful when they have contact type coolers and soaking pits. The application of pre-heater systems is limited to feed materials which do not degrade during calcining.

Rotary kilns are available to handle capacities from 50 tons per day (which is unusually small) up to 650 tons per day. This maximum tonnage will probably go to a much higher rate in the future although the largest

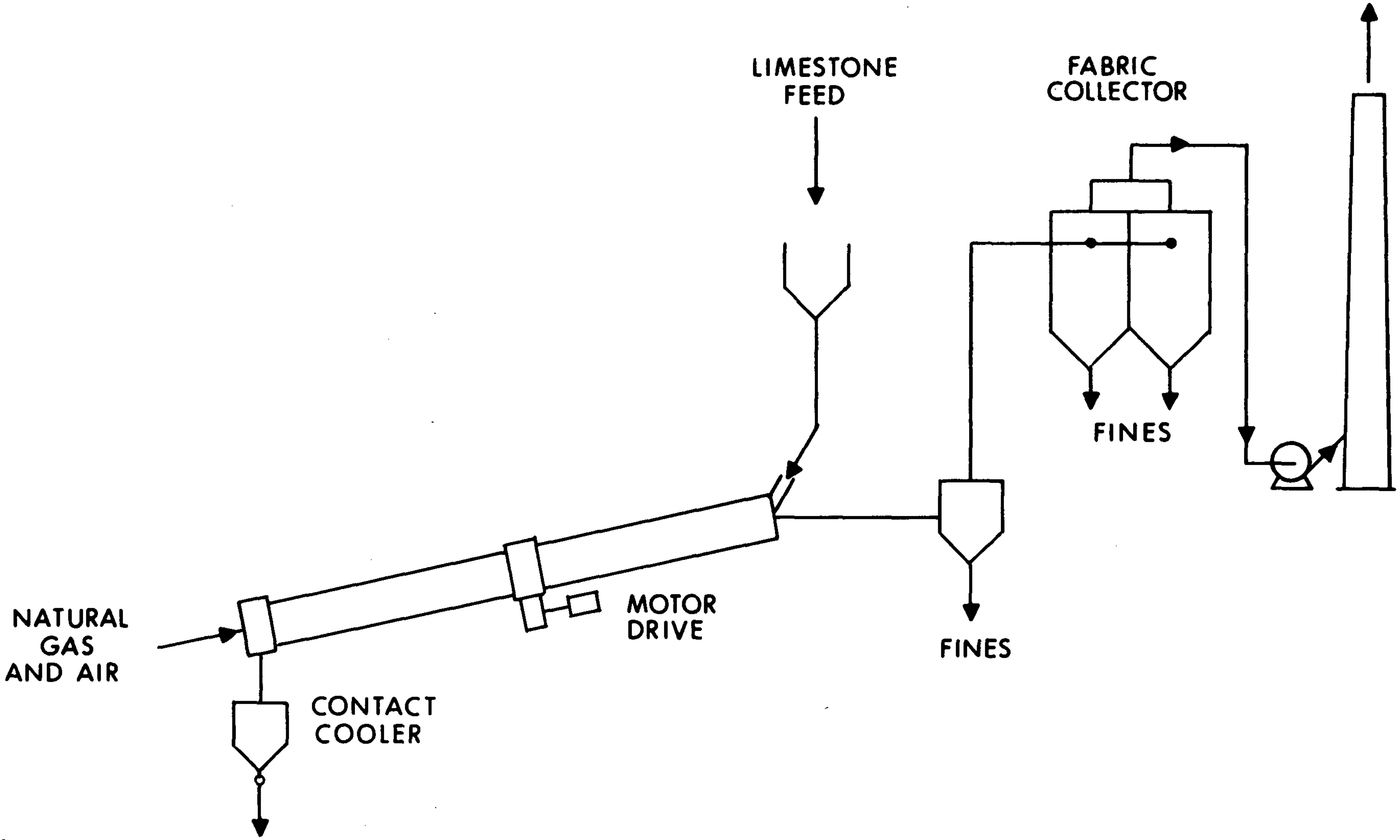


Figure 1

Process Flow Sketch for Typical Lime Kiln commercial installation at this date is 650 TPD. Kilns vary in size from 6 feet to 12 feet in diameter and up to 400 feet in length.

At the feed end of the kiln hot gases are cooled by pre-heating the stone, while at the other end the kiln discharges the lime quite hot. For this reason, product coolers are usually provided to pre-heat the combustion air. Heat efficiency may sometimes be improved through the use of chain sections and pre-heating tubes at the feed end.

As long as the feed size range is narrow and the minimum size is about 1/2", good mixing takes place in the bed and produces a very uniform lime. However this bed motion also contributes to abrasion and dust formation and gives rise to the need for efficient dust collection equipment.

The efficiency of dust collection required varies with the feed size and stone quality, as well as with discharge gas concentration limits. Large systems are generally required because gas volumes are high; tempering with air or quenching with water may be required, and both of these contribute additional gas volume. Two collection stages are common. Sludge kilns with fine feed sizes have highest dust loadings in the exit gases.

Product cooling equipment used with rotary kilns is generally of two types, either satellite coolers for finer materials or contact type coolers for coarse lime. Satellite coolers are less effective but involve less maintenance and operating costs than contact coolers. Contact coolers result in considerably better fuel consumption but have higher operating costs and headroom requirements. Rotary coolers and grate type coolers are secondary choices in the lime industry.

Although rotary kilns have a much higher fuel consumption than shaft kilns or other calcining systems, the majority of U. S. lime plants use the rotary kilns. The main reasons for the selection of rotary kilns are:

1. Can handle a wider range of feed sizes

2. Can use all three major fuels singly or in combination

3. Are easily controlled and can be fully automated

4. Can handle smaller feed sizes than shaft kilns

5. Can produce a uniform product in practically any desired quality over a

wide range of product grades. This is because of the ease of control and good mixing in the bed

6. Can operate at high capacity with great operating flexibility

There are some disadvantages, however:

1. Rotary kilns require more space, especially if they are not equipped with pre-heat systems

2. The first cost is higher than most other systems

3. They have higher fuel consumption

4. They are especially uneconomical for low capacities

5. The refractory cost is higher because of the possible movement of the refractory within the kiln shell. Stresses are imposed on the refractory which do not exist in a stationary kiln.

FEED MATERIALS

The carbonates of calcium or magnesium are obtained from deposits of limestone, marble, chalk, dolomite or oyster shells. Although limestone is the usual raw material for manufacture of lime, some of the operations use oyster shells. This is particularly true in the Gulf Coast area. Limestone deposits exist in every State in the U. S., but only a small portion is of sufficient purity for industrial use. For chemical usage, a rather pure limestone is preferred as a starting material because of the high calcium lime that results. The lower grades are generally suitable for agricultural purposes. Table 9 gives some typical feed compositions.

More than 90% of the limestone quarried is from open pit operations with the remainder from underground mines. The quarries are generally chosen which furnish a rock that contains a low percentage of impurities such as silica, clay or iron.

The limestone feed to the kilns consists of stone sizes between 1/4" and 2". In general for most applications, however, the feed is maintained in the 1/4" - 1/2" size range.

Table 9

TYPICAL ANALYSIS OF COMMERCIAL

HIGH CALCIUM AND DOLOMITIC LIMESTONE

	High Calcium	Dolomitic
	Wt. %	
Calcium Carbonate ($CaCO_3$)	97.40	52.34
Magnesium Carbonate ($MgCO_3$)	1.25	47.04
Iron Oxide (Fe_2O_3)	0.11	0.04
Aluminum Oxide (Al_2O_3)	0.35	0.20
Silica (SiO_2) + acid insolubles	0.95	0.26
Loss on ignition (CO_2)	43.40	47.67

PRODUCTS

Limestone and lime are employed in more industries than any other natural substance. Lime is second only to sulfuric acid in tonnage production among the pure chemicals. Lime is usually sold as a high calcium quick lime containing not less than 90% of calcium oxide. Other constituents are magnesia (0-5%) and small percentages of calcium carbonate, silica, alumina and ferric-oxide impurities. The suitability of a lime for any particular use depends on its composition and physical properties. These can be controlled by the selection of the limestone and the detail of the manufacturing process.

Many chemical and metallurgical processes require high calcium lime. In sulfite paper processing, however, a magnesia lime works better. Other uses of lime include air and water pollution control. Lime slurries have been used for scrubbing of stack gases to remove HCl, HF, SO_2, etc.

There are many municipalities which use lime softening in their water treatment plants. The acidity of industrial waste water is effectively controlled by the use of lime as a reagent.

PROCESS CHEMISTRY

There are three essential factors in the kinetics of limestone's decomposition:

(a) *The stone must be heated to the dissociation temperature of the carbonates.* For calcite ($CaCO_3$) this temperature is approximately 1648°F while dolomite ($CaCO_3 \cdot MgCO_3$) dissociates in the range of 930-1480°F. Because $MgCO_3$ dissociates at a much lower temperature (755-895°F) than $CaCO_3$, the dissociation temperature for the mixture varies with the proportions of $MgCO_3$. The heat consumed to attain the theoretical minimum dissociation temperature is approximately 1.5 million Btu/ton high calcium quicklime and 1.25 million Btu/ton dolomitic quicklime produced.

(b) *The dissociation temperature must be maintained until all of the carbon dioxide is expelled.* The heat requirement during this period is approximately 2.8 million Btu/ton high calcium quicklime and 2.6 million Btu/ton dolomitic quicklime produced.

(c) *The carbon dioxide gas must be removed* to keep recarbonation to a minimum because of the reversible nature of the dissociation reaction.

NATURE OF THE AIR POLLUTANTS

The nature of air pollutants emitted from rotary lime kilns is a function of the type of limestone charged (high calcium or dolomitic) and the type of fuel burned (coal, oil or natural gas).

The gaseous effluent is usually between 800 and 1800°F. It is composed of carbon dioxide, water vapor and nitrogen. Sulfur dioxide and sulfur trioxide are also present if sulfur-containing oil or coal are used as fuels.

The composition and volume of gases discharged from rotary lime kilns varies with the type of limestone feed, the fuel used, completeness of combustion, quantity of excess air, etc.

An approximate relationship between gas flow and process weight is presented in Table 10. This is influenced by the fuel composition to some degree. Natural gas and pulverized coal represent the major fuel types used in this application. Other fuels utilized to a minor degree in rotary lime kilns include fuel oil, wood, sawdust and propane. However, these fuels are usually uneconomical, unavailable or unsuitable because of poor combustion characteristics.

A typical overall kiln exhaust gas composition is as follows:

N_2	–	59.7%	(by vol.)
CO_2	–	24.3%	
H_2O	–	15.3%	
O_2	–	0.7%	

Table 10

Typical Exhaust Gas Production for Various Kiln Sizes

EXHAUST GAS, SCFM

Process Wt. Tons Lime Produced per Day	Gas Fired Kiln	Fuel/Lime Ratio Coal Fired Kiln 1:3	1:4	1:5
125	11,000	8800	6900	5700
250	26,600	17600	13800	11400
500	46,900	35200	27600	22800

The CO_2 content of lime kiln gases is relatively high because the exhaust gases contain CO_2 released during the chemical reaction (limestone→lime) as well as the CO_2 resulting from combustion of the fuel.

Minor gaseous contaminants include SO_2, SO_3 and oxides of nitrogen, in concentrations which depend upon the type of fuel used. For instance, virtually no SO_2 or SO_3 is present in the exhaust gases from a kiln fired with natural gas, while concentrations of SO_2 in the range of 0.05 - 0.3% (by vol.) occur with coal firing. Oxides of nitrogen (NO_x) are present in combustion gases from the burning of natural gas, coal or fuel oil in concentrations of 100 ppm to 1400 ppm.

The particulate emissions can include raw limestone and completely calcined lime dust, fly ash, tars and unburned carbon (if pulverized coal is used as the fuel). The quantity of dust emitted from a rotary lime kiln can be as high as 15% of the product lime weight.

The particulate emissions from rotary lime kilns can be in the range of 2 - 20 gr/scf with typical chemical analyses from gas fired kilns as shown in Table 11.

The calcination or thermal decomposition of high calcium limestone ($CaCO_3$) or dolomitic limestone ($CaCO_3 \cdot MgCO_3$) proceeds in accordance with the following reversible reactions:

1. $CaCO_3 + \text{heat} \rightleftarrows CaO \text{ (quicklime)} + CO_2 \uparrow$

2. $CaCO_3 \cdot MgCO_3 + \text{heat} \rightleftarrows CaO \cdot MgO \text{ (dolomitic quicklime)} + 2\ CO_2 \uparrow$

2) Air Pollution Control Equipment

The kiln exhaust gases represent the single largest source of airborne particulate matter in the lime industry. The major contaminant is quicklime dust caused by the abrasion of the stone in the kiln. The stone becomes friable as it approaches the decomposition temperature and dusting occurs. The lime dust presents a difficult control problem as it is hot, dry and not easy to wet. It is a dust of mixed composition varying all the way from the raw limestone to final completely calcined products. It will also be mixed with flyash, tars, and unburned carbon if pulverized coal is the fuel. The dust control problem is much more critical with rotary limestone kilns since recirculation of hot exhaust gases is not practical after pre-heating the kiln feed.

Table 11

Typical Chemical Analysis of Lime Kiln Emissions

Component	High Calcium	Dolomitic
CaO	66.3	7.2
$CaCO_3$	23.1	64.3
$Ca(OH)_2$	6.4	–
MgO	1.4	28.2
$CaSO_4$	1.2	.3
Other	1.6	–

If pulverized coal is used as a fuel, the particulates would also include flyash (consisting mostly of the oxides of silicon, aluminum and iron) and soot and tars resulting from incomplete combustion.

The approach that has been taken in the selection of gas cleaning equipment on existing installations has been made strictly on the ability of the equipment to remove the particulates.

In recent years, however, there has been an increase in the concern for effective control of gaseous emission (SO_2, SO_3 and NO_x) but this has not yet become a major consideration in the selection of dust control equipment. The emission of lime dust has been considered mainly a nuisance rather than one creating a health hazard.

The total quantity of dust discharged from the kiln ranges from 5-15% of the weight of the lime produced. Exhaust gas temperatures will range from 800° to 1800° F. It has also been established that the dust concentration will increase as the gas volume increases under conditions when the kiln capacity is pushed. An increase in production rate from 100 to 135 percent of design capacity could double the quantity of dust discharged.

The gases leaving the kiln are usually first passed through a dust settling chamber where the coarser material settles out. On many installations, a first stage primary dry cyclone collector is used to collect a large percentage of the coarse material. This primary collector stage, therefore, consists either of a low efficiency dust chamber or a high efficiency dry cyclone. The removal efficiency (by weight) at this stage can vary anywhere from 25% to 85% of the dust being discharged from the kiln.

The lime dust collected in this primary stage is taken to a waste dump, used as land fill or used for agricultural land treatment. The inclusion of a first stage depends on two considerations: (1) whether or not the coarse lime has a resale value, and (2) whether the kiln operation or the feed material (the stone) will create higher than normal kiln outlet loadings. If the loading is estimated to be higher than the 5-15% figure, a primary cyclone should be seriously considered to alleviate the operating and maintenance problems that go with high loadings. This is especially true in the case of wet scrubbers since extremely high loadings could increase the potential material build-up in the collector and also impose a heavy load on the slurry disposal system.

The selection of the second stage or final dust collector depends on a variety of factors. On the basis of overall collection efficiency only, at the high efficiency level in this study (.03 grains/ACF) any one of the three major categories of collection equipment, (wet scrubber, fabric filter or electrostatic precipitator) could be selected and achieve the required stack control on particulate emission. At the lower efficiency (LA-Process Weight) a single stage medium pressure drop scrubber could be selected and would carry a total installed cost figure somewhat less than what would be required for the high efficiency scrubbers (Venturi or two stage dynamic). Depending upon equipment size, this difference could be only marginal and it may be more practical to select a higher efficiency system even in areas where code requirements are not very stringent. The high efficiency wet scrubber is the logical choice if the wet scrubber is selected.

The selection of the type of gas cleaning equipment must be based on consideration of several factors in addition to efficiency. In order to determine what kind of collector (wet scrubber, fabric filter, electrostatic) best suits the particular application and the compliance with local air pollution codes, one must evaluate capital equipment costs; codes; operating and maintenance costs; water availability; horsepower requirements; in the case of fabric filters and electrostatic precipitators, handling of dry collected material; in the case of scrubbers, the required slurry handling system; water pollution and requirements of control of gaseous pollution (SO_2, SO_3, NO_x, etc.)

The size analysis of the dust being discharged from the kiln may contain as much as 30% below 5 microns and 10% below 2 microns. It is accepted that secondary dry cyclone collectors are unable to meet even the less stringent code requirements. The choice must be among the other three categories. A brief description of each follows:

Fabric Filters

Fabric filter installations for lime kilns consist of compartmented units called "Baghouses". These contain tubes or envelopes made of glass fiber cloth to withstand temperatures up to 550° F. As the kiln exhaust temperatures are higher than this, cooling is required. It is achieved by (1) evaporative water sprays, (2) indirect radiation convection heat exchange by means of U-tube coolers, (3) ambient air dilution, or (4) a combination of these. Even though glass fabric can withstand temperatures in the 550°F range, it is fragile due to the loss in strength resulting from the interyarn friction produced during flexing of the cloth. The flexing is done during the cleaning process.

In order to maintain acceptable pressure drop values (usually less than 5" wg), the collected dust cake must be removed periodically. This is accomplished by isolating one of the compartments and collapsing or shaking the bags lightly by reverse gas flow. (Mechanical shakers are seldom used with glass cloth.) Each compartment is "off-line" for a nominal time of 2-5 minutes to complete the cleaning. The dust falls to the hopper during cleaning. The total dust load will control the time required between repeated cleaning of each compartment.

As one compartment is usually off-line for cleaning, the total available filtration area is thus reduced. Filter units are specified on the basis of air to cloth ratios (cfm of gas per square foot of cloth) for the total unit and for one compartment off-line for cleaning. Air to cloth ratios for this service are nominally 2.2/1 when one compartment is off-line.

If the air to cloth ratio, which is by definition superficial face velocity, is excessively high, the pressure drop will increase, dust impaction may cause cake breakage, and dust "bleed through" may occur. Each manufacturer knows the optimum ratio for his type of fabric and method of cleaning for satisfactory operation.

Insulation of the equipment may be required if condensation of moisture can occur due to the combination of high moisture content in the gas and extremely low ambient temperatures. Condensation can cause many maintenance problems including (1) deterioration of the enclosure, (2) malfunction of the dust handling equipment, and (3) most important — blinding of the filter surface. Sometimes a partial enclosure can reduce or eliminate excessive effects of wind and low air temperatures.

Replacement of the fabric is the largest single cost item in the maintenance of this equipment. This is a true case in point of the adage that "an ounce of prevention is worth a pound of cure". Regular inspections and repair or replacement of failed bags can provide significant savings as well as maintain a consistently high collection efficiency. A nominal two year life is achieved for fabric in this application.

Waste handling equipment generally consists of screw conveyors to remove the dust from the hoppers or move it to a collection point from the hopper valves. Sometimes air assisted gravity conveyors are used in place of screws for dust handling.

<u>Electrostatic Precipitators</u>

Precipitators for lime kiln application are of the dry, horizontal flow, plate type construction common to many other applications. They are constructed of carbon steel, and therefore the kiln gases must be cooled to an acceptable level.

Cooling might be accomplished by air dilution or water evaporation. Evaporative cooling is preferred because it results in a lower final gas flow, and the moisture additive may improve the dust precipitability.

Multiple, independently energized electrical sections are used for better power distribution so as to sustain high level performance.

The kiln gas enters the precipitator and flows through passages created by parallel rows of collecting plates. Discharge electrodes are centered in each passage, and charge the dust particles negatively. The charged dust particles precipitate on the collecting surface, from which they are removed by the use of programmed rapping. The dislodged material falls by gravity into hoppers.

The efficiency of a precipitator is a function of the gas velocity and treatment time. Thus, higher efficiencies are attained in any process by increasing the precipitator size. Virtually any desired efficiency can be obtained.

Wet Scrubbers

This category includes a considerable number of commercially available units of different designs in the low to medium pressure drop operating range, (6-8" wg) that could be applied and would meet the LA-Process Weight code. As stated, however, savings in initial cost may not justify this selection and make itmore advisable to consider the higher efficiency units that are available. The wet scrubber selected to meet the more stringent code (this report, .03 gr/ACF) would be either a multi-stage dynamic scrubber or a Venturi-type scrubber operating at a pressure drop of 14-15" wg at conditions. This study included the multi-stage dynamic type for the high efficiency level as tabulated in Table 19. A distinct advantage of the wet scrubber for this application is that it can be fabricated to include a pre-humidification section as part of the scrubber design, therefore, eliminating the need for a separate pre-cooler or gas quenching stage.

The wet scrubber can also continue to perform under severe conditions of operation and minimum maintenance until proper operating conditions are restored. Wet scrubbers, however, do carry potential problems that are not associated with dry systems. These are basically – the internal material build-up in the scrubber if liquid rates fall or if dust loadings become unusually high because of upset conditions; the build-up at the wet-dry zone especially on horizontal gas inlets; the potential corrosion which must be considered if sulphur bearing fuels are used; the fact that there will be a visible steam plume;

the proper consideration and attention that must be given to the disposal of slurry.

In considering the slurry disposal system, one must avoid unusually long and horizontal runs if slurry is being led to settling ponds or basins. Some areas also may require treatment of the very highly alkaline slurry before disposal. Consideration should also be given to the proper location of the primary exhaust fan if a Venturi-type scrubber is used. Placing this fan before the scrubber is not practical at the high gas temperatures. This places the fan on the discharge of the scrubber in the cool gas stream. In this location, the fan may require alloy construction to avoid corrosion. Fan maintenance may be excessive if conditions of condensation or scrubber water entrainment exist. These cause material build-up on the fan resulting in fan imbalance. Frequently this can be avoided by reheating the gases slightly (10-20°F) before they enter the fan.

All three categories of collectors have been used commercially although most of the installations are wet scrubbers.

All three types of equipment have met high performance standards where they have been properly designed and operated. Reports regarding operating and maintenance costs for wet scrubbers and fabric collectors vary widely although it appears that on the average, these costs are higher for wet scrubber and fabric filters than for electrostatic precipitators.

b. SPECIFICATIONS AND COSTS FOR ROTARY LIME KILN APPLICATIONS

The specifications for each type of equipment were prepared in the same form as the Sample Specification given in Appendix IV. For simplicity, only the parts of the specification relating to the application in question are given for each of the equipment types in this section of the report.

1) ELECTROSTATIC PRECIPITATORS FOR LIME KILNS

Precipitators are not often utilized for rotary lime kilns. They have been applied successfully to dusts of this type, however, and are economical for the larger installations.

SPECIFICATIONS

The information provided the member companies for quoting these units is given in Tables 12 and 13. These Tables present the information furnished as pages 3 and 4 of a specification, leaving only the general conditions and terms to be covered in pages 1, 2, 5 and 6. Ordinarily, a good deal more data will be supplied to the equipment manufacturer, particularly when requesting installed costs. Drawings of the existing process equipment, soil conditions, source test results, etc. are often appended.

COSTS

Two cases are specified for each of the precipitator sizes. The first of these corresponds to the LA-Process Weight regulation, given in Appendix III. The prices quoted for this case are listed in Table 14a. The higher efficiency case involves larger and more costly precipitators, as shown in Table 14b.

Several descriptive comments by the precipitator manufacturer are included in the following paragraphs. In each case the comments cover the equipment items only, although the turnkey cost includes other items such as ductwork, foundations, etc.

LA-PROCESS WEIGHT

The *Small Electrostatic Precipitator* quotation includes:

One (1) precipitator, containing 11 gas passages, 9" x 20'-0" x 18'-0", (when treating 24,500 cfm at 700°F, will be 98.1% efficient). Two (2) 250 ma rectifier sets will be used to energize the precipitator. A cooling tower capable of removing 105,500 Btu/Min. which will cool 35,000 cfm of gas at 1200°F to 700°F, requiring 10 gal. of water per minute. A dust system consisting of a 530 cubic foot storage hopper adjacent to the precipitator, a screw conveyor and elevator.

The *Medium Electrostatic Precipitator* quotation includes:

One (1) precipitator, containing 23 gas passages, 9" x 24'-0" x 18'-0", (when treating 59,500 cfm at 700°F, will be 98.6% efficient). Two (2) 250 ma rectifier sets will be used to energize the precipitator. A cooling tower capable of removing 256,500 Btu/Min. will cool 85,000 cfm of gas at 1200°F to 700°F, requiring 24 gal. of water per minute. A dust system consisting of a 1230 cubic foot storage hopper adjacent to the precipitator, a screw conveyor and elevator.

The *Large Electrostatic Precipitator* quotation includes:

Table 12

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR ROTARY LIME KILN SPECIFICATION

The electrostatic precipitator is to handle the exhaust gas from a rotary lime kiln fired by natural gas. The precipitator will be used to remove limestone and lime dust from the exhaust gas. The rotary kiln is fed with 1/4" to 1/2" limestone. There is no preheater on the kiln and the feed end of the kiln is equipped with a dust fall-out chamber. The dust chamber is followed by a flash cooling system which reduces the gas temp from 1200°F to 550 - 500°F.

The exhaust gas will be brought from the feed end housing to a point twenty feet outside the building and twenty feet above grade. The precipitator will be located at grade in an area beyond the duct work and the area is free of space limitations. A fan will follow the precipitator and then a stack 50 feet in height.

The precipitator is to operate in such a manner as to continuously reduce the outlet loading to the specified levels. An automatic control should be supplied to give maximum dust removal. Two or more electrical fields in direction of gas flow must be included. The hoppers should have a minimum side and valley angle of 60°. A screw conveyor system to bring the dust to one point 3 feet outside the precipitator is to be included. A safety interlock system must be included on all access openings to the inside of precipitator. The rapping system must have a variable impact and timing cycle. From the common dust point the dust will be elevated to a dust bin adjacent to the collector. The bin will have a fifteen (15) foot clearance from grade. Hoppers and conveyors should be insulated.

For purposes of this quotation, the external hoppers and conveyor will be considered auxiliary equipment.

Table 13

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS

FOR ROTARY LIME KILN SPECIFICATION

Three sizes of electrostatic precipitators are to be quoted at each of two efficiency levels as specified below:

	Small	Medium	Large
Kiln capacity, ton/day	125	250	500
Process weight, lb/hr	18,700	37,400	74,800
Kiln outlet gas			
Flow, ACFM	35,000	85,000	150,000
Temp., °F	1,200	1,200	1,200
% moisture	12	12	12
Precipitator inlet			
Flow, ACFM	20,000	50,000	90,000
Temp., °F	550	550	550
% moisture	16	16	16
Precipitator inlet loading, lb/hr	815	1,960	3,500
Precipitator inlet loading, gr/ACF	4.75	4.55	4.55
Case 1 — LA Process Weight			
Outlet loading, lb/hr	15.4	26.9	40
Outlet loading, gr/ACF	0.090	0.063	0.052
Efficiency, wt %	98.1	98.6	98.85
Case 2 — High Efficiency			
Outlet loading, lb/hr	5.15	12.9	23.2
Outlet loading, gr/ACF	0.03	0.03	0.03
Efficiency, wt %	99.4	99.3	99.3

Table 14a

Electrostatic Precipitator Cost Data
for Rotary Lime Kilns
(LA—Process Weight)

INFORMATION		ELECTROSTATIC PRECIP.		
		SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day		125	250	500
Inlet Gas Volume, ACFM		24,500	59,500	105,000
Efficiency, Wt. %		98.1	98.6	98.85
Controlled Emission, gr/ACF		.090	.063	.052
Type of Charge		Limestone	Limestone	Limestone
Inlet Gas Temperature, °F		700	700	700
System Horsepower	Fan (3" Wg)	12	30	50
	Precip. HVPS*	42	60	74
Equipment Cost, $				
A. Collector		50,600	64,600	87,900
B. Auxiliaries		50,900	62,900	76,500
C. Gas Conditioning Equipment**		12,350	29,500	51,500
D. Waste Equipment		-		
E. Other		-		
Total		113,850	157,000	215,900
Installation Cost, $				
A. Grass-Roots		65,600	101,100	150,200
B. Add-On		72,200	111,200	165,200
Expected Life, Years		20	20	20
Operating and Maintenance, $/Year		1,500	1,500	2,500

* High voltage power supply, figured as horsepower equivalent.
** This includes the gas cooling system.

Table 14b

Electrostatic Precipitator Cost Data

for Rotary Lime Kilns

(High Efficiency)

INFORMATION	ELECTROSTATIC PRECIP.		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	125	250	500
Inlet Gas Volume, ACFM	24,500	59,500	105,000
Efficiency, Wt. %	99.4	99.3	99.3
Controlled Emission, gr/ACF	.03	.03	.03
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, °F	700	700	700
System Horsepower Fan (3" wg)	12	30	50
System Horsepower Precip. HVPS*	59	105	129
Equipment Cost, $			
A. Collector	68,200	79,400	102,500
B. Auxiliaries	57,800	72,600	85,000
C. Gas Conditioning Equipment	12,350	29,500	51,500
D. Waste Equipment			
E. Other			
Total	138,350	181,500	239,000
Installation Cost, $			
A. Grass-Roots	76,900	109,100	155,200
B. Add-On	84,600	120,000	171,000
Expected Life, Years	20	20	20
Operating and Maintenance $/Year	2,000	2,000	3,000

* High Voltage Power Supply, figured as horsepower equivalent.

Figure 2

Costs of Electrostatic Precipitators

For Rotary Lime Kilns

(LA—Process Weight)

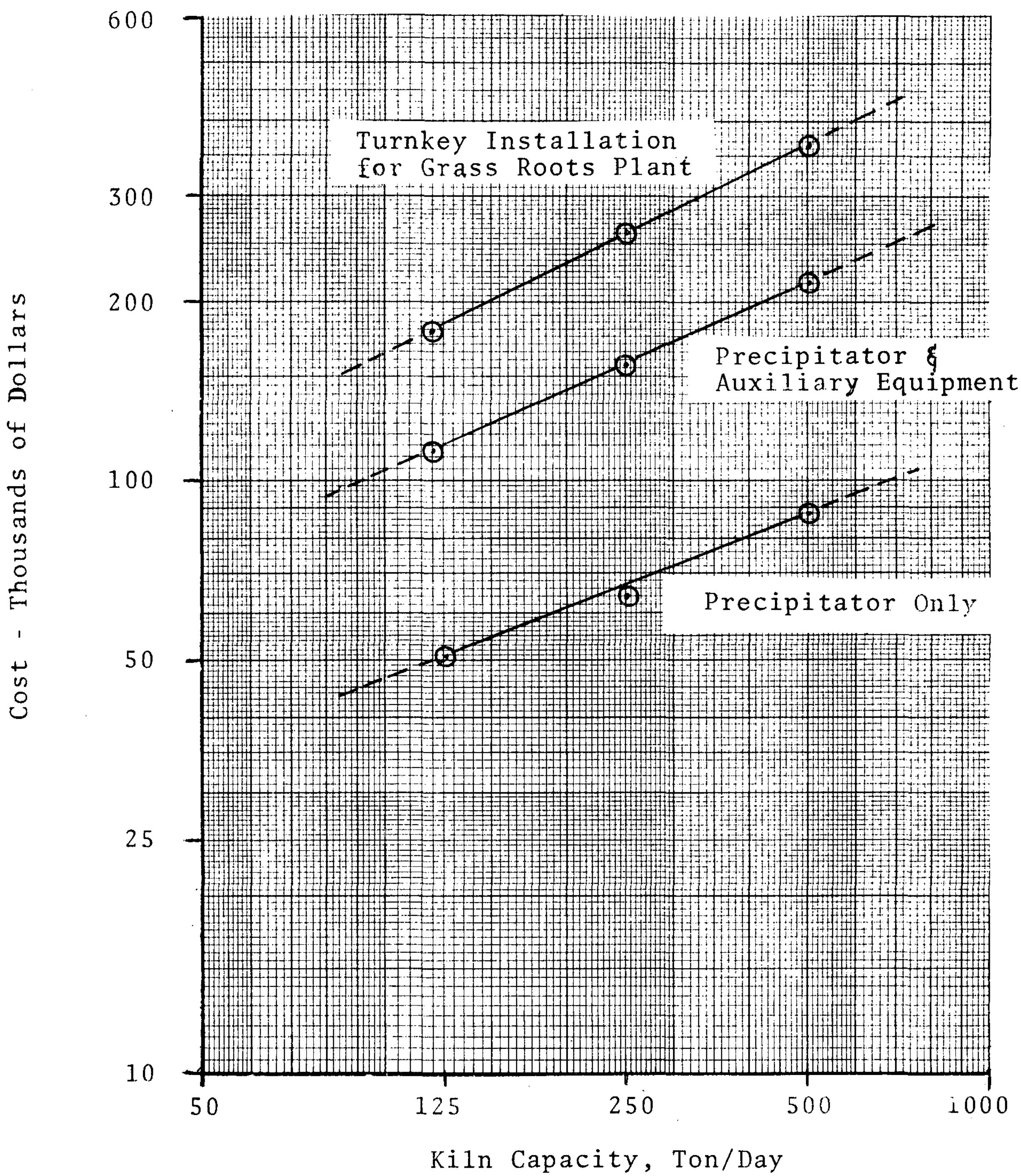
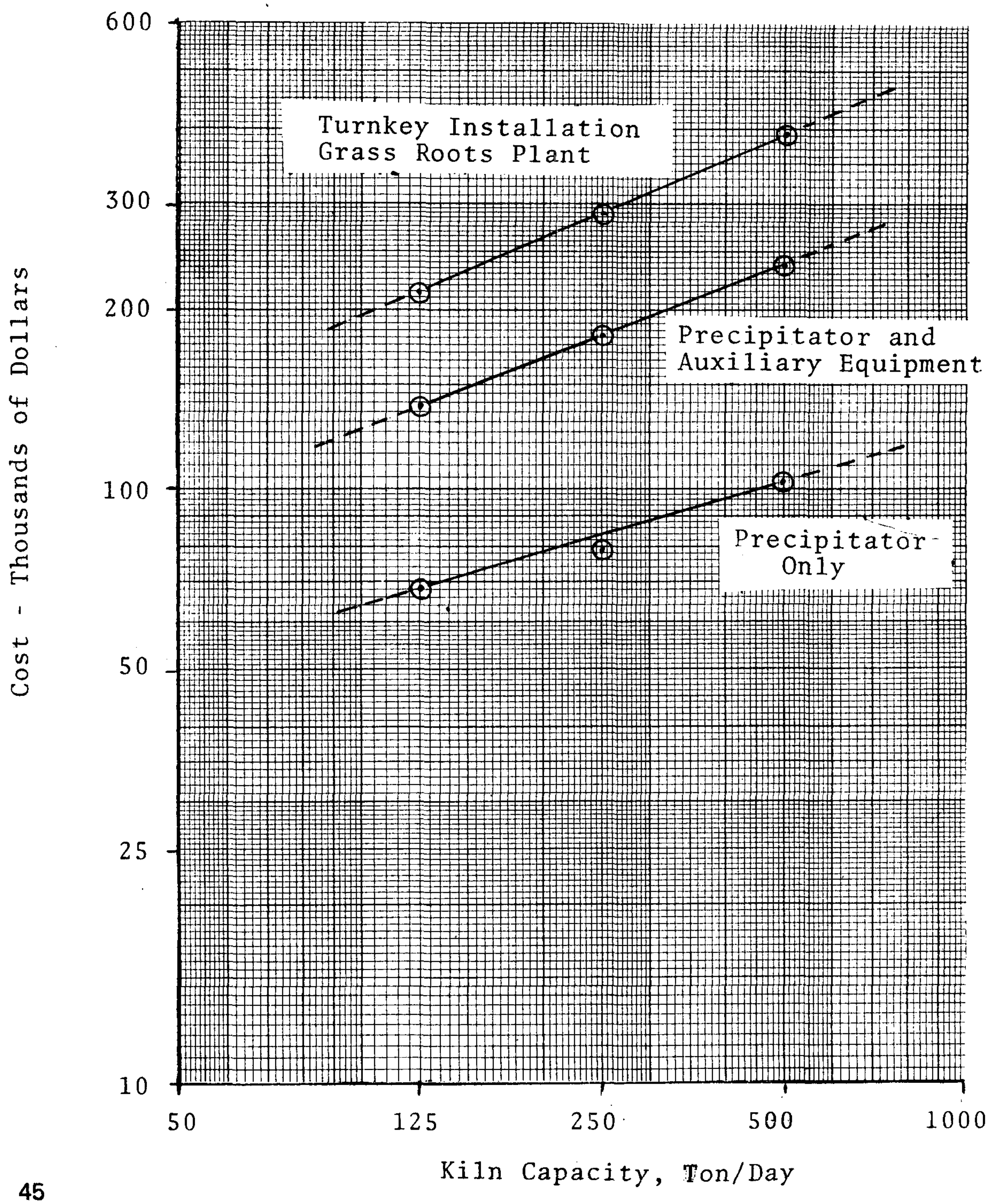


Figure 3

Costs of Electrostatic Precipitators

For Rotary Lime Kilns

(High Efficiency)



One (1) precipitator, containing 43 gas passages, 9" x 24'-0" x 18'-0", (when treating 105,000 cfm at 700°F, will be 98.85% efficient). Two (2) 500 ma rectifier sets will be used to energize the precipitator. A cooling tower capable of removing 451,000 Btu/Min. will cool 150,000 cfm of gas at 1200°F to 700°F, requiring 40 gal. of water per minute. A dust system consisting of a 2160 cubic foot storage hopper adjacent to the precipitator, a screw conveyor and elevator.

HIGH EFFICIENCY CASE

The *Small Electrostatic Precipitator* quotation includes:

One (1) precipitator, containing 13 gas passages, 9" x 15'-0" x 27'-0" (when treating 24,500 cfm at 700°F, will be 99.4% efficient). Three (3) 250 ma rectifier sets will be used to energize the precipitator. A cooling tower capable of removing 105,500 Btu/Min. will cool 35,000 cfm of gas at 1200°F to 700°F, requiring 10 gal. of water per minute. A dust system consisting of a 550 cubic foot storage hopper adjacent to the precipitator, a screw conveyor and elevator.

The *Medium Electrostatic Precipitator* quotation includes:

One (1) precipitator, containing 19 gas passages, 9" x 24'-0" x 27'-0", (when treating 59,500 cfm at 700°F, will be 99.3% efficient.) Three (3) 250 ma rectifier sets will be used to energize the precipitator. A cooling tower capable of removing 256,500 Btu/Min. will cool 85,000 cfm of gas at 1200°F to 700°F, requiring 24 gal. of water per minute. A dust system consisting of 1250 cubic foot storage hopper adjacent to the precipitator, a screw conveyor and elevator.

The *Large Electrostatic Precipitator* quotation includes:

One (1) precipitator, containing 33 gas passages, 9" x 24'-0" x 27'-0", (when treating 105,000 cfm at 700°F, will be 99.3% efficient.) Three (3) 500 ma rectifier sets will be used to energize the precipitator. A cooling tower capable of removing 451,000 Btu/Min. will cool 150,000 cfm of gas at 1200°F to 700°F, requiring 40 gal. of water per minute. A dust system consisting of a 2190 cubic foot storage hopper adjacent to the precipitator, a screw conveyor and elevator.

It should be noted that, whereas the operating conditions specified a temperature of 550°F after cooling, a temperature of 700°F was used for the quotation. The manufacturer's judgment was that the dust resistivity would be too high for good precipitator performance at 550°F, and that this condition could be corrected by increasing the operating temperature. Responses by manufacturers of air pollution control equipment often include such exceptions to the conditions specified and the experience of the precipitator manufacturer in treating similar problems should be utilized.

The costs reported in Tables 14a and 14b are plotted in Figures 2 and 3.

2) FABRIC FILTERS FOR LIME KILNS

Fabric filters are specified for both efficiency levels, but with the understanding that a fabric collector of ordinary design would have a higher efficiency than the "high efficiency" case. The pertinent process description and operating conditions are specified in Tables 15 and 16.

It should be noted that the operating conditions specified at the collector inlet were exactly the same for the fabric collector as for the electrostatic. The costs for the three filter sizes are given in Table 17. Whereas the electrostatic precipitator design temperature was modified by the precipitator manufacturer to 700°F, the filter manufacturer quoted equipment to operate at the specified 550°F. The costs given in Table 17 are plotted on log-log coordinate paper in Figure 4.

3) WET SCRUBBERS FOR LIME KILNS

The specification information for the wet scrubber is given in Tables 18 and 19. The scrubber inlet conditions are similar to those specified for precipitators and fabric filters, but the outlet volume (which sets the size of the scrubber and the fan) is considerably smaller, due to cooling of the gas as it becomes saturated.

The cost data submitted by the manufacturer is shown in Tables 20 and 21. Some descriptive information was supplied by the manufacturer which points up differences in the basic design of the equipment offered for the two efficiency levels.

LA – PROCESS WEIGHT

For the LA-Process Weight or Lower Efficiency requirement, the scrubber offered is a single stage centrifugal tower type scrubber fabricated of

Table 15

FABRIC COLLECTOR PROCESS DESCRIPTION FOR ROTARY LIME KILN SPECIFICATION

The bag filter is to handle the exhaust gas from a rotary lime kiln fired by natural gas. The filter will be used to remove limestone and lime dust from the exhaust gas. The rotary kiln is fed with 1/4" to 1/2" limestone. There is no preheater on the kiln and the feed end of the kiln is equipped with a dust fall-out chamber. The dust chamber is followed by a flash cooling system which reduces the gas temp. to 550°F - 500°F.

The exhaust gas will be brought from the feed end housing to a point twenty feet outside the building where a fan will be located. (The fan outlet is five (5) feet above grade). The fabric filter will be located in an area beyond the fan and the area is free of space limitations. The fabric filter should be of positive design.

The fabric filter is to operate in such a manner that a single compartment (with no more than one quarter of the total collecting surface area) is isolated for cleaning. The cleaning method is to be reverse air flow type. Each section should be capable of isolation for maintenance and have provisions for personnel safety when the filter is in use. The hoppers should have a minimum to side and valley angle of 60° with screw conveyors to bring the dust to a centrally located point 3 feet outside the filter. Dust removal should be a continuous process. The hopper valve is to be included in the quote. From this point the dust will be elevated to a dust bin adjacent to the filter. The bin will have a 15 foot clearance from grade. Treated glass cloth filter bags should not exceed 12" in diameter and 30 feet in length. The cleaning cycle should be adjustable in duration of compartment cleaning and total cycle length. No more than two bags must be removed to have access to all bags.

Table 16

FABRIC COLLECTOR OPERATING CONDITIONS
FOR ROTARY LIME KILN SPECIFICATIONS

3. *OPERATING CONDITIONS*

Three sizes of fabric collectors are to be quoted. While two levels of efficiency are specified, it is expected that a single fabric quotation will be supplied for each size range.

	Small	Medium	Large
Kiln capacity, ton/day	125	250	500
Process weight, lb/hr	18,700	37,400	74,800
Kiln outlet gas			
Flow, ACFM	35,000	85,000	150,000
Temp., °F	1,200	1,200	1,200
% moisture	12	12	12
Filter inlet			
Flow, ACFM	20,000	50,000	90,000
Temp., °F	550	550	550
% moisture	16	16	16
Filter inlet loading, lb/hr	815	1,960	3,500
Filter inlet loading, gr/ACF	4.75	4.55	4.55
Case 1 – LA Process Weight			
Outlet loading, lb/hr	15.4	26.9	40
Outlet loading, gr/ACF	0.090	0.063	0.052
Efficiency, wt %	98.1	98.6	98.85
Case 2 – High Efficiency			
Outlet loading, lb/hr	5.15	12.9	23.2
Outlet loading, gr/ACF	0.03	0.03	0.03
Efficiency, wt %	99.4	99.3	99.3

Table 17

Fabric Collector Cost Data

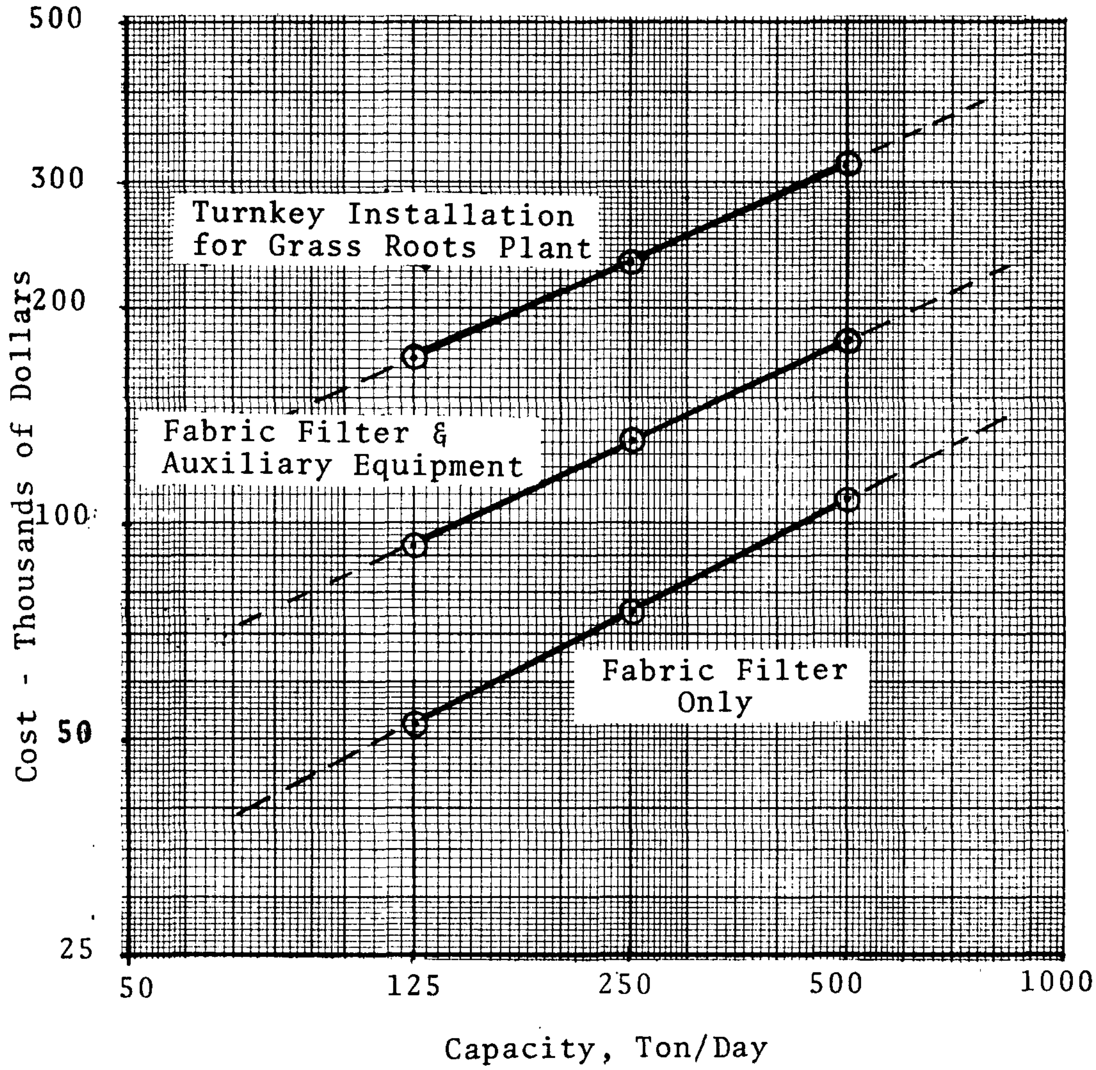
for Rotary Lime Kilns

INFORMATION	FABRIC FILTER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	125	250	500
Inlet Gas Volume, ACFM	20,000	50,000	90,000
Efficiency, Wt. %	99 Plus	99 Plus	99 Plus
Controlled Emission, gr/ACF	0.03	0.03	0.03
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, °F	550	550	550
System Horsepower	Hot 60 Cold 111	150 300	300 600
Equipment Cost, $ A. Collector B. Auxiliaries C. Gas Conditioning Equipment D. Waste Equipment E. Other Total	 53,250 10,480 3,740 18,610 6,610 94,690	 75,620 17,910 4,675 20,680 11,890 130,775	 106,515 27,840 6,440 23,250 16,405 180,450
Installation Cost, $ A. Grass-Roots B. Add-On	 75,750 --	 100,695 --	 135,340 --
Expected Life, Years	20 - 25	20 - 25	20 - 25
Operating and Maintenance $/year	11,000.00	18,000.00	30,000.00

Figure 4

Costs of Fabric Collectors

For Rotary Lime Kilns



carbon steel throughout. Operating pressure drop across the unit is 8.0" wg. Scrubber includes lower shell extension for humidification of hot inlet gases. Inlet connection has a 304 stainless steel insert sleeve. All doors are of the quick acting type.

"Auxiliaries" include the required main exhaust fan of the heavy duty radial bladed type; a TEFC motor (460 volt, 60 cycle, 3 phase); V-belt drive and guard; a recycle pump; a recycle and bleed pump with motor and drive; and a tank with liquid level and make-up water controls.

The installation cost item includes the ductwork from the kiln dust chamber take-off to the scrubber inlet – ductwork from scrubber outlet to the fan inlet and discharge stack at fan outlet. All structural supports; erection of the total system including excavation and concrete work, liquid feed piping and electric hook-up from adjacent power source are also included.

HIGH EFFICIENCY CASE

For the High Efficiency Level, the scrubber is a two stage dynamic scrubber including an integral wetted fan, which in addition to being the prime mover in the total system, is also the second stage of the scrubber. Fabrication of the collector is of carbon steel except for the fan wheel which is type 304 stainless steel. Scrubber to include lower shell extension for humidification of hot inlet gases. The inlet connection has a type 304 stainless steel insert sleeve. All doors are of the quick acting type with the flushed fan as an internal part of the scrubber.

The horsepower consumed by the fan is comparable to the horsepower requirement of a free standing scrubber operating at 8.0" wg pressure drop.

The auxiliaries include a TEFC drive motor (460 volt, 60 cycle, 3 phase); V-belt drive and belt guard; recycle tank; recycle and bleed pump with motor and drive; tank liquid level and make-up water controls.

Installation costs include the ductwork from the take-off of the dust chamber to the scrubber inlet, and the stack on top of the vertical scrubber discharge. Also included are all structural supports; erection of the total system including excavation and concrete work, liquid feed piping and electric hook-up from adjacent power source.

The following quantity of make-up water will be required to cover the evaporative loss and the bleed rate to maintain a 5% recycle slurry. This applies to both the low and high efficiency system:

125 TPD System	75 GPM
250 TPD System	180 GPM
500 TPD System	300 GPM

The costs given in Tables 20 and 21 are plotted on log-log coordinates in Figures 5 and 6.

Several points should be noted when comparing the equipment quoted for the LA-Process Weight and High Efficiency cases. The high efficiency scrubber is a proprietary design aimed at producing good efficiency at minimum cost for this specific application. Various proprietary designs are available as well as conventional Venturi or orifice-type scrubbers.

The cost comparison indicates that the high efficiency can be achieved with a lower expenditure of capital and operating cost. It is not unusual that the first costs of high efficiency scrubbers are little higher than lower efficiency designs; however, the power costs will ordinarily increase substantially with increases in efficiency. That they do not in this comparison (which shows almost identical horsepower requirements for the two efficiencies) is peculiar to the equipment of the manufacturer preparing these quotations. The lower efficiency design is for a Venturi scrubber, whereas the high efficiency scrubber is a dynamic type.

c. DISCUSSION OF COSTS FOR ROTARY LIME KILN APPLICATION

Rotary lime kiln applications are most frequently handled by wet scrubbers. The reason for this is apparent when the costs of the turnkey installations given for the three types of equipment are compared. Figure 7 shows these costs for the high efficiency case as a function of kiln size. The wet scrubber satisfies all of the process requirements, yet has an initial cost of less than 1/2 that for a precipitator or fabric filter. This holds true over the entire range of sizes.

There is a horsepower penalty involved with the scrubber operation, however. Rather surprisingly, this is not significant in comparison with the fabric collector. However, it requires much more power than the electrostatic precipitator.

Table 18

WET SCRUBBER PROCESS DESCRIPTION FOR ROTARY LIME KILN SPECIFICATION

The scrubber is to handle the exhaust gas from a rotary lime kiln fired by natural gas. The scrubber will be used to remove limestone and lime dust from the exhaust gas. The rotary kiln is fed with 1/4" to 1/2" limestone. There is no preheater on the kiln and the feed end of the kiln is equipped with a dust fall-out chamber. The dust chamber is followed by a wet scrubber with pre-cooling sprays or saturation chamber as required. Such pre-cooling equipment is to be located at the discharge from the fall-out chamber, and must cool the ductwork to a maximum of 550°F. It will be considered as an integral part of the scrubber for this quotation.

The exhaust gas will be brought from the precooling section to a point twenty feet outside the building where a fan will be located. (The fan outlet is five (5) feet above grade.) The scrubber will be located in an area beyond the fan. The area is free of space limitations. The scrubber is to be designed to withstand the full discharge pressure developed by the fan.

The scrubber is to operate in such a manner as to continuously attain the efficiency levels specified in the following section.

The scrubber shall have a conical bottom designed to avoid the collection of sediment or deposits. Liquor effluent is to be piped to a recirculation tank from which the recirculation pump takes suction. Fresh makeup water is to be added to the system at this point. Discharge from the recirculation pump is to be partially returned to the scrubber and part withdrawn to a slurry settling basin to be provided by the customer. The slurry withdrawal is to be set to maintain about 10 weight percent solids when the kiln is operating at design capacity.

The scrubber and external piping are to be constructed of carbon steel. Packing glands are to be flushed with fresh water to prevent binding of the seals.

For purposes of this quotation, the following is to be considered auxiliary equipment:

(1) pumps and reservoir
(2) fan
(3) external piping
(4) controls

Table 19

WET SCRUBBER OPERATING CONDITIONS
FOR ROTARY LIME KILN SPECIFICATIONS

Three sizes of scrubbers are to be quoted for each of two levels of efficiency.

	(A) Small	(B) Medium	(C) Large
Furnace capacity, ton	125	250	500
Production rate, lb/hr	10,400	20,800	41,600
Process weight rate, lb/hr	18,700	37,400	74,800
Inlet gas volume, ACFM	35,000	85,000	150,000
Inlet gas temperature, °F	1,200	1,200	1,200
Inlet loading, lb/hr	815	1,960	3,500
Inlet loading, gr/ACF	2.82	2.69	2.72
Outlet gas volume, ACFM	19,000	46,000	81,000
Outlet gas temperature, °F	164	164	164
Case 1 – LA Process Weight			
Outlet loading, lb/hr	15.40	26.7	40
Outlet loading, gr/ACF	0.094	0.068	0.058
Efficiency, wt %	98.1	98.6	98.9
Case 2 – High Efficiency			
Outlet loading, lb/hr	4.89	11.85	20.8
Outlet loading, gr/ACF	0.03	0.03	0.03
Efficiency, wt %	99.4	99.4	99.4

Table 20

Wet Scrubber Cost Data

for Rotary Lime Kilns

(LA—Process Weight)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	125	250	500
Inlet Gas Volume, ACFM	35,000	85,000	150,000
Efficiency, Wt.%	98.1	98.6	98.9
Controlled Emission, gr/ACF	0.094	0.068	0.058
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, F	1,200	1,200	1,200
System Horsepower	65	147	268
Equipment Cost, $			
A. Collector	7,200	13,100	23,600
B. Auxiliaries	10,850	16,770	36,960
C. Gas Conditioning Equipment			
D. Waste Equipment			
E. Other			
Total	18,050	29,870	60,560
Installation Cost, $			
A. Grass-Roots	57,900	79,700	103,900
B. Add-On	71,500	97,100	127,170
Expected Life, Years	10	10	10
Operating and Maintenance $/year	4,800	5,600	6,500

Table 21

Wet Scrubber Cost Data

for Rotary Lime Kilns

(High Efficiency)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	125	250	500
Inlet Gas Volume, ACFM	35,000	85,000	150,000
Efficiency, Wt.%	99.4	99.4	99.4
Controlled Emission, gr/ACF	0.03	0.03	0.03
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, F	1,200	1,200	1,200
System Horsepower	60	140	245
Equipment Cost, $			
A. Collector	14,300	25,800	44,700
B. Auxiliaries	9,250	12,600	16,700
C. Gas Conditioning Equipment			
D. Waste Equipment			
E. Other			
Total	23,550	38,400	61,400
Total Installation Cost, $			
A. Grass-Roots	48,900	66,300	86,900
B. Add-On	61,400	83,400	110,400
Expected Life, Years	10	10	10
Operating and Maintenance $/year	4,800	5,600	6,500

Figure 5

Costs of Wet Scrubbers

For Rotary Lime Kilns

(LA–Process Weight)

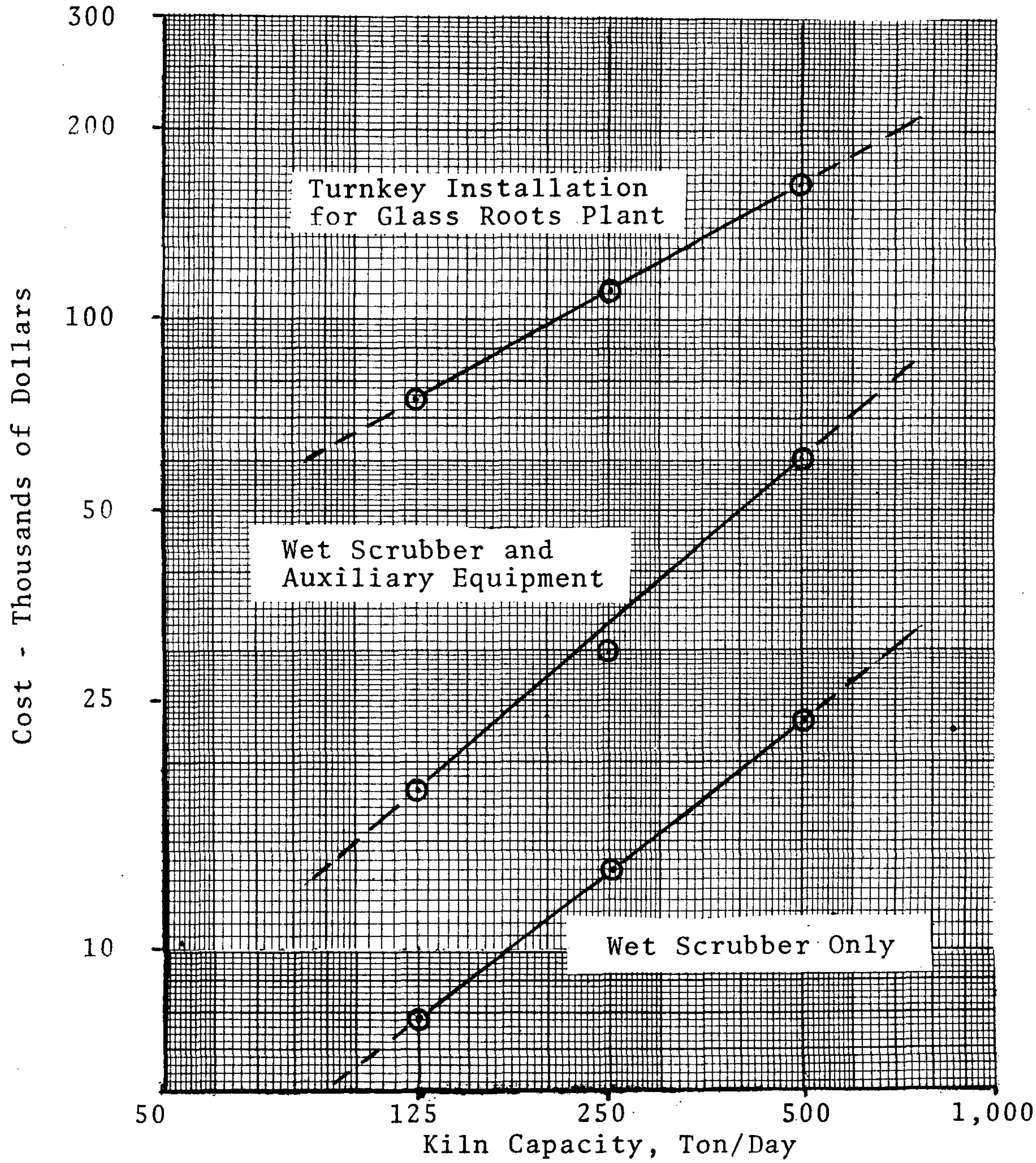


Figure 6

Costs of Wet Scrubbers

For Rotary Lime Kilns

(High Efficiency)

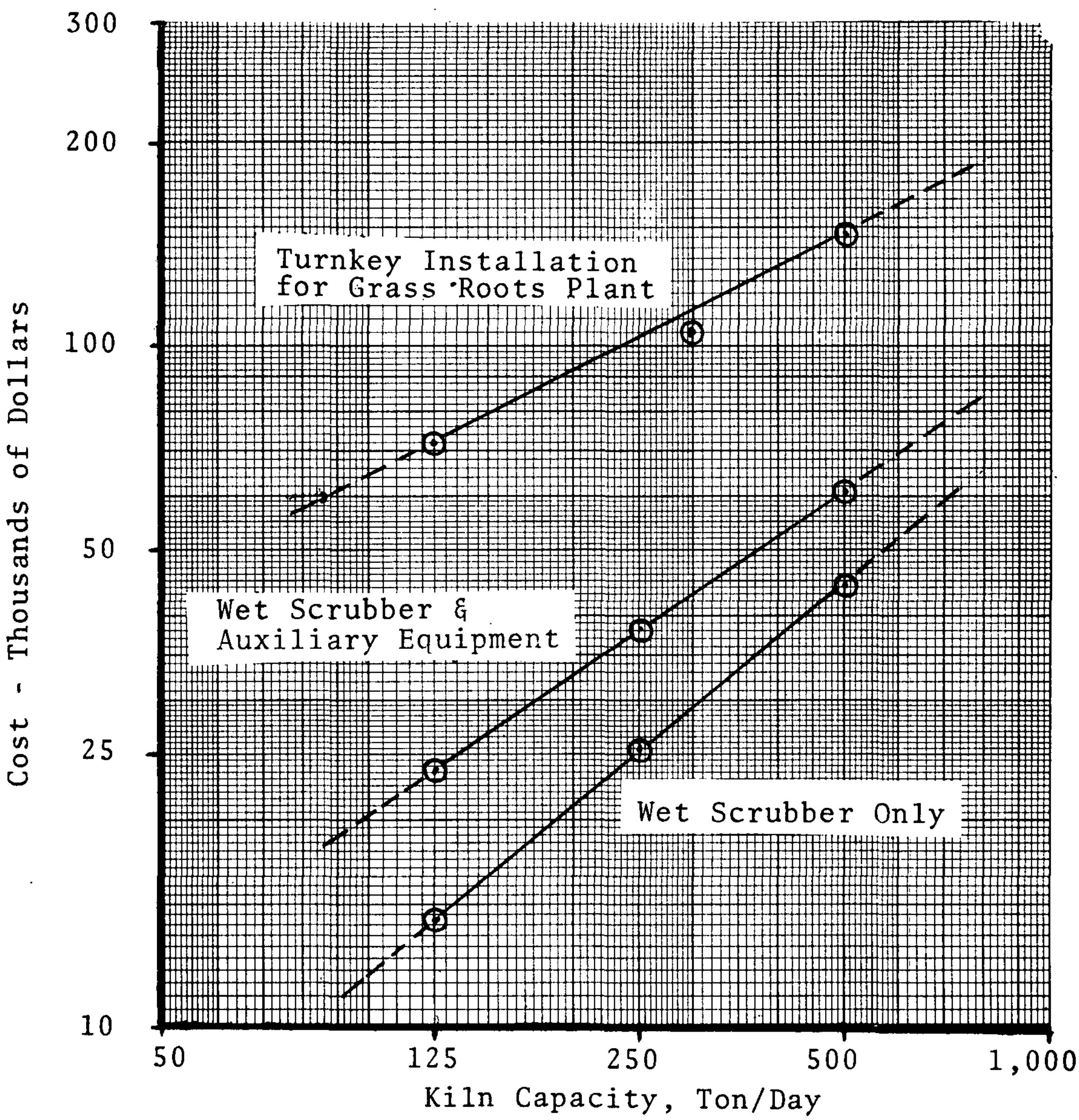
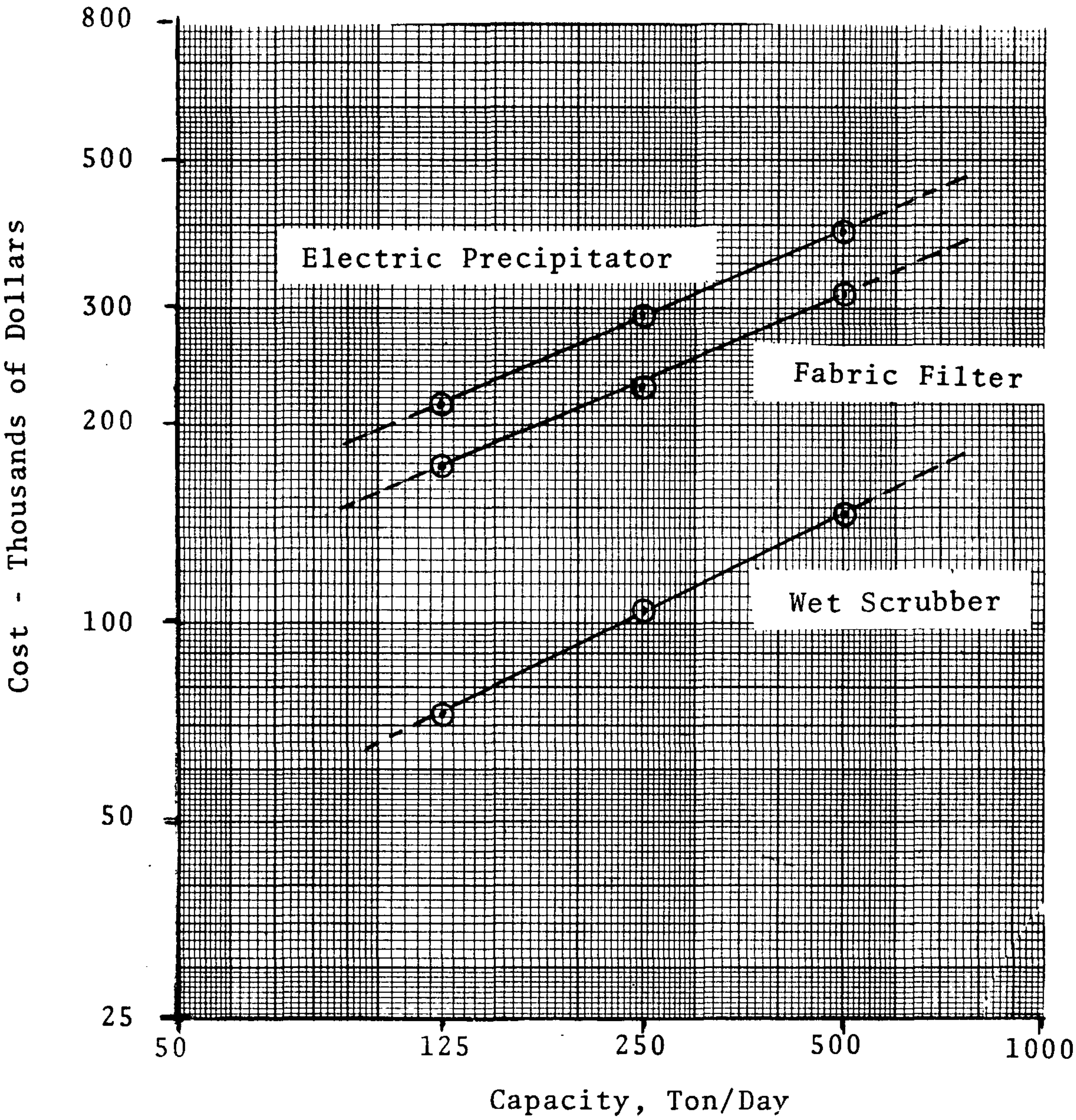


Figure 7

Comparison of Abatement Costs

for Rotary Lime Kilns



The horsepower shown for the 500 ton kiln in Table 21 is 245. If the operation is carried out 24 hours/day, 300 days/year, this would cost

$$245 \times 300 \times 24 \times 0.746/0.85 \times \$.01 = \$15,425$$

per year at 1¢ per kw-hr and 85% efficiency of the driver.

Several other factors merit some consideration in the choice of equipment. For example, the precipitator and fabric filter life was estimated at 20 or more years, whereas the scrubber shows only 10 years expected life. While differences in estimates made by different manufacturers have less significance than if all were prepared by the same person, it is likely that there is a difference due to the more difficult corrosion problems presented in wet scrubber applications.

Precipitator maintenance is principally involved with inspection, with only nominal cleaning and replacement of parts. Fabric filter maintenance consists mainly of bag replacement, which is a substantial cost that increases in proportion to the size of the collector. For the wet scrubber, more extensive cleaning, replacement of plugged or eroded nozzles, etc. involves a maintenance cost, which increases with the size of the scrubber.

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2. AIR POLLUTION CONTROL FOR BRASS/BRONZE REVERBERATORY FURNACES

a. PROCESS DESCRIPTION

Process Flow

The basic flow of the process begins with the raw material, which in the bronze and brass industry consists primarily of copper-base alloy scrap. The scrap contains many contaminants that must be removed. The common contaminants would include oil, grease, insulation, rubber, anti-freeze solutions and many other chemicals. A list of various copper bearing scrap follows in Table 22. Methods of pre-processing scrap fall into three basic categories: mechanical, hydrometallurgical, and pyrometallurgical. Of these separation techniques, the pyrometallurgical method contributes the most toward air contamination. A brief outline of these methods follows:

1) Mechanical
   - Hand sorting
   - Stripping (wire insulation)
   - Shredding
   - Magnetizing
   - Briquetting (Compressing scrap)

2) Hydrometallurgical
   - Concentrating (gravity separation in a liquid medium)

3) Pyrometallurgical
   - Sweating (low melting point metals)
   - Burning (rubber insulation, etc.)
   - Drying at low temperature (to drive off volatile impurities such as oil and grease)
   - Blast furnace or cupola (dense molten metal separates from the non-metallic slag)

The pre-processed scrap is then fed into a furnace such as the open hearth reverberatory. After the heat is begun additional charges of scrap are usually added. A diagramatic flow sheet relating these processes to the overall scheme is shown in Figure 8.

The next step in the process is the refining stage. Here the remaining impurities and other elements in excess of the specifications are removed. Many different methods are employed to achieve the desired results. Refining is primarily a process of purification using chemicals which are commonly called

Table 22

TYPES OF COPPER-BEARING SCRAP

1. No. 1 copper wire
2. No. 2 copper wire
3. No. 1 heavy copper
4. Mixed heavy copper
5. Light copper
6. Composition or red brass
7. Red brass composition turnings
8. Genuine babbitt-lined brass bushings
9. High-grade, low-lead bronze solids
10. Bronze papermill wire cloth
11. High-lead bronze solids and borings
12. Machinery or hard red brass solids
13. Unlined standard red car boxes (clean journals)
14. Lined standard red car boxes (lined journals)
15. Cocks and faucets
16. Mixed brass screens
17. Yellow brass scrap
18. Yellow brass castings
19. Old rolled brass
20. New brass clippings
21. Brass shell cases without primers
22. Brass shell cases with primers
23. Brass small arms and rifle shells, clean fired
24. Brass small arms and rifle shells, clean muffled (popped)
25. Yellow brass primer
26. Brass pipe
27. Yellow Brass rod turnings
28. Yellow brass rod ends
29. Yellow brass turnings
30. Mixed unsweated auto radiators
31. Admiralty brass condenser tubes
32. Aluminum brass condenser tubes
33. Muntz metal tubes
34. Plated rolled brass
35. Manganese bronze solids
36. New cupro-nickel clippings and solids
37. Old cupro-nickel solids
38. Soldered cupro-nickel solids
39. Cupro-nickel turnings and borings
40. Miscellaneous nickel copper and nickel-copper-iron scrap
41. New monel clippings and solids
42. Monel rods and forgings
43. Old monel sheet and solids
44. Soldered monel sheet and solids
45. Soldered monel wire, screen, and cloth
46. New monel wire, screen, and cloth
47. Monel castings
48. Monel turnings and borings
49. Mixed nickel silver clippings
50. New nickel silver clippings and solids
51. New segregated nickel silver clippings
52. Old nickel silver
53. Nickel silver castings
54. Nickel silver turnings

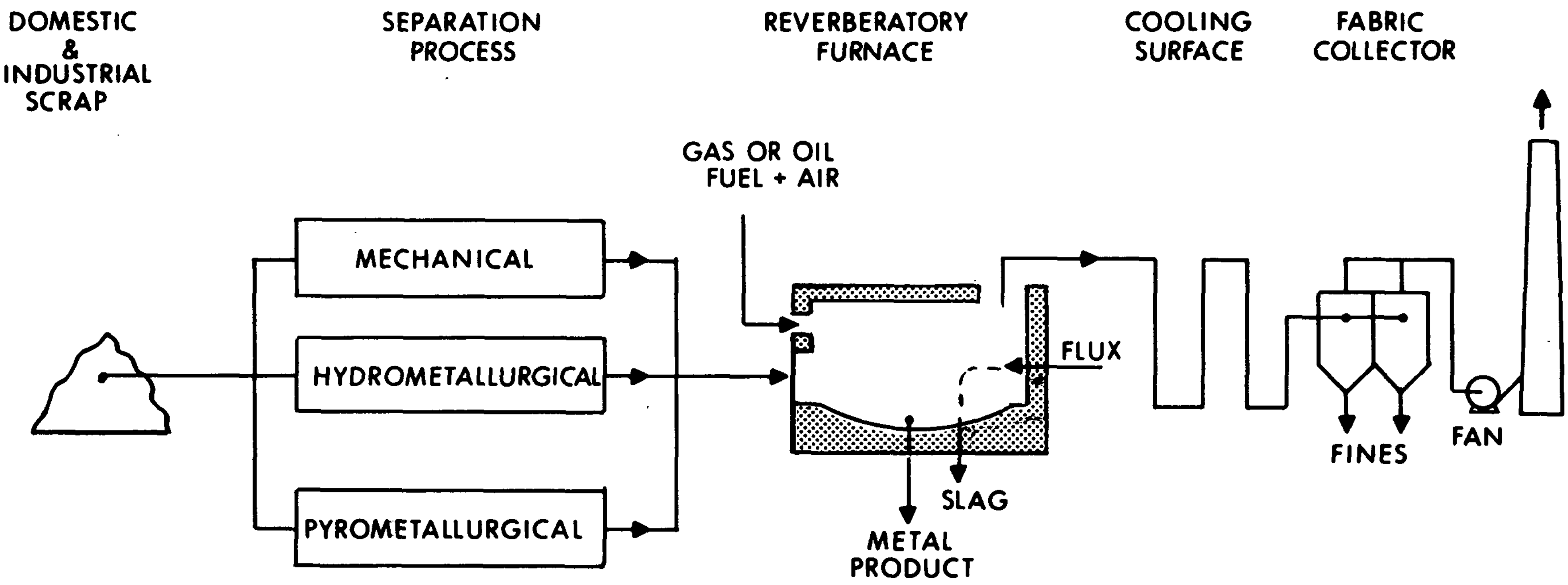


Figure 8

Process Flow Sketch of Brass/Bronze Reverberatory Furnaces fluxes. These may be solid, liquid, or gaseous. Compressed air is often used to oxidize the unwanted elements of aluminum, iron, manganese, and silicon by blowing it through the liquid pool. The less easily oxidized copper and tin remain in the bath. Part of the zinc, however, is unavoidably lost. Sometimes an inert gas such as nitrogen is used to carry gaseous impurities away from the liquid metal if oxidation is to be avoided.

A slag is usually formed on the surface of a melt. A layer of 1/4" to 1/2" of slag is desirable as a cover or heat retainer. The slag may aid the flux by degassing, densifying, fluidizing and homogenizing the alloy. It may also act as a hardener, or become part of the alloy depending upon its composition. When impurities can be removed by the flux as slag, no real air pollution problem will occur. An air pollution problem will occur when a gas is blown below the surface of a bath of metal causing impurities to be released.

Alloying the melt by adding various pure metals such as zinc or tin will result in the metallic characteristics required. It is usually best, however, to add slag formers while charging so that the cover will be formed early in order to protect the zinc from excessive oxidation.

The method of pouring molten alloy into ingot molds varies: It is either tapped directly into a moving automatic mold line or poured into a holding ladle and transferred to the mold line.

During the pouring process, large volumes of metallic oxide fumes are emitted as the alloy is no longer protected from the air by the slag cover. Smooth top ingots are produced by covering the metal surface with ground charcoal. The charcoal produces a shower of sparks which is difficult to capture in hoods. Hooding movable equipment of this type can be a very complex problem.

Equipment

The principal item of equipment is the reverberatory open hearth furnace. This furnace operates by transfering heat from the burner flames, roof and walls onto the charge. The entire roof is sloped down to form a restricted section or throat near the back of the hearth which maximizes the amount of reflected radiation. The furnace has a shallow, generally rectangular, refractory hearth for holding the metal charge. This is one of the least expensive methods of melting because the flame and products of combustion come in direct contact with the solid and molten metal.

Nature of Air Pollutants

Air or gas usage in the process gives rise to pollution. This usage, coupled with fumes from the furnace, causes pollutant emission. There are four principle factors which contribute metallic oxide fumes in brass and bronze smelting.

1) Alloy composition: the rate of loss of zinc is approximately proportional to the zinc percentage in the alloy.

2) Furnace type: direct-fired furnaces, such as the open hearth reverberatory, produce higher fume concentrations than crucible or electric-type furnaces because the hot, high velocity combustion gases come directly in contact with the metal resulting in excessive oxidation.

3) Excessive emissions result from poor foundry practices such as:

   Improper combustion
   Overheating of charge
   Addition of zinc at maximum furnace temperature
   Flame impingement on charge
   Heating charge too rapidly
   Insufficient flux cover
   Superheating metal
   Poor control of furnace atmosphere

4) Pouring temperature: for a given percentage of zinc, an increase in temperature of 100°F increases the rate of zinc loss about three times. Melting points for copper alloys are generally in the 1500-1800° F range.

Careful consideration of these factors will greatly reduce air contamination.

The gas effluent or the gas exiting from a direct-fired furnace producing brass or bronze metal is ordinarily in the temperature range of 1700°F to 2400°F. It may contain hydrocarbon compounds as well as any impurities from the charge which are picked up by the mixture of combustion products and infiltrated air. The latter include solid dust particles and oxide fumes.

A general description of pollutants encountered is as follows:

1) In copper based foundries, metallic oxides can account for as much as 98% of the particulate matter. Zinc oxide and lead oxide fumes occur in the submicron size range. The size range of these fumes produces a tremendous scattering of light which accounts largely for the visible plume discharge.

2) Other solid emissions may include dust, carbon, and smoke from burning charge impurities. If a sulfur containing fuel is used, sulfur oxides will also be released. Nitrogen oxides will be formed to some extent by the burner.

Furnace emission factors vary depending upon the type of charge, flux, slag, fuel and air conditions. Usually emission values for reverberatory furnaces run from 26 lb./ton to 160 lb./ton. Emission rates, however, frequently occur outside this range. Gas composition is described in a series of tests which were performed by the National Air Pollution Control Administration (NAPCA) to analyze the gas discharge from industrial furnaces and air pollution control systems. These tests are summarized in the following paragraphs:

Test 1

A heat of 85-5-5-5 red brass was made in a 100-ton reverberatory furnace. A total of 105,000 pounds of metal was charged to the furnace over a period of 6.7 hours. Oxygen was supplied to the burners for 5.3 of these hours to increase the melting rate. During a 9.3 hour refining period there was intermittent air blowing, and 500 pounds of fluxes were added. Pouring took 3.5 hours.

The air pollution control system serves three 100-ton reverberatory furnaces. The gases pass through a common spray chamber and then through a set of U-tube radiation coolers. From this point, the 450°F to 650°F gases are mixed with bleed-in air, go through the baghouse and a 75 horsepower fan, and pass to the stack. The 16-compartment shaker-type baghouse is fitted with heat-set Orlon bags. The total filter area is 7,360 square feet and the rated capacity is 19,000 cfm at 220° F. The design filter ratio, with one compartment out for cleaning, is 2.75/1.

Measured gas temperature at the baghouse inlet cycled between 200°F and 220°F. The measured gas volume averaged 15,000 SCFM (70°F). Baghouse pressure drop varied from 4 to 5 inches of water.

One inlet sample was taken during each of these three furnace periods: charging, refining, and pouring. A continuous baghouse outlet sample was taken over the entire heat, as listed in Table 23.

Test 2

A set of two 1-hour samples was taken at the stack of the system described in Test 1. Two reverberatory furnaces were operating during these tests. Both furnaces were melting during the first test and both were charging during the second test, as listed in Table 24.

Test 3

A reverberatory furnace rated at 60 tons was tested over a full cycle, with three baghouse inlet samples (charge, refine, pour) and a single baghouse outlet sample.

Furnace gases pass to a spray chamber and then to U-tube coolers. Air-bleed dampers are located at the U-tubes. The baghouse, with a rated capacity of 22,000 cfm at 180° F, has 5,940 square feet of Dacron fabric. The design filter ratio is 3.87/1. A 75 horsepower fan is used in the system. Measured stack gas volume was 18,000 SCFM (70°F) during this testing period. Capture efficiency of the hooding is estimated at 80 to 85 per cent. Results are in Table 25. Gaseous contaminants are listed in Table 26.

AIR POLLUTION CONTROL

The nature of contaminants in brass and bronze smelting requires careful consideration of ventilation and gas cleaning equipment used.

Hooding, Ventilating and Exhaust Requirements

Reverberatory furnaces require hoods over charge doors, slag doors, tap holes and the main stacks. Inlet velocities for these of 100 to 200 feet per minute are usually sufficient providing good industrial hood design technique is used. Arrangements should be provided to turn down or shut off furnace burners during periods when the furnace is open so as to not overload the fan exhaust capacity. The periods of concern are when the furnace is open for lancing, charging, rabbling, slag removal, charging metal or pouring metal.

Fabric Collectors

Fabric collectors are the most frequently used equipment to control

Table 23

BRASS/BRONZE REVERBERATORY FURNACE PARTICULATE EMISSIONS

Test 1

		Emissions, furnace[b]		Baghouse outlet[c]	
Cycle	Length, hr.	lb/hr.	Cycle total, lb.	lb/hr.	Total, lb.
Charge[a]	6.73	194.2	1,308	–	–
Refine	9.30	159.3	1,482	–	–
Pour	3.53	12.8	45	–	–
Total	19.56	–	2,835	3.32	64.8

[a]Total charge: 105,000 lb. Alloy produced: BBII Alloy No. 4A: 85-5-5-5

[b]Furnace emission factor: 53.7 lb/ton

[c]Collection efficiency: 97.7 per cent

Table 24

EMISSIONS FROM BAGHOUSE ON
BRASS/BRONZE REVERBERATORY FURNACES

Test 2

Sample	Baghouse Outlet gr/SCF	Baghouse Outlet lb/hr
D-1	0.025	5.13
D-2	0.031	6.37

Table 25

BRASS/BRONZE REVERBERATORY FURNACE PARTICULATE EMISSIONS

Test 3

		Emissions, furnace[b]		Baghouse Outlet[c]	
Cycle	Length, hr.	lb/hr.	Cycle total, lb.	lb/hr.	Total, lb.
Charge[a]	8.5	500.1	4,250.8	–	–
Refine	10.3	681.1	7,015.3	–	–
Pour	3.3	8.5	28.1	–	–
Total	22.1	–	11,294.2	2.17	47.9

[a]Total charge: 144,000 lb. Alloy produces: BBII Alloy No. 5A: 81-3-7-9

[b]Furnace emission factor: 156.9 lb/ton

[c]Collection efficiency: 99.6 per cent

Table 26

GASEOUS EMISSIONS FROM BRASS/BRONZE REVERBERATORY FURNACE

	Results	Test 1	Test 3
1.	O_2%	17.9	19.0
2.	CO_2%	0.89	0.57
3.	CO ppm	23.2	20
4.	SO_2 ppm	N/A	< 1
5.	NO_2 ppm	N/A	< 0.1
6.	H_2S ppm	N/A	< 1
7.	Hydrocarbons ppm	0.03	N/A
8.	Total Halogens	N/A	< 1

Note: O_2, CO_2, and CH_4 data are integrated samples over one cycle of the furnace; SO_2, NO_2, H_2S, and halogen data are detector tube samples.

N/A indicates data not available.

Results for Test 2 not available.

emissions. Efficiencies of 95% to 99.6% by weight are reported. Various fabric media are employed such as glass fibers, wool and synthetics like Orlon[R], Dacron[R] and Nomex[R]. By catching the larger particles and building up a mat they are capable of filtering in the submicron range. Glass media was the preferred high temperature filter but it is being replaced by Nomex. Although glass can withstand a higher temperature, the fibers gradually break because of the periodic flexing of the bag resulting in higher maintenance costs.

One of the critical factors in baghouse design is the filter velocity. With a relatively small concentration of fumes a velocity of 2.5 FPM is recommended. Larger concentrations require lower filter velocities. High velocities require more frequent shaking which results in excessive bag wear. A pressure drop of 2 to 6 inches of water is normal and high pressure differentials across bags should be avoided.

The baghouse should be completely enclosed to protect the bags from weather variations. The exhaust fan may be placed downstream from the baghouse to protect its impeller from material impingement which causes excessive wear.

Baghouses do have one disadvantage. The gas stream must be cooled before passing through the bags. This is usually accomplished by means of a water jacket type cooler which can effectively reduce a 2000 F discharge to about 900 F. An air cooled radiation convection system can then be used to cool the gas to a media-safe temperature.

High Energy Wet Collectors

High-energy Venturi scrubbers can be used for high efficiency cleaning. The collector uses a Venturi-shaped construction to establish gas throat velocities of much higher values than with other types of wet collectors. The principal mechanisms of collection are impaction and diffusion. Particles are accelerated to very high velocities and then impinged upon atomized water droplets. Water is supplied to the throat of the Venturi. The resulting mixture of gases, fume-dust agglomerates, and dirty water must be channeled through a separation section for the elimination of the impurities. Pressure drops of 50" to 60" of water are needed for high efficiency cleaning. Gas velocities may range from 18,000 to 24,000 FPM in the throat. Water rates to the throat will range from 10 to 15 GPM per 1000 ACFM of gas.

Electrostatic Precipitators

While precipitators are highly efficient devices, they are not ideally suited for the brass/bronze smelting industry, mainly because of the low gas flows used.

Comparison of Equipment Types

The relative merits of fabric filters and high-energy Venturi scrubbers in brass and bronze smelters are as follows:

FABRIC COLLECTORS

Advantages	Disadvantages
1. Efficiency is very high.	1. Bag replacement cost is high.
2. Recovers dry product.	2. Bags may be damaged by overheating.
3. Pressure drop and horsepower requirements are low.	3. Condensation will produce caking and interfere with operation.
4. No water pollution problem exists.	4. First cost is high

WET SCRUBBERS

Advantages	Disadvantages
1. Tolerates high temperatures (for metal construction)	1. May create a water disposal problem.
2. Can collect gases as well as particulates.	2. Product is collected wet.
3. First cost is low.	3. Corrosion problems are more severe than with dry system.
4. Maintenance cost is relatively low.	4. Steam plume opacity may be objectionable.
5. There is no condensation problem if gases are cooled too much.	5. Pressure drop and horsepower requirements are high.
	6. Solids build up at the wet–dry interface may be a problem

Equipment Design Considerations

Fabric filters require a low temperature gas stream; less than 550° F. Orlon and Dacron cannot be used above 275° F. Temperature reductions in the gas stream can be obtained by means of a water jacket type cooler used in series with an air cooled convection system. Caution must be used to avoid condensation on fabric filters by over-cooling. If water condenses on the fabric, it may cause caking and blinding of the filter. Acid attack must also be considered if condensation occurs where CO_2 and sulfur oxides are present.

Venturi scrubbers require some precooling of high temperature gas to prevent rapid evaporation of fine droplets. The precooling can be accomplished by a direct spray quencher. Special consideration must be given to corrosion problems in the duct work.

Efficiencies of fabric filters are usually higher than for Venturi scrubbers. Fabric filter efficiencies are in the range of 95% to 99.6%. Venturi scrubber efficiencies are directly related to the pressure drop across the throat and the gas stream particle characteristics. Manufacturers usually will not guarantee Venturi scrubber efficiencies without a background of field test experience.

b. SPECIFICATIONS AND COSTS FOR BRASS/BRONZE REVERBERATORY FURNACE APPLICATIONS

As in the case for the rotary lime kilns, a complete equipment specification was prepared for both fabric filters and wet scrubbers to serve a series of brass/bronze reverberatory furnace sizes. The electrostatic precipitator was not considered applicable to this process, so no prices were obtained for precipitators.

Only the parts of the specification which pertain to this application were included in this section of the report. A complete sample specification is given in Appendix IV.

1) FABRIC FILTERS FOR BRASS/BRONZE FURNACES

Fabric filters are the most widely used pieces of equipment for brass/bronze furnace air pollution abatement. A typical process description for inclusion in a fabric filter specification is shown in Table 27. The operating conditions for each of three sizes of furnaces are given in Table 28. Although the specification includes a low efficiency case (89.6 to 93.2%) to meet the

Table 27

FABRIC COLLECTOR PROCESS DESCRIPTION
FOR BRASS/BRONZE REVERBERATORY FURNACE SPECIFICATION

The reverberatory open-hearth is an oil fired furnace where the products of combustion and metallic fumes are normally vented directly from the furnace through a cooling device to a fabric collector. The furnace is a side charged, non-tilting type, fired with low sulfur No. 2 oil. The sulfur content will not exceed 2% by weight.

Hooding

The hooding shall consist of vents over the side charge door, pour spout and flue for general combustion and metallic fumes emission control.

Cooling

A "U" tube cooler (not forced draft tube bundle type cooler) shall deliver dust laden gases to the I.D. fan. The "U" tube cooler hopper will terminate into 9" screw conveyor.

Emergency bleed in of ambient air shall be provided to quench gas temperature to the collector. The entering air temperature to the collector will not exceed 270°F.

As corrosion may occur if fluxes contain compounds of a hygroscopic nature, provision for standby heat is required. The heater is to be direct fired thermostatically controlled.

Physical Layout – Equipment

The furnace is located on an outside wall of the melt building. Duct work will be required to tie into stack that is presently in existence (in case of new installation hooding on the vents over the side charge door, pour spout must tie into stack or flue from main furnace). The stack shall be capped with a hand operated damper for emergency by-pass. Take-off from the stack shall be at the 40' above ground level. Duct work will enter the "U" tube cooler. Duct work will be mild steel 1/4" plate construction into the "U" tube cooler. The "U" tube cooler will be a minimum of 10 ga with hoppers no less than 3/16" plate. The collector will be provided adequate space in an area 200' x 50' immediately outside the melt building.

Filter Baghouse – Shaker Type

The fabric filter shall be a continuous, automatic, compartmentized tubular cloth filter designed for uninterrupted service. The collector is to be arranged in separate compartments which are periodically isolated by individual automatic dampers. There shall be at least four individual compartments. The air to cloth ratio (net) with one compartment off for cleaning shall not exceed 2.3:1.

Table 27
(continued)

The housing shall not be less than 14 ga. Auxiliaries shall include ladders, platforms, outside shaker motors and drives, and catwalk access to outside shakers.

The housing shall be capable of withstanding a maximum of 20" wg negative pressure.

Hopper discharge equipment shall consist of trough type hoppers employing a 9" screw conveyor (heavy duty) terminating in a discharge spout. A rotary lock shall be provided for discharge from screw conveyor.

The control panel shall consist of but not be limited to the following:

(1) "U" tube manometer or Magnehelic[R] gages to indicate pressure drop across each compartment.

(2) High temp warning system (alarm).

(3) Sequencing timer for shaker drives.

The fan provided shall be a paddle wheel or radial blade heavy duty industrial exhauster capable of continuous operation at design conditions.

The exhauster shall include flanged inlet and outlet clean-out door, heat radiation shield on shaft, and drain. Outlet multi-blade manual control damper shall also be provided.

Table 28

OPERATING CONDITIONS FOR

BRASS/BRONZE REVERBERATORY FURNACE SPECIFICATION

Three sizes of fabric collectors are to be quoted in accord with the following operating conditions. Two efficiency levels are specified, but it is expected that a single fabric filter will be quoted for each size.

	Small	Medium	Large
Furnace capacity, ton	20	50	75
Melting rate, lb/hr	5,000	12,500	20,000
Inlet gas volume, ACFM	2,200	5,500	8,250
Inlet gas temperature, °F	270	270	270
Inlet loading, lb/hr	64	160	240
Inlet loading, gr/ACF	3.4	3.4	3.4
Case 1 – LA Process Weight			
Outlet loading, lb/hr	6.67	11.58	16.19
Outlet loading, gr/ACF	0.35	0.24	0.23
Efficiency, wt. %	89.6	92.1	93.2
Case 2 – High Efficiency			
Outlet loading, lb/hr	0.19	0.47	0.71
Outlet loading, gr/ACF	0.01	0.01	0.01
Efficiency, wt. %	99.7	99.7	99.7

LA-Process Weight requirements, it would not ordinarily be possible to operate at low efficiency because of the dense plume which would be discharged. For practical purposes, a fabric filter will perform in accord with the "High Efficiency" case, and will not produce a highly visible plume.

The cost data returned by the manufacturer is shown in Table 29. These costs are plotted using log-log coordinates in Figure 9.

2) WET SCRUBBERS FOR BRASS/BRONZE REVERBERATORY FURNACES

While wet scrubbers are capable of providing satisfactory air pollution abatement for this application, they do not automatically produce the high efficiency levels achieved by the fabric filter. It is necessary to consider the efficiency level required when specifying a scrubber. In particular, caution is necessary when the scrubber is selected to meet a process weight limitation such as the LA-Process Weight regulation, because serious plume opacity problems may be encountered at this efficiency level.

Tables 30 and 31 contain all of the specification material pertinent to the wet scrubber application. In Table 31 both low and high efficiency cases are specified, although only the high efficiency case is likely to produce an acceptable stack appearance.

The costs produced in response to the two specified efficiency levels are listed in Tables 32 and 33 for the low and high efficiency cases respectively. These figures are plotted in Figures 10 and 11 for ease of interpolation.

Note that the manufacturer has responded to the request for a quotation, but has indicated that the specified high efficiency level cannot be guaranteed without field testing.

c) DISCUSSION OF COSTS FOR BRASS/BRONZE REVERBERATORY FURNACES APPLICATIONS

Whereas more rotary lime kilns are equipped with wet scrubbers than other types of collectors, the brass and bronze reverberatory furnaces most often have fabric collectors. The reasons for this are apparent from the costs given in Tables 29 and 33 and plotted in Figure 12. The basic wet scrubber is less expensive than the fabric collector, but the higher cost of auxiliaries and installation makes the scrubber more costly than the fabric collector. In addition, the horsepower requirement is substantially higher for the scrubber.

Table 29

Fabric Collector Cost Data for

Brass/Bronze Reverberatory Furnaces

INFORMATION	FABRIC FILTER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	20	50	80
Inlet Gas Volume, ACFM	2,200	5,500	8,250
Efficiency, Wt. %	99.7	99.7	99.7
Controlled Emission, Gr/ACF	.01	.01	.01
Type of Charge	Scrap & Dross	Scrap & Dross	Scrap & Dross
Inlet Gas Temperature, °F	270	270	270
System Horsepower	21	48	84
Equipment Cost, $			
A. Collector	10,800	15,470	19,630
B. Auxiliaries	1,332	2,206	3,122
C. Gas Conditioning Equipment	11,570	15,890	22,400
D. Waste Equipment	--	--	--
E. Other	450	450	525
Total	24,152	34,016	45,677
Total Installation Cost, $			
A. Grass-Roots	21,800	30,800	36,500
B. Add-On	--	--	--
Expected Life, Years	15	15	15
Operating and Maintenance Requirements $/year	1,368	1,512	2,232

Figure 9

Costs of Fabric Collectors for

Brass/Bronze Reverberatory Furnaces

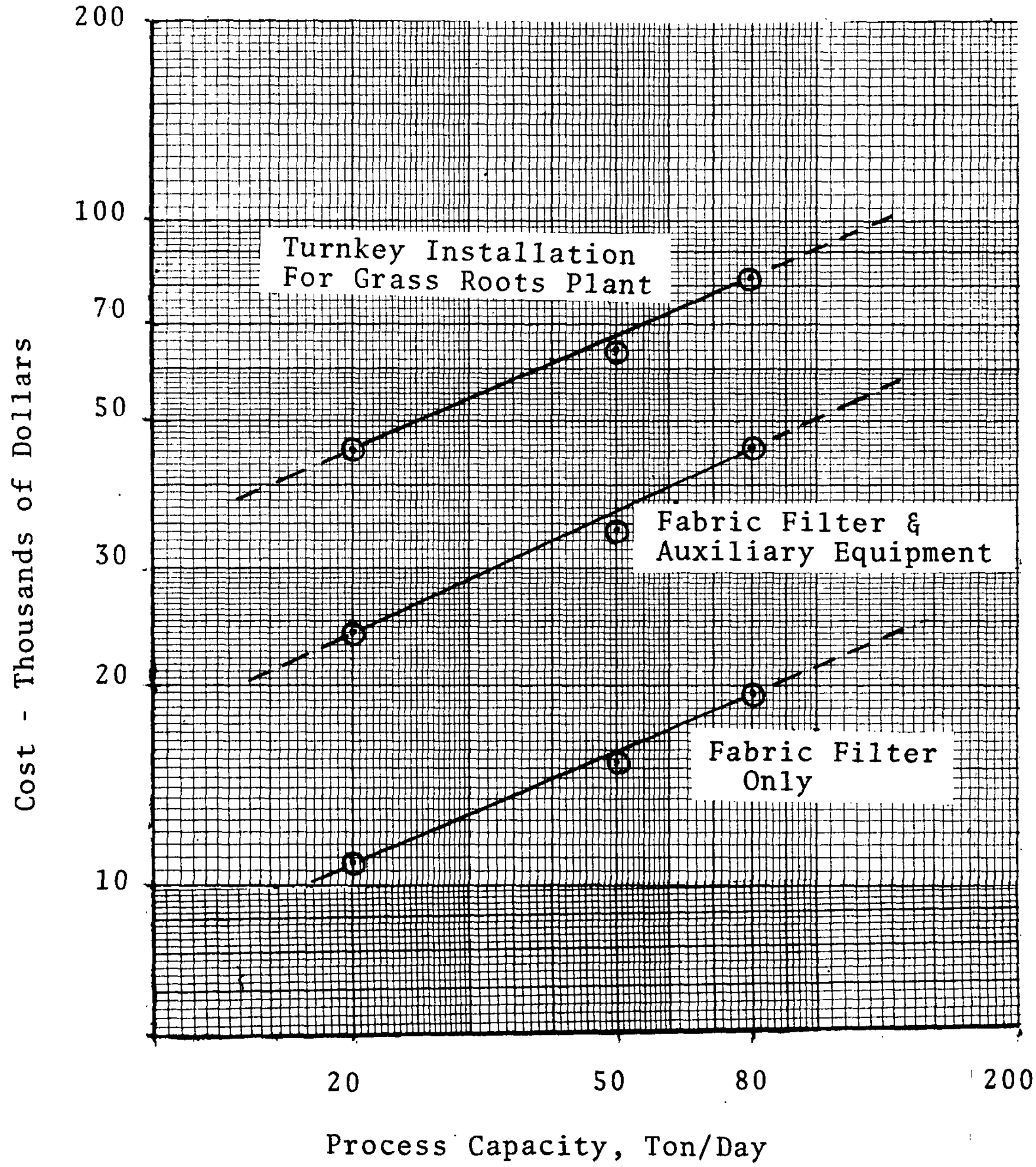


Table 30

WET SCRUBBER PROCESS DESCRIPTION FOR

BRASS/BRONZE REVERBERATORY FURNACE SPECIFICATION

The reverberatory open-hearth is an oil fired furnace where the products of combustion and metallic fumes are normally vented directly from the furnace to the scrubber. The furnace is side charged, non-tilting type, fired with low sulfur No. 2 oil. The sulfur content will not exceed 2% by weight.

Hooding

The hooding shall consist of vents over the side charge door, pour spout and flue for general combustion and metallic fumes emission control.

Physical Layout — Equipment

The furnace is located on an outside wall of the melt building. Duct work will be required to tie into stack that is presently in existence (in case of new installation hooding on the vents over the side charge door, pour spout must tie into stack or flue from main furnace). The stack shall be capped with a hand operated damper for emergency by-pass. Take-off from the stack shall be at the 40′ above ground level. Duct work will be mild steel 1/4″ plate where unwetted by scrubbing liquor and 304 ss. or equivalent where wetted. The scrubber will be provided adequate space in an area 200′ x 50′ immediately outside the melt building.

Wet Collector Spec.

The wet collector shall be a Venturi-type scrubber capable of developing the necessary pressure drop to scrub gases of contaminants to meet outlet emissions specified in the operating conditions.

The Venturi scrubber shall consist of the converging and diverging section. The converging section causes the inlet gas to be accelerated to high velocity where water introduced to the throat is atomized and the contaminant particles are trapped. The gas stream is decelerated in the diverging section. The water droplets are removed from the gas stream in the mist separator.

The Venturi scrubber and cyclonic separator are to be constructed of 304 ss. wherever wetted by the scrubbing liquor. The mist eliminator shall be a cone-bottom center drained vessel to avoid settling or clogging.

Pumps shall be rubber lined carbon steel or equivalent.

Fan shall be capable of developing the necessary static pressure to perform in accordance with the operating conditions. The ductwork static pressure is 8″ wg.

Table 30
(continued)

The pressure drop shall be no less than 50" wg to meet the LA County costs and no less than 60" wg to meet the higher efficiency requirement.

Auxiliaries

For purposes of this quotation, the following are to be considered as auxiliary equipment:

(1) *fan and drive*
(2) *pumps and drives*
(3) *external piping*
(4) *dampers*
(5) *controls*

Table 31

WET SCRUBBER OPERATING CONDITIONS FOR BRASS/BRONZE REVERBERATORY FURNACE SPECIFICATION

Three sizes of scrubbers are to be quoted in accord with the following operating conditions. Two efficiency levels are to be quoted for each size.

	Small	*Medium*	*Large*
Furnace capacity, ton	*20*	*50*	*75*
Melting rate, lb/hr	*5,000*	*12,500*	*20,000*
Inlet gas volume, ACFM	*7,520*	*18,600*	*27,800*
Inlet gas temperature °F	*2,000*	*2,000*	*2,000*
Inlet loading, lb/hr	*64*	*160*	*240*
Inlet loading, gr/ACF	*1.01*	*1.01*	*1.01*
Outlet gas volume, ACFM	*3,320*	*8,150*	*12,200*
Outlet gas temp., °F	*172*	*172*	*172*
Case 1 — LA Process Weight			
Outlet loading, lb/hr	*6.67*	*11.58*	*16.19*
Outlet loading, gr/ACF	*0.23*	*0.17*	*0.15*
Efficiency, wt. %	*89.6*	*92.7*	*93.2*
Case 2 — High Efficiency			
Outlet loading, lb/hr	*0.28*	*0.70*	*1.04*
Outlet loading, gr/ACF	*0.01*	*0.01*	*0.01*
Efficiency, wt. %	*99.6*	*99.6*	*99.6*

Table 32

Wet Scrubber Cost Data for

Brass/Bronze Reverberation Furnace

(LA–Process Weight)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	20	50	75
Inlet Gas Volume, ACFM	3,320	8,150	12,200
Efficiency, Wt.%	89.6*	92.7*	93.2*
Controlled Emission, gr/ACF	0.23	0.17	0.15
Type of Charge	Scrap	Scrap	Scrap
Inlet Gas Temperature, F	2,000	2,000	2,000
System Horsepower BHP at start up	57 32	140 77	207 114
Equipment Cost, $ A. Collector & Quencher B. 304 S.S. Exhauster C. Pipe D. 304 S.S. Pump & Motor E. Fan & Pump Motor Starter Total	 5,025 14,500 550 646 347 21,068	 9,890 20,000 670 926 728 32,214	 13,795 21,400 800 1,252 2,006 39,253
Installation Cost, $ (not including equip.) A. Grass-Roots B. Add-On	 47,200 55,200	 72,300 94,300	 88,000 104,000
Expected Life, Years	10	10	10
Operating and Maintenance $/year	600	600	600

* This efficiency will be exceeded at the horsepower specified.

Table 33

Wet Scrubber Cost Data for

Brass/Bronze Reverberatory Furnace

(High Efficiency)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	20	50	75
Inlet Gas Volume, ACFM	3,320	8,150	12,200
Efficiency, Wt.%	99.6*	99.6*	99.6*
Controlled Emission, gr/ACF	0.01	0.01	0.01
Type of Charge	Scrap	Scrap	Scrap
Inlet Gas Temperature, F	2,000	2,000	2,000
System Horsepower BHP at start up	66	163	240
System Horsepower BHP during operation	36	90	132
Equipment Cost, $			
A. Collector & Quencher	5,180	9,980	13,900
B. 304 S.S. Exhauster	21,050	23,000	32,050
C. Pipe	550	670	800
D. 304 S.S. Pump & Motor	646	926	1,252
E. Fan & Pump Motor Starter	347	728	2,006
Total	27,773	35,304	50,008
Installation Cost, $			
A. Grass-Roots	62,300	79,300	112,500
B. Add-On	70,300	91,300	128,500
Expected Life, Years	10	10	10
Operating and Maintenance $/year	600	600	600

* This efficiency guarantee contingent upon field sampling.

Figure 10

Costs of Wet Scrubbers for

Brass/Bronze Reverberatory Furnaces

(LA–Process Weight)

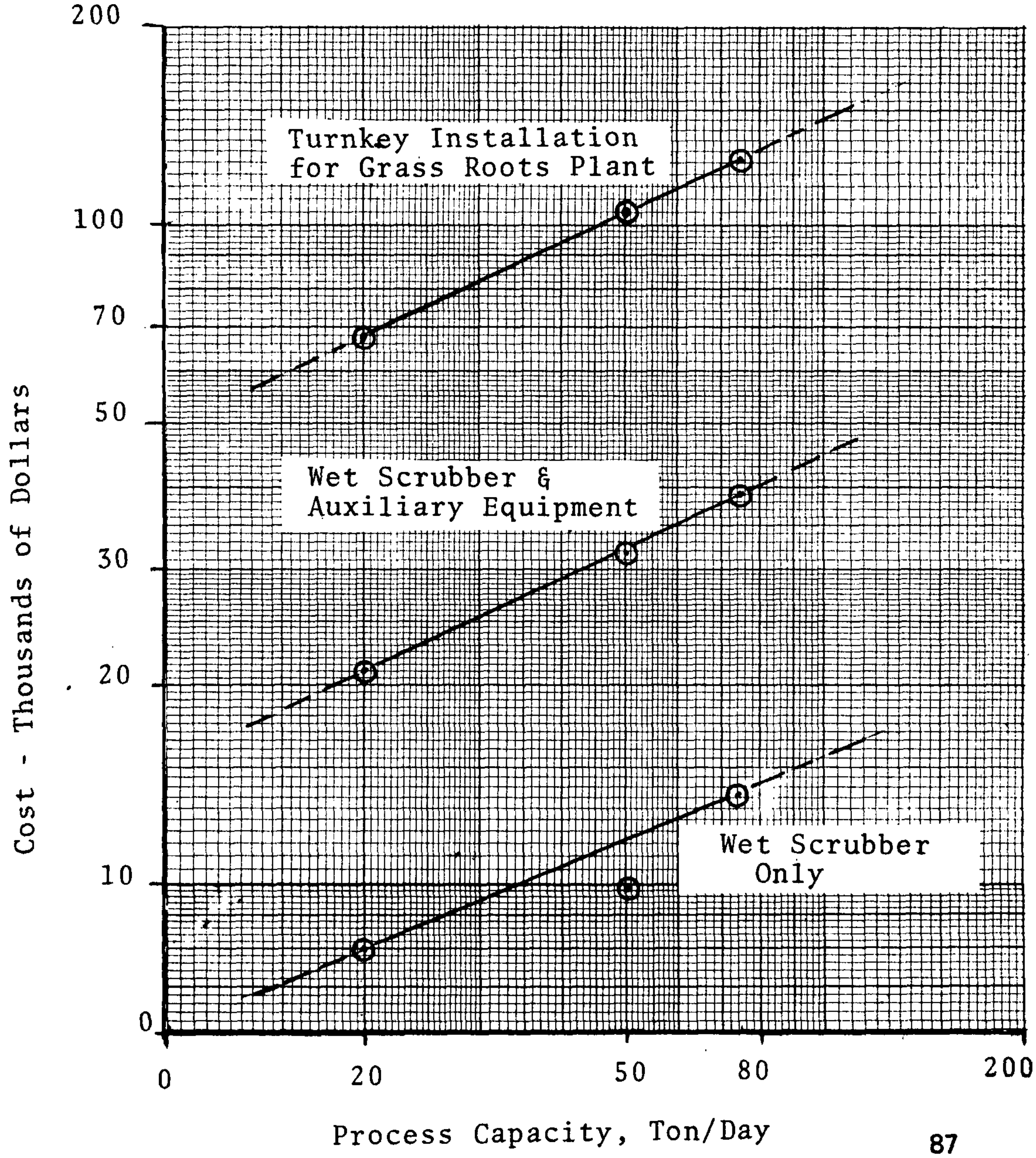


Figure 11

Costs of Wet Scrubbers for

Brass/Bronze Reverberatory Furnaces

(High Efficiency)

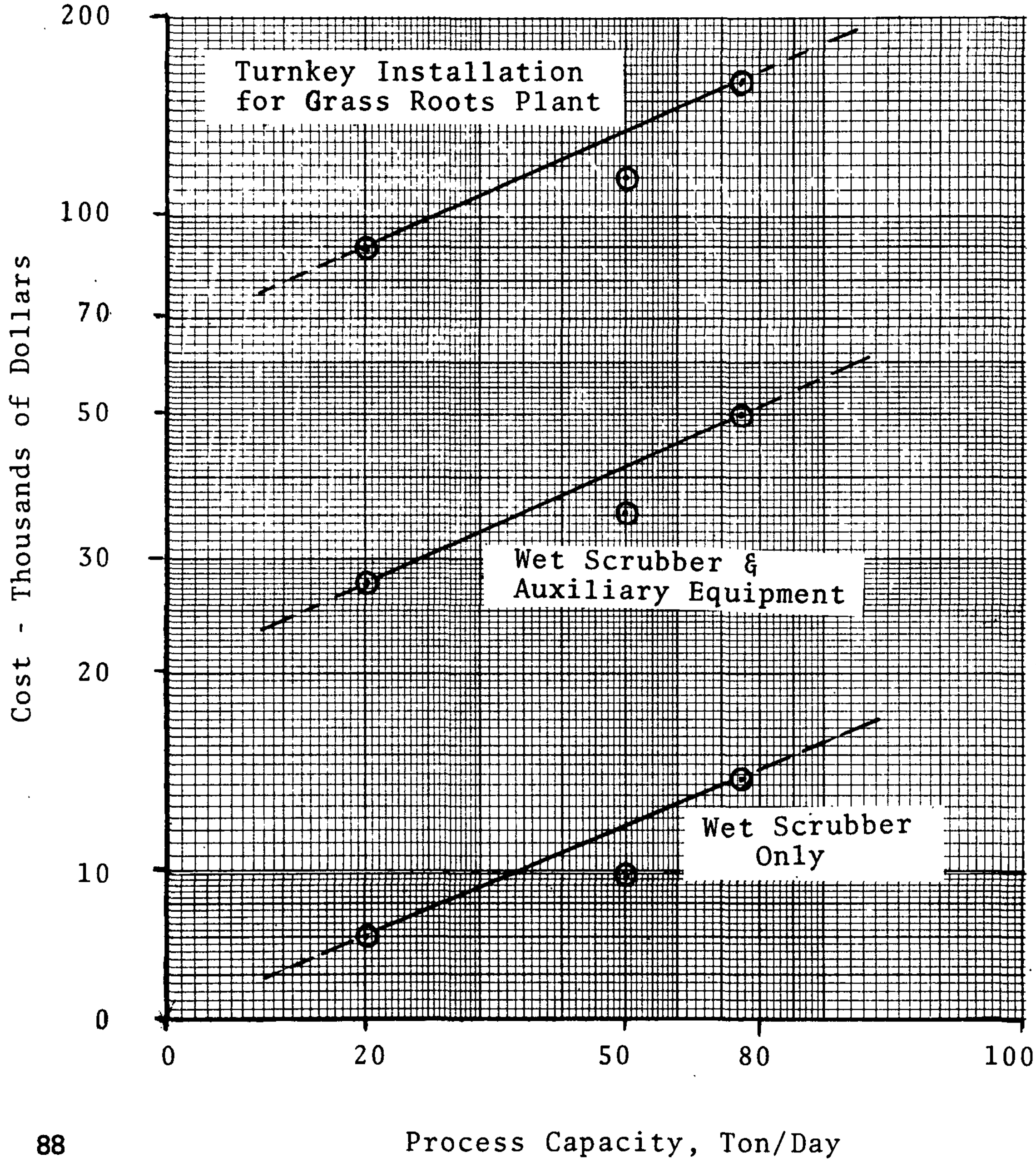
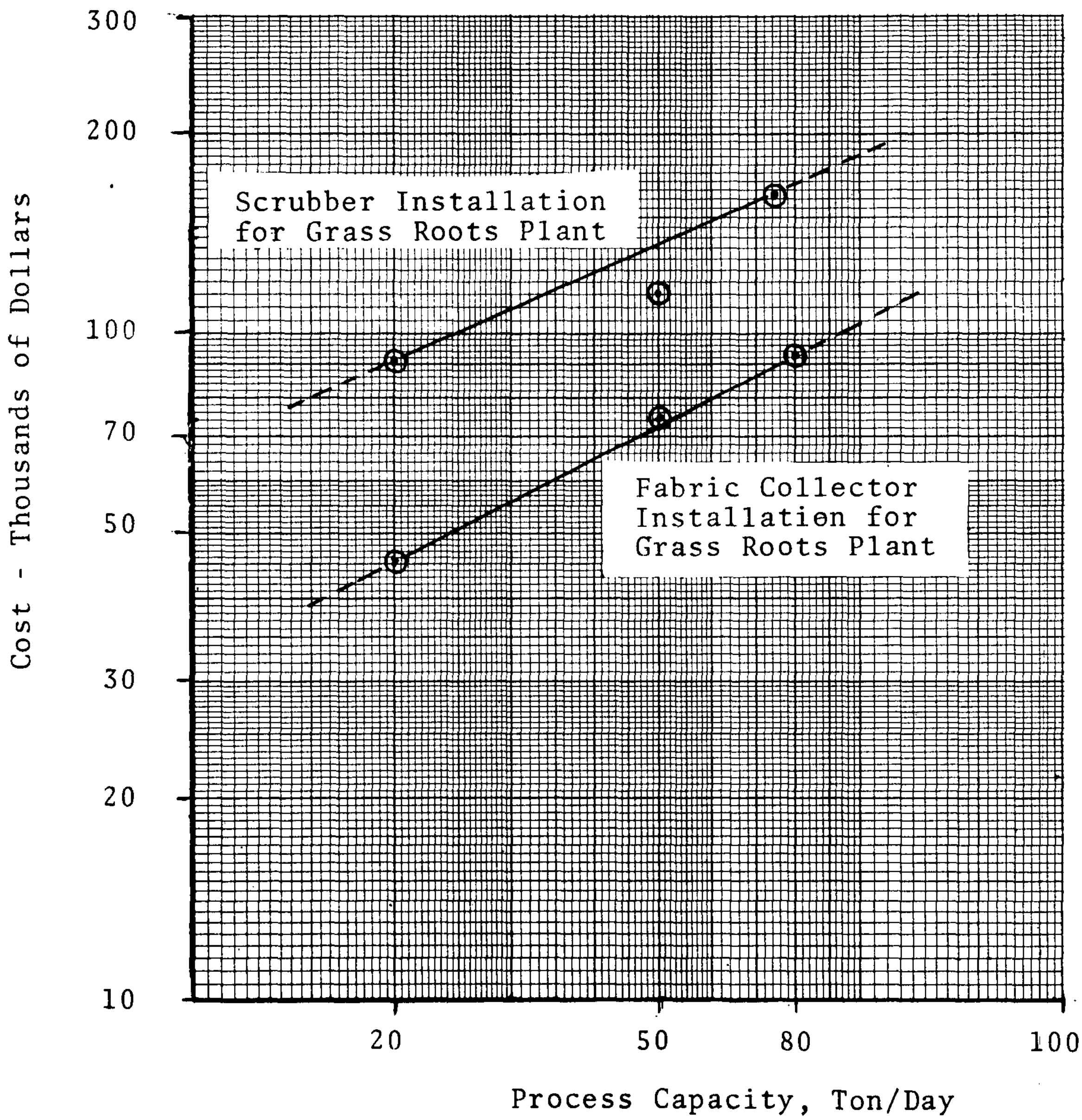


Figure 12

Comparison of Abatement Costs for Brass/Bronze Reverberatory Furnaces (Based on Turnkey Installation)



While these circumstances indicate a fabric collector most economical for the conditions specified in this study, some circumstances favor scrubbers. For example, if acidic materials from burnout or sweating operations are included in the gas stream discharged into the collector, it may be necessary to use a scrubber to control the gas emission, or to eliminate the possibility of deterioration of the bags. In particular, if sulfur dioxide emissions from a lead smelting operation are to be included in a common air pollution control system, the scrubber may be required for SO_2 control in the future. In this case the scrubber cost would be higher than shown because of the need for special materials of construction.

REFERENCES FOR BRASS/BRONZE REVERBERATORY SECTION

1. Brass and Bronze Ingot Institute and National Air Pollution Control Administration, "Air Pollution Aspects of Brass and Bronze Smelting and Refining Industry" (U.S. Dept. of H.E.W., Public Health Service, August, 1969, p. 9

2. J. A. Danielson, "Air Pollution Engineering Manual" (U.S. Dept. of H.E.W., Public Health Service, Publication No. 999-AP-40, 1967), p. 235

3. American Conference of Governmental and Industrial Hygienists, "Industrial Ventilation" (Library of Congress Catalog Card Number: 62-12929, 11th Edition, 1970), p. 10-11

4. IGCI Publication F2, "Fundamentals of Fabric Collectors and Glossary of Terms", IGCI, Box 448, Rye, N.Y.

3. AIR POLLUTION CONTROL FOR LEAD CUPOLAS

a. PROCESS DESCRIPTION

The lead blast furnace or cupola is a vertical production furnace similar to the iron cupolas used in ferrous smelting practice. Unlike the reverberatory furnace, the cupola serves a very specific function. The cupola is used to reduce oxidized metal. Frequently, metal scrap is charged to the cupola in combination with lead dross or other forms of oxide. However, because the blast furnace is less efficient in retaining the metal, and cannot be used for purification of the molten metal, it is more common to charge scrap for melting and purification to a reverberatory furnace.

1) <u>MANUFACTURING ASPECTS</u>

Figure 13 is a process flow sketch for a typical lead cupola. Charge stock is fed at the top of the furnace through the charging doors. The lower section of the furnace is water cooled, and the upper section consists entirely of refractory. The furnace is charged with a mixture of lead oxide dross and slag, limestone, coke, and some scrap cast iron. Air is injected through tuyeres in the bottom of the furnace and combustion of the coke serves as the source of heat for the melting and reduction process. Additional limestone, dross and coke are added through the charging door toward the top of the cupola and molten metal is tapped off at the bottom. The limestone and iron form a slag that reduces the oxidation of the molten lead. The slag is tapped periodically, and it is customary to maintain a continuous flow of lead from the bottom of the cupola. The process is "semi-continuous" in that charge is added over a period of one or two days and product is withdrawn nearly continuously during this period.

CHARGE STOCK AND PRODUCTS

Cupola charge stock consists of the lead oxide to be reduced, plus coke, limestone, scrap iron and rerun slag. The principal sources of the lead oxide are

a) Reverberatory furnace dross
b) Melt furnace dross
c) Reverberatory furnace slag

The drosses may contain substantial amounts of lead entrained mechanically in the lead oxide. Also, there may be a variety of metal oxides from melting operations in which lead is alloyed with other materials. One

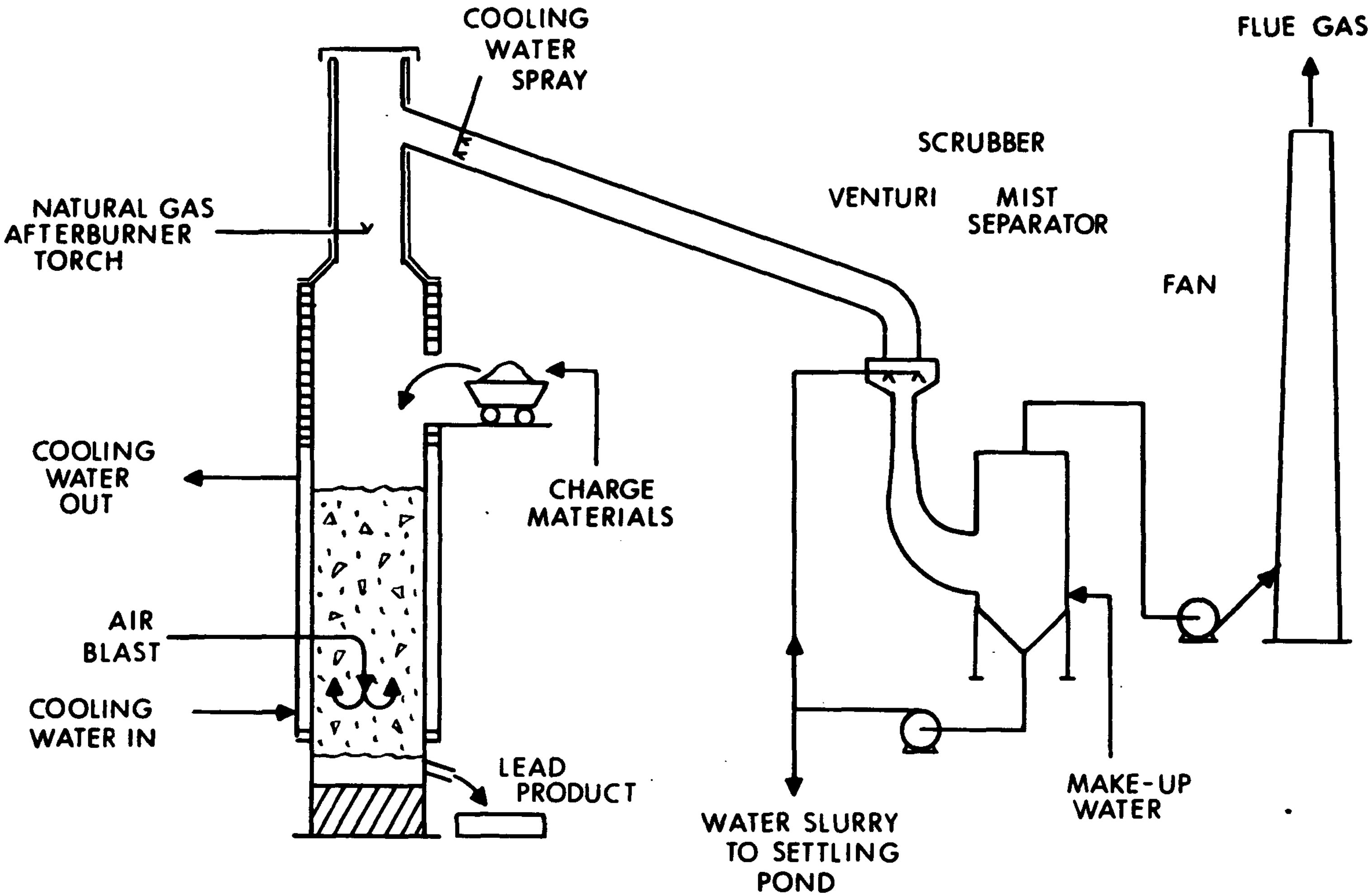


Figure 13

Process Flow Sketch of Lead Blast Furnace or Cupola common source is the lead oxide drosses produced in letter press printing using lead-tin-antimony typemetal.

The composition of a typical cupola charge is shown in Table 34. This table also gives a rough measure of the feed rates for a 25T/D cupola.

The principal product of the lead cupola is antimonial or "hard lead". Antimony-containing lead alloys have better physical properties at low temperatures – up to the boiling point of water – and antimony is included in many alloys where the physical strength is important. Lead-antimony alloys have many uses such as in piping, stereotype plate production in printing, etc. These alloys are frequently unsuitable for very corrosive services, and must be refined in a reverberatory or pot furnace to produce a high purity or "chemical lead". The inclusion of antimony lowers the melting point of the alloy, which makes it more suitable for lead stereotype plates and less suitable for high temperature structural uses. The composition of hard lead, and some of the physical properties are given in Table 35.

High purity lead alloys are usually specified for construction of chemical equipment resistant to acids. These alloys are described as "chemical lead", "acid lead", etc. These alloys, which cannot be produced directly from the cupola, are described in more detail in the section on lead reverberatory furnaces.

About three-fourths of the charge is withdrawn as product with the remaining material tapped off intermittently as slag or lost with the flue gas. Some of the slag is retained for recharging to the furnace and the remainder discarded. The hard lead may be sold directly as a product, or charged to either reverberatory or crucible type furnaces for further refining to remove the metallic impurities by oxidation.

EQUIPMENT

The cupola is an extremely simple apparatus from a mechanical design standpoint. It consists of a vertical shaft into which the charge materials are dumped. The cupolas used in ferrous smelting are lined with refractory over the entire length to withstand the high temperatures required to melt cast iron. For lead applications the cupola operates at much lower temperatures and the lower section can be of refractory-lined or water-cooled steel construction.

A molten metal level is maintained at the bottom, above which a mixed mass of charge solids is contacted with air to burn the fuel, reduce the lead

Table 34

Typical Composition of Lead Cupola Charge

Component	Wt. % of Total	Lb/Hr Average
Dross	82.5	2200
(15%) Metallic Lead		
Pb		
Sb		
Sm		
(85%) Metal Oxides		
PbO		
SbO		
SnO		
Rerun Slag	4.5	120
Scrap Iron	4.5	120
Limestone	3.0	80
Coke	5.5	150
	100.0	2670

Table 35

Typical Properties of Cast Hard Lead

Composition	Wt. %
Lead	92.5
Antimony	6.0
Arsenic	0.4
Tin	1.0
Copper	0.1
Nickel	0.01
	100.0
Tensile Strength, lb/in^2	6800
Brinnel Hardness	12
Density, lb/in^3	0.393
Specific Gravity	10.9
Melting Point, °F	554

oxide, and melt the product. Relatively high temperatures are reached locally in this section, but the gases cool as they pass upward through the fresh charge added to the top of the mass.

The fuel for heating and melting is the coke added with the charge, or in alternate loads, at the charging door. This is oxidized with blast air furnished by an air compressor to the tuyeres at the bottom of the furnace. If infiltration of air at the charge door level were not a factor, the flue gas would consist of the combustion products of the blast air and coke, with some additional gas released by the decomposition of the metal oxides and the limestone. However the gas flow is usually far in excess of the blast air flow.

The charge doors are usually designed to accommodate addition of charge materials by a bucket which is swung into the cupola and dumped. Other methods of charging include conveyors or chute feeders. In the case of bucket feed, the charge doors must be large and are frequently left open or removed altogether. This allows a very high rate of air infiltration into the cupola. When air pollution control equipment is installed, it is necessary to limit infiltration at this point to minimize the size requirement and the operating cost.

Torches or gas burners are frequently installed in the cupola directly above the charging door to burn carbon monoxide and to abate smoke and odor nuisances to some extent. The afterburner section must have some air infiltration to provide for burning the CO, but will be costly to operate without good sealing at the charge doors.

NATURE OF AIR POLLUTION PROBLEM

The chemical reactions taking place in the lead blast furnace are:

(a) oxidation of coke for heat production according to the reaction

$$C + 1/2\,O_2 \rightarrow CO, \qquad \text{or}$$

$$C + O_2 \rightarrow CO_2$$

(b) Reaction of carbon with lead dross according to

$$PbO + C \rightarrow Pb + CO$$

The principal air contaminants produced by the process are carbon monoxide from partial oxidation of the coke fuel, and particulate matter entrained by the highly agitated gases passing through the vertical shaft. The particulate contaminant consists mainly of lead oxide, but also has iron oxide, and oxides of the metals which are constituents in the hard lead. Other charge constituents may also be mechanically entrained. In addition there will be some sulfur dioxide and carbonaceous material.

In addition to the particulate matter entrained by the turbulent flow of gases upward through the charge materials, there will be some vaporization of lead, antimony, and other metals, which condense as metal fumes at the lower temperature in the exhaust system. The *vapor pressure* of these metals is a measure of the tendency to form vapors in the furnace. Table 36 illustrates the concentration of lead and antimony in equilibrium with the flue gas from the cupola as a function of temperature. Vapor pressures are usually given in millimeters of mercury or atmospheres; however, in this case they are calculated in terms of the grain loading they will produce at atmospheric pressure.

2) AIR POLLUTION CONTROL EQUIPMENT

In order to reduce the emission of smoke and carbon monoxide, the cupola should be equipped with an afterburning section directly above the charging door. This section should be sufficiently tall to allow for a residence time of approximately 0.5 seconds or so for the gases leaving the smelting section of the cupola. It should be equipped with gas burners to boost the gas temperature to the 1200°F level during start up, and provide an ignition source at other times as required. It is apparent that excessive leakage inward at the charging door will increase the fuel requirements for the afterburning section significantly, and should therefore be avoided. For cupolas without air pollution control equipment, the natural draft produced by the high gas temperature provides adequate ventilation at the charge door when it is open. However, when air pollution control equipment is added after the afterburner, it is necessary to set the gas flow through this section by the accurate sizing of the fan and air pollution control device. The selection of a gas flow rate through the air pollution control device is one of the critical steps in the design of the air pollution control system. It must satisfy the requirements for inward ventilation at the charging door when it is open, but not establish an uneconomically high rate of ventilation.

GAS FLOW RATE

The gas flow rate leaving the cupola when ventilation at the charge door

Table 36

Calculated Concentrations of

Lead and Antimony Fume

	Lead		Antimony	
Temp.,° F	Metal Fume PPM	Grain Loading gr/SCF	Metal Fume PPM	Grain Loading gr/SCF
1150	23.69	.0895	78.25	.1737
1175	28.04	.1059	92.65	.2056
1200	33.01	.1247	109.13	.2422
1225	38.68	.1461	127.93	.2840
1250	45.11	.1704	149.27	.3313
1275	52.38	.1979	173.39	.3849
1300	60.56	.2288	200.57	.4452
1325	69.74	.2634	231.05	.5128

is adequate but not excessive should be carefully measured using accepted source testing techniques before equipment is selected for air pollution control. For budgetary purposes, the approximate size may be established on the assumption that about 1 SCF will be required per pound of charge to the cupola. This gas will leave the cupola at the charge door level on the order of 1200 - 1500°F. Afterburning in an incineration section above the charge door may increase the temperature to as high as 2000°F. The gas flow leaving the cupola is somewhat less for each pound of charge than would be the case for a reverberatory furnace, because of the ability of the cupola to transfer heat to the charge material before it reaches melting temperature. Also, in the cupola the fuel is burned with less than the theoretical amount of air in order to produce a reducing atmosphere. Both of these factors tend to limit the rate of generation of flue gas for a given charging rate.

PARTICULATE LOADING

The fume loading leaving the afterburning section is likely to be extremely high for the cupola. As much as 10% of the material charged to the furnace may be entrained in the flue gas and carried into the air pollution control equipment. A good average figure is 7% of the total charge. The gases leaving the cupola are ordinarily cooled by infiltration of ambient air rather than by heat exchange or quenching with water if a fabric filter is to be installed as the air pollution control device. In this case, some dilution air can be withdrawn from a hood over the charging door and additional dilution air taken in immediately at the beginning of the duct to the fabric filter. This reduces the temperature for which the duct as well as the filter must be designed. Special care must be taken in designing the system to avoid the possibility of ignition of the filter bags in the event that the ventilating fan stops, or when the exit temperature becomes excessive during "burn down" at the end of a run.

Where a wet scrubber is to be installed to collect the particulate matter, it is possible to limit the size of the scrubbing equipment by using water for quenching rather than by using infiltration air. The point of introduction of the quench water may be immediately after the afterburning section of the cupola in which case the duct can be sized for a relatively low gas volume but must be made of corrosion-resistant material such as a refractory-lined carbon steel or stainless steel. The ducting to the scrubber may be made to withstand the maximum temperature expected at the top of the cupola, and the water supply introduced immediately ahead of the scrubber, or in the scrubber throat itself.

For a wet scrubber, the grain loading will be considerably higher than for the fabric filter with introduction of quench air.

SPECIAL PROBLEMS

Several problems associate themselves specifically with cupola operation in a secondary smelting plant. These are discussed in some detail in the following paragraphs.

The geometry of the cupola makes the estimation of the proper gas flow rate for the air pollution control equipment one of the most difficult problems. This is because the ventilation rate measured at the top of the charge door for the untreated cupola may be many times the minimum requirement for correct ventilation. Prior to the installation of air pollution control equipment, there is no reason to limit the gas flow at this point. However, the addition of an afterburning section has a fuel requirement associated with it if too much infiltration air is allowed at the charge door level. Even more costly is the design of particulate collection equipment to handle several times the minimum gas flow required. For this reason, it is not always possible to select a proper gas flow for the air pollution abatement system by performing a source test on the untreated cupola. In addition, it is necessary to make a careful estimate of the minimum ventilating rate which will be acceptable at the charge door prior to the selection of abatement equipment.

Another problem peculiar to the cupola involves the use of solid fuel. Whereas reverberatory furnaces and crucibles are frequently gas fired and subject to nearly instantaneous control of the fuel and air rates used for combustion, the cupola is fired by the addition of coke in batches at the charging door. After a load of coke has been dumped into the cupola, it is difficult to control the combustion if an emergency situation arises. For example, if the ventilating fan power fails it is not possible to have the combustion cut back instantaneously without producing a very serious operating problem. For this reason, the provisions for operating in high temperature emergency situations without damage to the air pollution control equipment should be considered in the initial design.

When fabric filters are used for collection of the oxide particulate materials, the disposal problem is minimized because the oxides can be recharged to the cupola. However, when wet scrubbing systems are utilized, the oxides are recovered in a dilute slurry which may be difficult to recycle. The simplest mechanism for handling the recovered material is shown in the flow scheme in Figure 13, where the slurry is simply conducted to a settling pond where it is allowed to stand for a minimum of several days. The particulate matter settles to the bottom and may be dredged out, and air dried for recycle to the cupola. The other alternatives involve using an intermediate settler and filter, or a filter alone for separation of the oxides from the scrubbing medium. Ordinarily, it is not possible to return the water to the sewage system or to a natural body of water with the substantial concentration of lead compounds.

b. SPECIFICATIONS AND COSTS

The lead blast furnace is frequently treated in combination with other furnaces in a secondary lead plant. When this is done, it is possible to use a single air pollution control system to service several applications. The specifications written for IGCI member companies to use in quoting equipment prices were based on the system serving the cupola alone, but could be modified to handle a reverberatory furnace or a sweating furnace without much additional cost.

The cupola effluent can be treated satisfactorily by either a fabric filter or a scrubber of adequate design. The fabric filter will provide positive control of particulate emissions to a low level, but has some disadvantages relating to the unstable operating conditions of the cupola furnace. Condensation during shutdown and possible temperature surges are examples.

The specifications for the fabric filter quote are given in Table 37. This indicates that all of the cooling must be done by air contact and dilution, rather than water quenching, to protect the filter from plugging with wet cake if temperature drops suddenly. The operating conditions are given in Table 38. As in the previous sections of this report, the complete specification consisted of these two pages plus the general conditions in Appendix IV.

The equipment and installation costs submitted by the member companies are given in Table 39. Only a single response was made for both the LA - Process Weight and the High Efficiency cases, as was true of all the fabric applications. The costs are plotted as a function of size in Figure 14.

The process description and the operating conditions were modified for the wet scrubber because of the use of a spray quench in this case. The description and operating conditions are given in Tables 40 and 41, and the member company response in Tables 42 and 43. These costs are plotted in Figure 15.

Table 37

FABRIC COLLECTOR PROCESS DESCRIPTION

FOR LEAD CUPOLA SPECIFICATION

The fabric filter is to serve a lead cupola or blast furnace charging the following materials:

rerun slag	*4.5%*
scrap cast iron	*4.5%*
limestone	*3.0%*
coke	*5.5%*
dross and slag	*82.5%*
	100.0%

The flue gas exiting the cupola is passed through an afterburning section in which torches ignite the carbon monoxide and other combustibles produced in the cupola. This section is immediately above the charging door and utilizes air infiltration at the charge door to provide sufficient oxygen for combustion.

Immediately following the afterburner section, additional air is drawn into the system to decrease the temperature level to the specified temperature for the fabric filter. The cooled gases are then passed through carbon steel ducts through the wall of the building to a fabric filter located outside. The filter is to be located at ground level, adjacent to the building with sufficient elevation to provide 8′ of clearance beneath the dust hopper valve for truck access. The fan following the filter will be located on a shed roof 28′ above grade and will discharge into a new 70′ stack.

The fabric filter is to operate in such a manner that a single compartment (with no more than one quarter of the total collecting surface area) can be isolated for shaking. The hopper is to have sufficient capacity to hold the dust collected over a 24 hour period without interfering with normal operation of the collector. The hopper valve is to be included in the filter quotation.

Dacron tubular bags shall be used with a gas/cloth ratio of 1.0 FPM/FT^2 or less at operating conditions.

For purposes of this quotation, the following shall be considered to be auxiliary equipment:

(1) Fan and Drive

(2) Dampers

Table 38

FABRIC COLLECTOR OPERATING CONDITIONS

FOR LEAD CUPOLA SPECIFICATION

Three sizes of fabric collectors are to be quoted. While two levels of efficiency are specified, it is assumed that a single fabric collector quotation will be supplied for each size.

	Small	Medium	Large
Furnace Capacity, ton/day	12	25	50
Process weight (charge), lb/hr	1,300	2,670	5,340
Inlet gas volume, ACFM	5,000	10,000	20,000
Inlet gas temperature, °F	270	270	270
Inlet loading, lb/hr	115	230	460
Inlet loading, gr/ACF	2.68	2.68	2.68
Case 1 – LA Process Weight			
Outlet loading, lb/hr	3.26	4.80	6.92
Outlet loading, gr/ACF	0.076	0.056	0.040
Efficiency, wt. %	96.9	97.9	98.5
Case 2 – High Efficiency			
Outlet loading, lb/hr	1.29	2.57	5.15
Outlet loading, gr/ACF	0.03	0.03	0.03
Efficiency, wt. %	98.9	98.9	98.9

Table 39

Fabric Collector Cost Data

for Lead Cupola

INFORMATION	FABRIC FILTER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	12	25	50
Inlet Gas Volume, ACFM	5,000	10,000	20,000
Efficiency, Wt. %	98.9	98.9	98.9
Controlled Emission, gr/ACF	.03	.03	.03
Type of Charge	Dross & Slag	Dross & Slag	Dross & Slag
Inlet Gas Temperature, °F	270	270	270
System Horsepower	22	33.5	65.5
Equipment Cost, $			
A. Collector	12,254	16,813	25,429
B. Auxiliaries	1,195	2,283	3,347
C. Gas Conditioning Equipment	3,100	4,000	4,500
D. Waste Equipment	-----	-----	-----
E. Other	450	450	525
Total	16,999	23,536	33,801
Installation Cost, $			
A. Grass-Roots	13,428	19,022	27,265
B. Add-On	-----	------	------
Expected Life, Years	10	10	10
Operating and Maintenance $/year	1,556	2,232	3,836

Figure 14

Cost of Fabric Collectors

for Lead Cupola

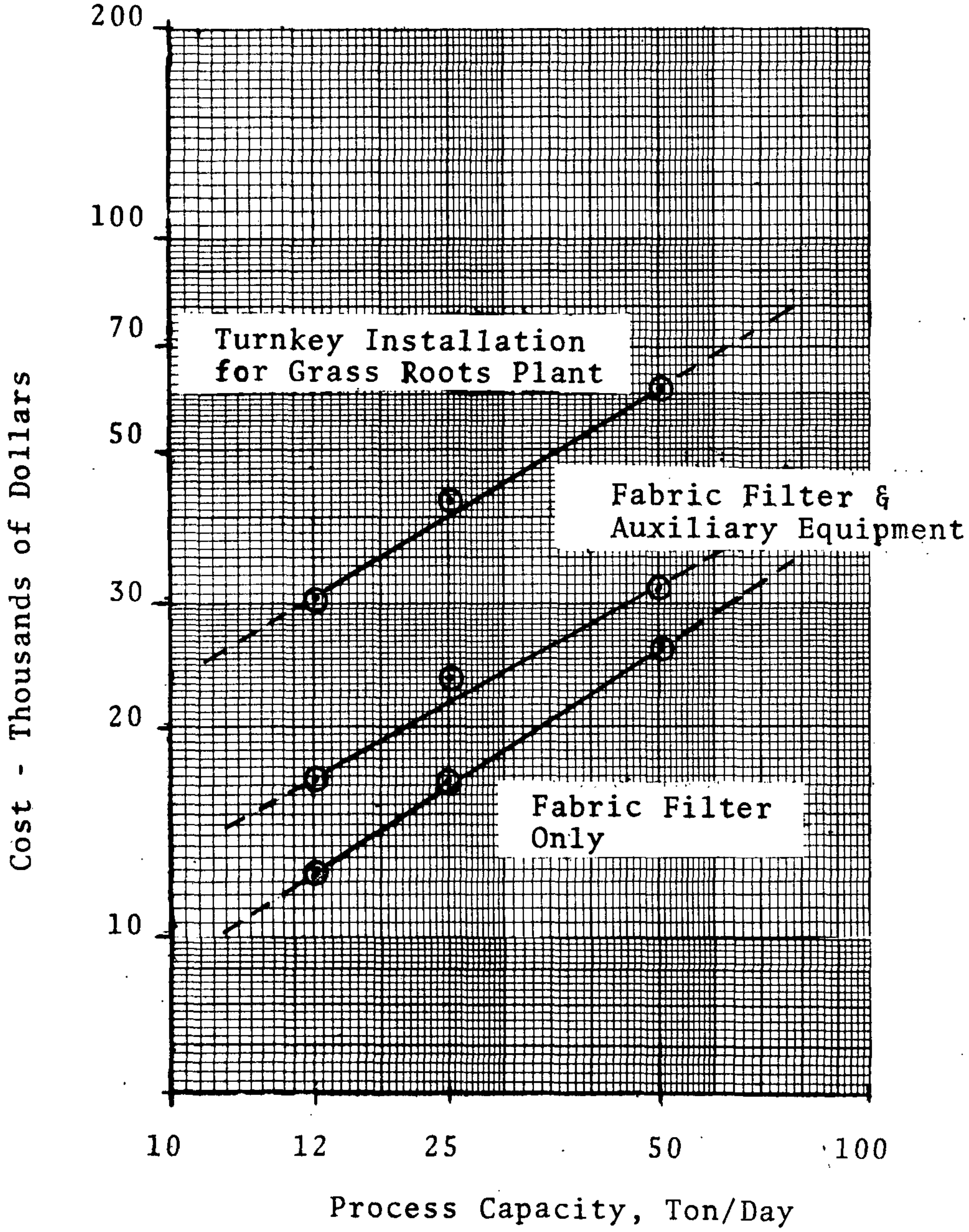


Table 40

WET SCRUBBER PROCESS DESCRIPTION

FOR LEAD CUPOLA SPECIFICATION

The scrubber is to serve a lead cupola charging the following materials:

rerun slag	*4.5%*
scrap cast iron	*4.5%*
limestone	*3.0%*
coke	*5.5%*
dross and slag	*82.5%*
	100.0%

The flue gas exiting the cupola is passed through an afterburning section in which torches ignite the carbon monoxide and other combustibles produced in the cupola. This section is immediately above the charging door and utilizes air infiltration at the door to provide sufficient oxygen for combustion.

Immediately following the afterburner, a spray quench is provided to reduce the gas temperature to the 500°F level. The cooled gases are passed through carbon steel ducts through the wall of the building at an elevation of 20′ above grade and into the scrubber. The scrubber is to be located in a clear area adjacent to the building. The fan will be located after the scrubber on an adjacent shed roof approximately 20′ above grade and will discharge into a new 70′ stack.

The ductwork after the quench section is to be 304 stainless steel or have equivalent corrosion resistant properties. The scrubber is to be constructed of 304 L or equivalent stainless steel wherever wetted by the scrubbing liquor.

The external piping and pumps will be rubber-lined carbon steel or equivalent. The pump is to be equipped with fresh water flushed glands to prevent damage to the packing. The liquor containing the collected particulate matter is to be discharged into a settling pond within 100′ of the scrubber. The scrubber pressure drop shall be no less than 50″ wc (or equivalent energy input) for the LA-Process weight specification, and no less than 60″ wc (or equivalent energy input) for the high efficiency case.

For purposes of this quotation, auxiliaries shall include:

(1) Fan

(2) Pump or pumps

(3) External piping

(4) Controls

(5) Dampers

Table 41

WET SCRUBBER OPERATING CONDITIONS

FOR LEAD CUPOLA SPECIFICATION

Three sizes of scrubbers are to be quoted for each of two levels of efficiency.

	Small	Medium	Large
Furnace Capacity, ton	12	25	50
Production rate, lb/hr	1,000	2,000	4,000
Process weight rate, lb/hr	1,300	2,670	5,340
Inlet gas volume, ACFM	3,675	7,350	14,700
Inlet gas temperature, °F	500	500	500
Inlet loading, lb/hr	115	230	460
Inlet loading, gr/ACF	3.65	3.65	3.65
Outlet gas volume, ACFM	3,550	7,100	14,200
Outlet gas temperature, °F	190	190	190
Case 1 — LA Process Weight			
Outlet loading, lb/hr	3.26	4.80	6.92
Outlet loading, gr/ACF	0.11	0.079	0.057
Efficiency, wt. %	96.9	97.9	98.5
Case 2 — High Efficiency			
Outlet loading, lb/hr	0.91	1.89	3.56
Outlet loading, gr/ACF	0.03	0.03	0.03
Efficiency, wt. %	99.2	99.2	99.2

Table 42

Wet Scrubber Cost Data

for Lead Cupola

(LA-Process Weight)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	12	25	50
Inlet Gas Volume, ACFM	3,675	7,350	14,700
Efficiency, Wt.%	96.9*	97.9*	98.5*
Controlled Emission, gr/ACF	0.11	0.079	0.057
Type of Charge	Dross & Slag	Dross & Slag	Dross & Slag
Inlet Gas Temperature, °F	500	500	500
System Horsepower BHP at start up	67	135	270
System Horsepower BHP during operation	40	81	161
Equipment Cost, $			
A. Collector & Separator	2,900	4,020	7,940
B. 304 S.S. Exhauster	16,500	16,900	22,500
C. Pipe	935	1,000	1,060
D. 304 S.S. Pump & Motor	750	840	930
E. Fan & Pump Motor Starter	560	1,080	2,542
Total	19,645	23,840	34,972
Installation Cost, $			
A. Grass-Roots	44,200	53,500	78,500
B. Add-On	48,200	59,500	86,500
Expected Life, Years	10	10	10
Operating and Maintenance Hrs/Month	600	600	600

* Will probably produce higher efficiency at the specified pressure drop.

Table 43

Wet Scrubber Cost Data

for Lead Cupola

(High Efficiency)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	12	25	50
Inlet Gas Volume, ACFM	3,675	7,350	14,700
Efficiency, Wt.%	99.2*	99.2*	99.2*
Controlled Emission, gr/ACF	0.03	0.03	0.03
Type of Charge	Dross & Slag	Dross & Slag	Dross & Slag
Inlet Gas Temperature, F	500	500	500
System Horsepower BHP at start up	85	169	338
System Horsepower BHP during operation	49	98	196
Equipment Cost, $			
A. Collector & Separator	3,050	4,220	8,350
B. 304 S.S. Exhauster **	21,500	23,000	29,400
C. Pipe	935	1,000	1,060
D. 304 S.S. Pump & Motor	750	840	930
E. Fan & Motor Pump Starter	560	1,080	2,542
Total	26,795	29,140	42,282
Installation Cost, $			
A. Grass-Roots	.60,400	66,600	95.200
B. Add-On	64,400	72,600	103,200
Expected Life, Years	10	10	10
Operating and Maintenance $/year	600	600	600

* Guarantee contingent upon field testing.

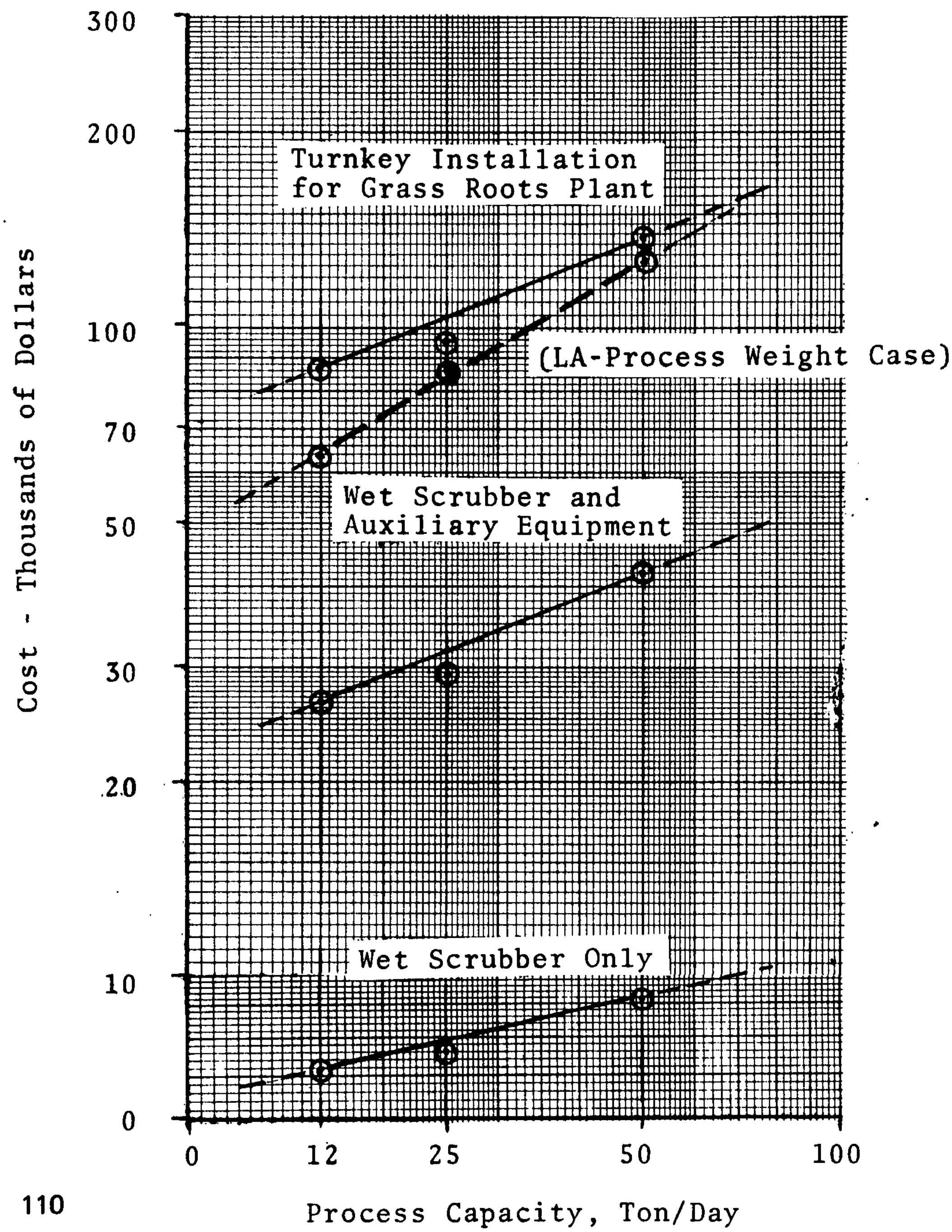
** 316 L S.S. recommended by manufacturer.

Figure 15

Costs of Wet Scrubbers

for Lead Cupola

(High Efficiency)



c. DISCUSSION OF COSTS

Both fabric filters and wet scrubbers are used for lead cupola air pollution abatement. The fabric filter is more costly than the basic scrubber for these applications, but is simpler to install. On the basis of equipment plus auxiliaries, the fabric collector is less expensive, and an even larger difference in favor of the filter appears in the "turnkey" figures.

The scrubber has a significant process advantage in that it can be used to remove SO_2 from the flue gas as well as particulate matter. This may become an important advantage in the future as SO_2 emission regulations become more restrictive. It is most likely to be an important factor when lead cupola effluents are combined with those from reverberatory furnaces, or other sources which are likely to contain high concentrations of SO_2.

REFERENCES FOR LEAD CUPOLA SECTION

1. Danielson, John A., "Air Pollution Engineering Manual", NAPCA, U.S. Govt. Printing Office, Public Health Service Publication No. 999-AP-40

2. Norton, Frederick Harwood, "Refractories", McGraw-Hill, New York, 4th edition, (1968)

3. Perry, John H., "Chemical Engineers Handbook", 4th edition, McGraw-Hill, New York (1963)

4. AIR POLLUTION CONTROL FOR LEAD/ALUMINUM SWEATING FURNACES

a. PROCESS DESCRIPTIONS

1) MANUFACTURING ASPECTS

The metal recovery process generally referred to as sweating is distinct from purely metallurgical processes which involve alloying, fluxing, and the like, and is best described as a metal separation process. The sweating process is quite literally the sweating, or slow melting, of the low melting constituent from a metallic scrap containing a variety of both metallic and non-metallic impurities. Aluminum is the most common metal recovered by the sweating process; however, tin, lead, zinc, copper, and even iron are reclaimed in this manner, but on a considerably smaller scale.

FURNACE EQUIPMENT AND OPERATION

The type of furnace equipment employed in a sweating operation depends largely upon the size of operation. Open hearth-type reverberatory furnaces are used in many large aluminum recovery plants. Smaller rotary or tube type reverberatory furnaces are used in small aluminum operations and in operations recovering other metals such as lead and tin. This is not always the rule, however. Many times, perhaps due to simplicity of design and operation, a small sweating operation will employ a crude open hearth type reverberatory furnace even though it is a less efficient operation. In the open hearth type reverberatory furnace, the hearth is constructed with a slight incline to the rear of the furnace, which allows the continuous tapping of molten metal as the sweated component melts and separates from the solid charge. The rotary furnaces are tapped periodically from ports which are normally sealed during rotation and firing. The furnaces are generally refractory lined, however, in the case of tin and lead sweating, cast iron construction is possible due to the relatively low melting points of these metals. Most of the furnaces are used to recover alternatively a variety of metals, and consequently, refractory construction is essential. This is especially true in the smaller metal recovery operations. The reverberatory furnaces can be either gas or oil fired. The choice of fuel depends on availability and price.

A typical sweating heat involves charging scrap to the furnace hearth and gradually heating the scrap to a temperature slightly above the melting point of the metal to be separated. As the metal is sweated from the scrap it is tapped into ingots. Fresh charge is continuously added until either the available scrap is depleted or the heat is terminated according to a planned schedule. As the unmelted residual scrap accumulates, it must be periodically raked from the hearth for further processing, sale, or disposal. In a typical small metals recovery plant the sweating operation is a batch-type process, where accumulations of scrap are sweated periodically, according to inventory demands.

The majority of these sweating operations are completely devoid of pollution control facilities. Again, this is especially true of the smaller plants. Sometimes an afterburner is included either as a separate entity or, more commonly, incorporated in the furnace itself.

A typical open hearth type reverberatory sweating furnace facility is shown in Figure 16. It should be noted that this system has no fan, and depends solely on the natural draft produced in the stack for ventilation of the furnace.

The foregoing discussion is valid for most reverberatory sweating furnaces. The pollution problems and their solutions, however, are specific to a given sweating process; the exact solution must be determined by the specific metal being separated and the nature of the scrap charge.

ALUMINUM SWEATING

The aluminum sweating process takes place at a temperature slightly in excess of 1220° F (the melting point of aluminum). There is very little fuming or oxidation of the aluminum metal itself; however, the contaminants in a typical scrap charge produce large amounts of both gaseous and particulate emissions. The scrap charged to an aluminum sweating furnace may include any one or combination of the following: drosses; skims; aircraft engines, seats, and wreckage; painted aluminum sheet metal; insulated wire; automotive parts; etc.

Smoke is evolved from the incomplete combustion of organic compounds in these charge materials, and fumes are produced from the oxidation of zinc and magnesium contaminants. The sweating of aluminum drosses and skims is particularly troublesome because they contain halide salts which hydrolize to form very corrosive solutions of hydrochloric acid. Along with the gaseous pollutants evolved including oxides of sulfur and carbon, aluminum chloride gas, and others, a considerable amount of particulates are evolved in the aluminum sweating process.

Published emission rates from uncontrolled aluminum sweating furnaces indicate an average rate of 33 pounds particulate per ton processed aluminum

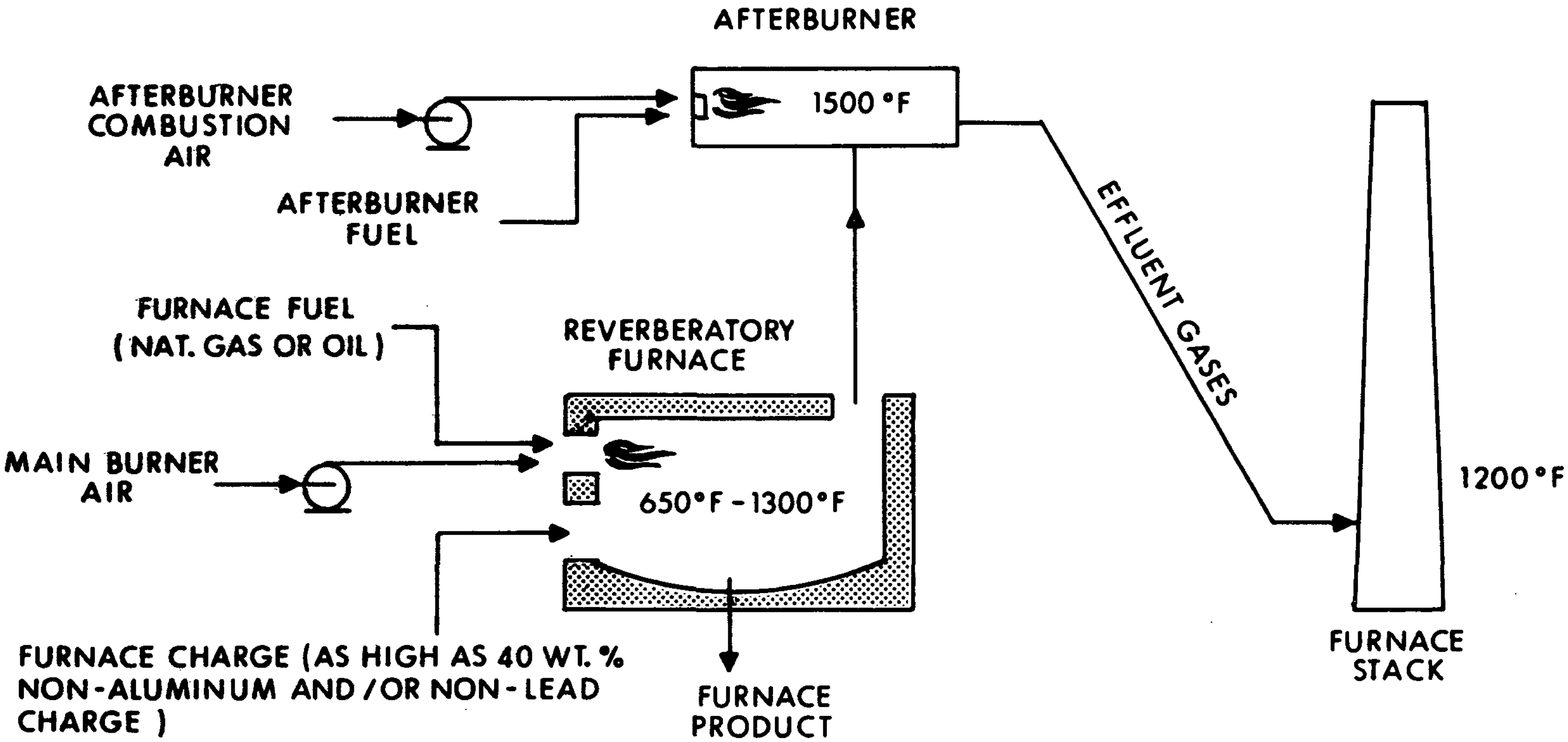


Figure 16

Process Flow Sketch of Typical Reverberatory Furnace Sweating Facility metal. Assuming a typical 60 weight percent recoverable aluminum in the scrap, one pound of particulates will be evolved for each 100 pounds of charge material. An average furnace with a capacity of 1000 pounds of processed aluminum per hour will produce 10 pounds of particulates per hour, a large percentage of which is of sub-micron particle size.

LEAD SWEATING

The lead sweating process is inherently more troublesome than aluminum sweating from a pollution standpoint. Although it is carried out at a considerably lower temperature (approximately 650°F) and therefore produces less metallic fumes, the nonmetallic contaminants in a typical scrap charge produce large amounts of pollutants. One of the primary constituents of most lead scrap charges, the junk automobile storage battery, is responsible for a large portion of these emissions. In addition to lead storage batteries, lead drosses and skims, lead sheathed cable and wire, aircraft ballast weights, and other materials are charged to the sweating furnace. Large amounts of sulfur oxides, as well as other sulfur compounds, are released from the incineration of the lead storage batteries. The sulfuric acid produced by the hydrolysis of sulfur trioxide gas is particularly corrosive to both furnace and pollution control equipment. The asphaltic battery cases, grease, oil, and other organic contaminants are only partially incinerated in the sweating furnace and produce large amounts of smoke and soot.

It is common practice to employ a single furnace for a variety of sweating processes, and the 1000 pound per hour aluminum sweating furnace cited earlier could be employed for lead sweating also. However, due to the large difference in heat required to melt lead and aluminum, this same furnace could sweat 10,000 pounds of lead per hour, at an equivalent fuel rate. Published data indicate that approximately 150 pounds of particulates are evolved per ton of scrap metal charge. Assuming 60 weight percent recoverable metallics in the charge, the 10,000 pound per hour lead sweating furnace would emit 1250 pounds of particulates per hour, or 250 pounds of particulates per ton of processed lead. This particulate matter is very fine, generally in the submicron range, with some particles as small as 0.001 micron.

2) AIR POLLUTION CONTROL EQUIPMENT

The control of aluminum and lead sweating furnace emissions is a difficult abatement problem, and the requirements should not be underestimated. However, good control is wholly within the capabilities of our present technology. It is essential, however, that the individual nature of each source be appreciated and the potential pitfalls considered.

The maximum allowable particulate emission levels are generally specified as a function of process weight (as in the Los Angeles County Air Pollution Control District) or by the opacity of the effluent gas stream. When the allowable emission levels are expressed in terms of collection efficiency, the opacity basis indicates efficiency requirements which are independent of process size; whereas, the process weight efficiency requirements increase with process size. The most stringent opacity requirement is, of course, a "clear" stack, which for an aluminum or lead sweating process is approximately 0.03 grains per actual cubic foot. Several collection efficiency requirements have been calculated for both aluminum and lead sweating operations over a range of process sizes; these values are included in the specifications (Air Pollution Control Equipment Specifications for Lead/Aluminum Reverberatory Sweating Furnace). The required collection efficiencies range from 77.3 weight percent to 99.7 weight percent.

In addition to venting the products of combustion from the sweating furnace, an air pollution control system should also include hooding facilities to provide ventilation during furnace charging and tapping. Properly designed canopy hoods should suffice for the open hearth type reverberatory furnaces; however, more complicated hooding may be necessary for the rotary, or tube type reverberatory furnaces.

Of the common high-efficiency type collection equipment presently available, only the fabric filters and wet scrubbers can provide a satisfactory solution to the pollution problems of the lead/aluminum sweating furnace. Although the electrostatic precipitator has the necessary performance potential, the required auxiliary equipment and additional electrical power supply services render the electrostatic precipitator economically impractical for the relatively small gas volumes handled in sweating facilities.

The oily and combustible nature of the sweating furnace effluent presents an explosion hazard and many other operational problems. An afterburner is essential to any pollution control equipment. The afterburner must be designed to provide adequate mixing and sufficient retention time for complete combustion at firing temperatures. This is true whether it is an integral part of the sweating furnace or a separate piece of equipment. A luminous flame afterburner operating at between 1200°F and 1500°F is generally recommended.

FABRIC FILTERS

The installation of a fabric collector is perhaps the most common approach to the sweating furnace abatement problem. However, due to the temperature limitations on filter fabrics, the afterburner effluent gases must first be cooled to an acceptable temperature level, usually around 250 F. Evaporative cooling with a water spray, and mixing with ambient air are used, but the most successful method uses radiant/convection U-tube heat exchangers. Both evaporative cooling and cooling by ambient air dilution have caused condensation of water and acid vapors in some cases. Relatively heavy, woven Dacron bags, applied at superficial velocities of approximately two feet per minute are commonly used in this application. Orlon has also been employed successfully in some instances.

If the baghouse temperature is allowed to drop below the water or acid vapor dew point, hydrolysis of halide salts may take place. Direct condensation of hydrochloric, sulfuric, or hydrofluoric acid will occur, with devastating effects on both the baghouse shell and the fabric bags themselves. For this reason strict temperature control must be maintained on any fabric filter installation. Ideally a baghouse should be both fully insulated and equipped with standby heating facilities to insure the minimum of condensation, even during periods when the furnace is not being fired. As an added precaution most baghouses are epoxy coated to prevent corrosion. To protect against uncontrolled temperature surges or cooler failure an emergency dilution, or bypass damper may be installed upstream of the baghouse, shown in Figure 17.

WET SCRUBBERS

High-energy wet scrubber systems have been successfully applied to aluminum/lead sweating facilities and afford an excellent solution to the pollution control problem. However, the high operating costs, the potential water pollution problems, and the relative complexity of the equipment have limited the appeal of scrubbers. Considerably less space is required for the installation of a scrubber system than an equivalent baghouse. This is because scrubbers do not require cooling of the inlet gas, and because they are, ordinarily, smaller than the equivalent baghouse. Perhaps the most important advantage of a scrubber system is the ability to remove corrosive gases and mists from the furnace effluent gases as well as extremely fine particulate matter.

An aluminum/lead sweating facility will require a high-energy Venturi

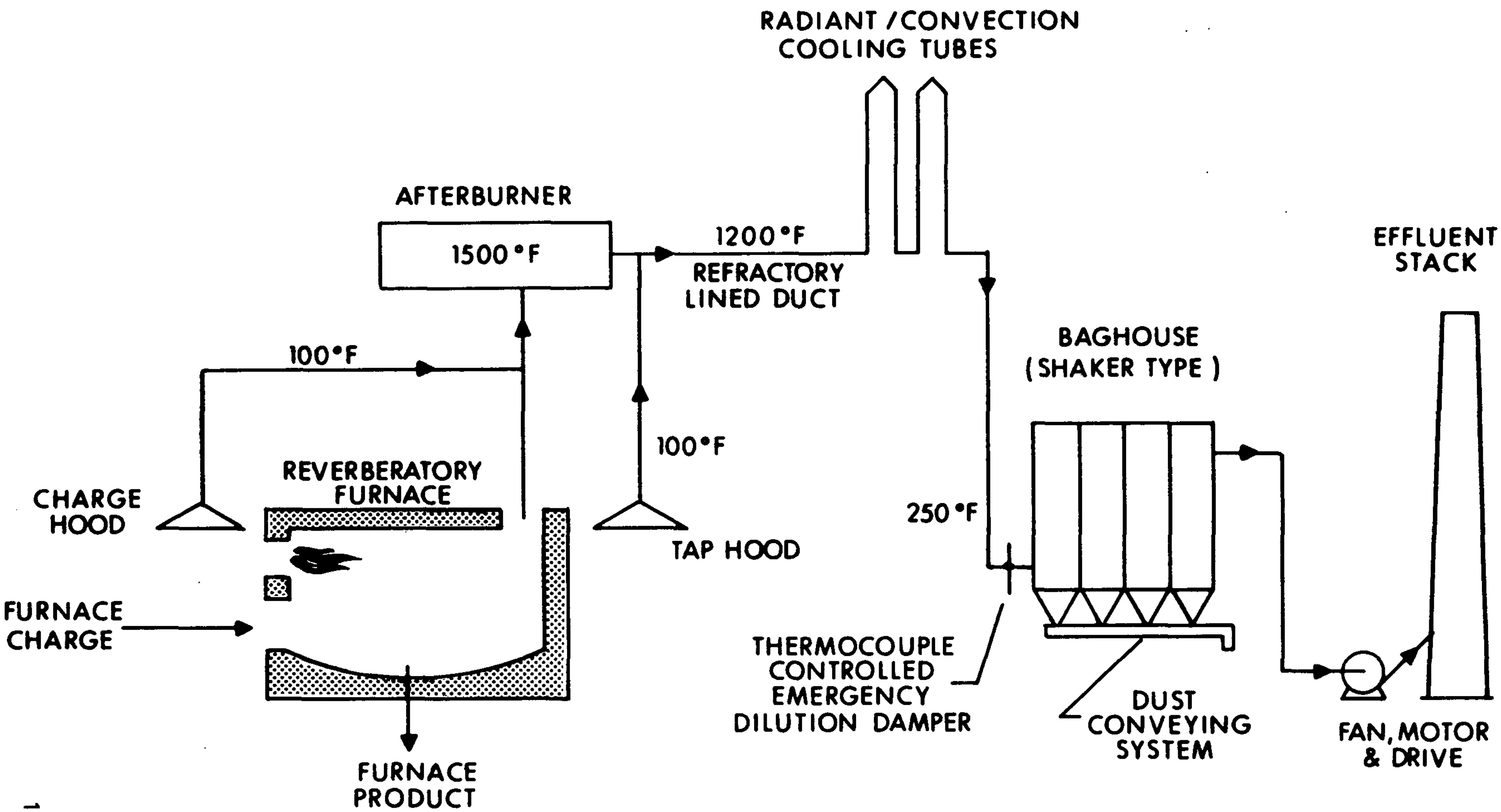


Figure 17

Typical Fabric Collector Installation

for Reverberatory Furnace Sweating Facility scrubber possibly requiring as much as 40 or 50 inches wg differential pressure across the transfer zone, or an equivalent scrubber, to provide the necessary particulate collection efficiency. The portion of the scrubber system exposed to high temperatures and/or abrasion must be refractory lined. The remainder of the downstream system should be fabricated of corrosion resistant materials. With caustic addition using a pH controller and possibly clarification, the effluent slurry will be acceptable to most municipal sewage treatment plants, without costly inplant water treatment facilities. To avoid damage to the scrubber during start up either a by-pass damper or an electrically interlocked fan/pump system is recommended, as in Figure 18.

In rare cases, where the scrap charge evolves unusually large quantities of corrosive or noxious gases and a scrubber alone cannot reduce the particulate pollutants to an acceptable level, a combination pollution control system may be necessary. The sweating of PVC coated wire, which evolves hydrochloric acid and organic vapors, and Teflon^{R} coated wire, which evolves hydrofluoric acid, are particularly troublesome in this context. To overcome this problem of excessive gaseous emissions, a packed absorption tower, in addition to a scrubber or baghouse, may be necessary.

b. SPECIFICATIONS AND COSTS

The sweating furnace effluent can be treated adequately by either a fabric collector or a wet scrubber. The variability of the sweating operation makes it difficult to generalize as to the size and performance requirements for air pollution control equipment to fit a given furnace.

Careful measurement of the actual gas flows, particulate contaminant loadings and gas contaminants over the normal range of operations carried out in the furnace to be treated provides an effective, although costly, basis for design.

Another alternative is to minimize the effect of the variable flow from the sweating furnace by combining the effluent with that of the cupola or other smelting equipment.

For purposes of this study, the process description and operating conditions are specified for a furnace which may alternately handle aluminum sweating and lead sweating, but which is treated apart from any other equipment in the smelting plant.

The process description used for the fabric collector case is given in

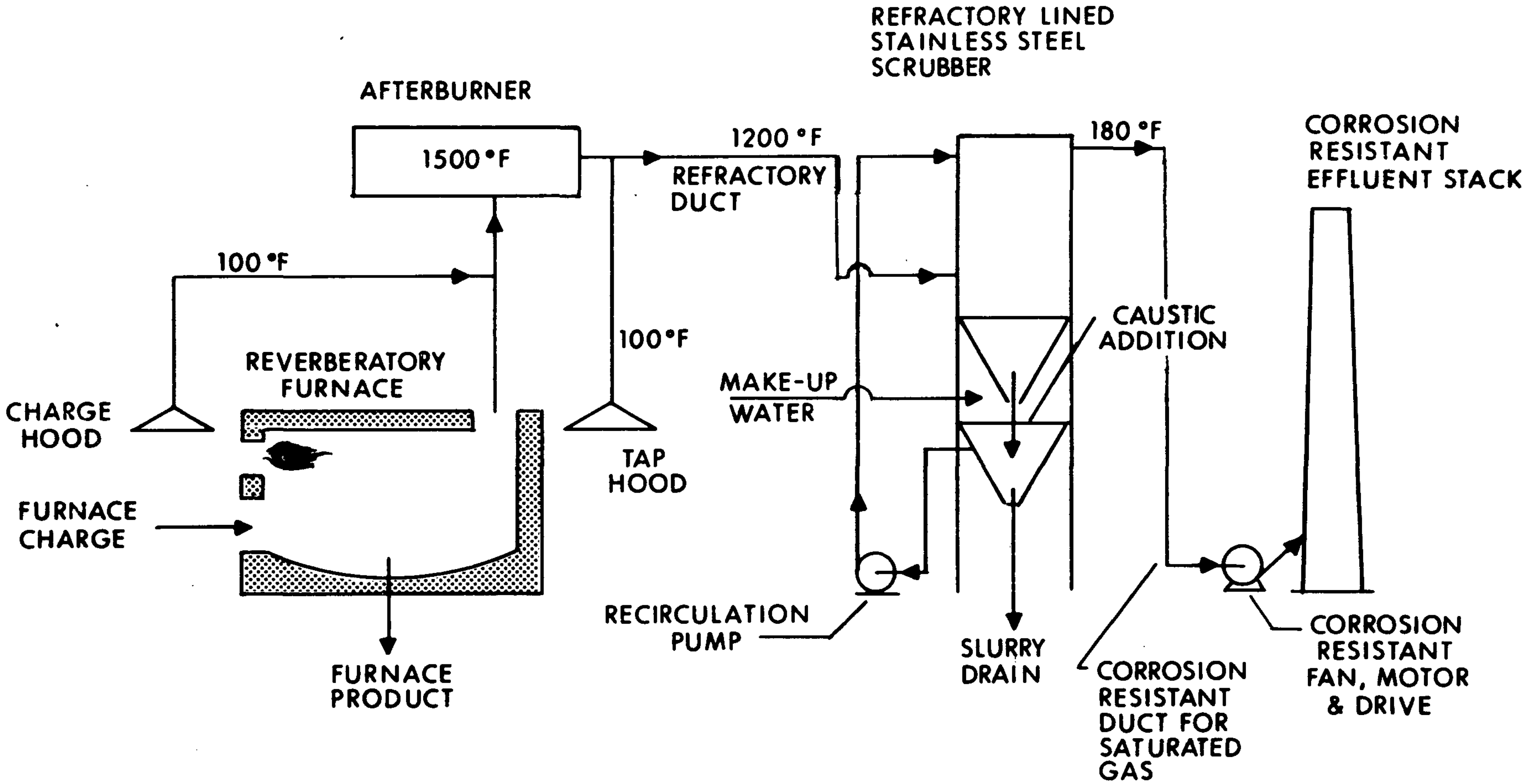


Figure 18

Typical Wet Scrubbing Installation

for Reverberatory Furnace Sweating Facility

Table 44, and the operating conditions in Table 45. The quoted costs are summarized in Table 46, and plotted in Figure 19.

The wet scrubber specifications are detailed in Tables 47 and 48, and the prices received in response in Table 49. These are plotted in Figure 20. As was the case for the fabric collector, the scrubber manufacturer did not distinguish between the low and high efficiency cases.

c. DISCUSSION OF COSTS FOR LEAD/ALUMINUM SWEATING FURNACES

The cost of treating a furnace to be used for sweating operations may vary over a wide range depending upon the charge stock and desired products. Sweating either lead or aluminum from "clean" scrap with little organic or fine particulate material can probably be carried out without air pollution control equipment.

For the more general case in which nearly any lead or aluminum containing material may be included in the charge, both afterburning and particulate collection are required. The afterburning function is most frequently carried out in the furnace proper. Particulate collection by fabric filtration is more expensive in terms of first cost, but has a lower operating cost and longer life.

These factors tend to reduce the apparent cost difference, and if the operation is run on a nearly continuous basis the fabric collector may be less expensive. This is illustrated in Table 50, which compares the "Total Annual Cost" for the two collector types at several levels of usage. In this example, the fabric collector is more costly than the scrubber for 2000 hours of operation per year, but more economical at 4000 or more hours/year. Figure 21 is a plot of operating cost versus annual hours of operation.

Table 44

FABRIC COLLECTOR PROCESS DESCRIPTION FOR SWEATING FURNACE SPECIFICATION

The fabric filter is to serve one aluminum reverberatory or tube furnace used for sweating lead and aluminum alternatively. The capacity of the furnace is given in terms of the rate of product production, which varies between the two operations. For example, 1000 lb/hr aluminum and 10,000 lb/hr lead are alternative designations for the same furnace.

The charge materials will include, but will not be limited to, the items checked below:

	LEAD	ALUMINUM	
√	Auto batteries (Complete)	Magnesium stampings	√
√	Lead sheathed cable & wire	Scrap aluminum sheet	√
√	Tooling dies	Pots and pans	√
√	Dross and skimmings	Aircraft engines	√
√	Rubber insulation	Airframe scrap	√
√	Plastic insulation	Insulated wire	√
____	Other ____	Other ____	____

The furnace will be used to melt lead and aluminum (the above materials) selectively, and to burn the extraneous materials. The molten metal products are tapped into ingot molds through a spout requiring ventilation in addition to the furnace flue gas.

The furnace is hand charged through doors at the front of the furnace. The burners are fired at 2,200,000 BTU/hr with natural gas. There is an afterburner with a maximum heat input of 2,200,000 BTU/hr which produces a maximum exit temperature of 1500°F at 100% excess air. During the burnout phase of the operation, as much as 40% of the charge by weight may comprise insulation with a fuel value of 10,000 to 18,000 BTU/lb.

Operating conditions will vary widely during the day as the charge materials and products vary.

POLLUTION ABATEMENT EQUIPMENT

The baghouse will be installed downstream of the afterburner. A radiant convection tube cooler will bring the gas temperature down from 1500°F to 250°F. A further safety provision shall be made by the installation of a thermocouple controlled air dilution inlet damper. Water cooling of gas by evaporation is not acceptable.

The bag filter shall be an automatic, continuous orlon cloth filter at an air:cloth ratio of not over 2:1. The bag filter shell and hopper shall be constructed of mild steel.

Installation of baghouse will be adjacent to furnace building and be located outside subject to ambient conditions.

Table 44
(continued)

Auxiliary equipment for bag filter shall include:

(1) Fan, motor, drive and damper
(2) Screw conveyor under bag filter
(3) Thermocouple controlled air dilution inlet damper
(4) Gas cooling system

Table 45

OPERATING CONDITIONS FOR SWEATING FURNACE

FABRIC COLLECTOR SPECIFICATION

(Data for aluminum sweating/data for lead sweating)

	Small (1 Furnace)	Medium (2 Furnaces)	Large (3 Furnaces)
Furnace Capacity, ton	–	–	–
Melting rate, lb/hr	1000/10,000	2000/20,000	3000/30,000
Process Wt., lb/hr	1600/16,000	3200/32,000	4800/48,000
Inlet gas volume, ACFM*	15,400	30,800	46,200
Inlet gas Temp., °F*	250	250	250
Inlet Loading, lb/hr*	17/1230	88/2460	50/3670
Inlet loading, gr/ACF*	0.129/9.32	0.129/9.32	0.129/9.32
Case 1 – LA Process Weight			
Outlet loading, lb/hr	3.66/13.74	5.27/23.44	6.52/33.1
Outlet loading, gr/ACF	0.028/0.104	0.020/0.089	0.0165/0.084
Eff., Wt. %	78.5/98.9	84.0/99.0	87.0/99.1
Case 2 – High Efficiency			
Outlet loading, lb/hr	3.86	7.72	11.6
Outlet loading, gr/ACF	0.03	0.03	0.03
Eff., Wt. %	77.3/99.7	77.3/99.7	77.3/99.7

*After air dilution

Table 46

Fabric Collector Cost Data

for Sweating Furnaces

INFORMATION	FABRIC COLLECTOR		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	19.2	38.4	57.6
Inlet Gas Volume, ACFM	15,400	30,800	46,200
Efficiency, Wt. %	99.5	99.5	99.5
Controlled Emission, gr/ACF	<.01	<.01	<.01
Type of Charge	Lead/Al/Mg/dross		
Inlet Gas Temperature, °F	250	250	250
System Horsepower	50	100	150
Equipment Cost, $			
A. Collector	15,677	27,841	41,762
B. Auxiliaries	6,557	11,320	17,158
C. Gas Conditioning Equipment	60,125	117,250	174,375
D. Waste Equipment			
E. Other			
Total	$83,359	$156,411	$233,295
Installation Cost, $			
A. Grass-Roots	$61,770	$117,310	$174,975
B. Add-On *			
Expected Life, Years	25	25	25
Operating and Maintenance $/year	$4,536	$7,776	$11,664

* No substantial difference from grass roots.

Figure 19

Cost of Fabric Collectors

for Sweating Furnaces

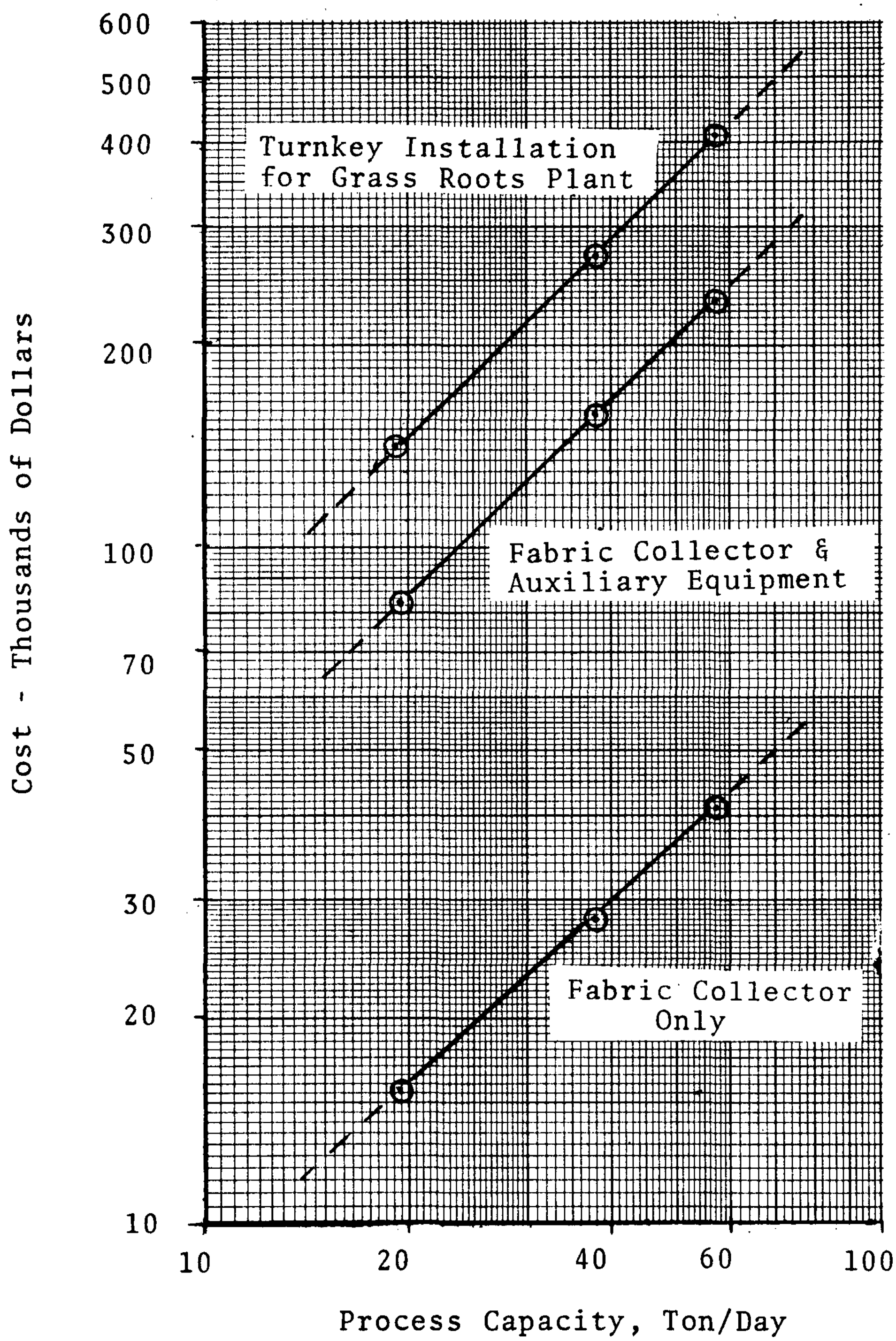


Table 47

WET SCRUBBER PROCESS DESCRIPTION
FOR SWEATING FURNACE SPECIFICATION

The scrubber is to serve one aluminum reverberatory or tube furnace used for sweating lead and aluminum alternatively. The capacity of the furnace is given in terms of the rate of product production, which varies between the two operations. For example, 1000 lb/hr aluminum and 10,000 lb/hr lead are alternative designations for the same furnace.

The charge materials will include, but will not be limited to, the items checked below:

	LEAD	ALUMINUM	
√	Auto Batteries (Complete)	Magnesium stampings	√
√	Lead sheathed cable & wire	Scrap aluminum sheet	√
√	Tooling dies	Pots and pans	√
√	Dross and skimmings	Aircraft engines	√
√	Rubber insulation	Airframe scrap	√
√	Plastic insulation	Insulated wire	√
___	Other ______________	Other ______________	___

The furnace will be used to melt lead and aluminum, the above materials, selectively and to burn the extraneous materials. The molten metal products are tapped into ingot molds through a spout requiring ventilation in addition to the furnace flue gas.

The furnace is hand charged through doors at the front of the furnace. The burners are fired at 2,200,000 BTU/hr with natural gas. There is an afterburner with a maximum heat input of 2,200,000 BTU/hr which produces a maximum exit temperature of 1500 F at 100% excess air. During the burnout phase of the operation, as much as 40% of the charge by weight may comprise insulation with a fuel value of 10,000 to 18,000 BTU/lb.

Operating conditions will vary widely during the day as the charge materials and products vary.

The scrubber system will be installed downstream of an afterburner. The scrubber shall be installed following a run of refractory-lined duct to suit the location of the scrubber. The scrubber material shall be type 316 ELC stainless steel, refractory-lined in areas subject to high temperature and/or abrasion. The draft loss across the scrubber shall be not less than 40" wg or the equivalent in energy input.

Installation of scrubber shall be adjacent to furnace building and located outside subject to ambient conditions.

Table 47
(continued)

Auxiliary equipment for scrubbers shall include:

(1) Fan, motor, drive and damper
(2) Slurry handling system (not including interconnecting pipe)
(3) Pumps
(4) Water conditioning system

Table 48

OPERATING CONDITIONS FOR SWEATING FURNACE

WET SCRUBBER SPECIFICATION

(Data for aluminum sweating/data for lead sweating)

	Small (1 Furnace)	Medium (2 Furnaces)	Large (3 Furnaces)
Melting Rate, lb/hr	1000/10,000	2000/20,000	3000/30,000
Process Wt., lb/hr	1600/16,000	3200/32,000	4800/48,000
Inlet gas vol., ACFM	42,500	85,000	127,500
Inlet gas temp., °F	1,500	1,500	1,500
Inlet loading, lb/hr	17/1230	33/2460	50,3690
Inlet loading, gr/ACF	0.046/3.38	0.046/3.38	0.046/3.38
Outlet Gas Volume, ACFM	15,000	30,000	45,000
Outlet Temp., °F	180	180	180
Case 1 – LA Process Weight			
Outlet loading, lb/hr	3.66/13.74	5.27/23.44	6.52/33.1
Outlet loading, gr/ACF	0.028/0.108	0.020/0.091	0.017/0.086
Eff., Wt. %	78.5/98.9	84.0/99.0	87.0/99.1
Case 2 – High Efficiency			
Outlet loading, lb/hr	3.86	7.72	11.6
Outlet loading, gr/ACF	0.03	0.03	0.03
Eff., Wt. %	77.3/99.7	77.3/99.7	77.3/99.7

Table 49

Wet Scrubber Cost Data

for Sweating Furnaces

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	19.2	38.4	57.6
Inlet Gas Volume, ACFM	42,500	85,000	127,500
Efficiency, Wt.%			
Controlled Emission, gr/ACF	< .03	<.03	<.03
Type of Charge	—— Per	Specification	——
Inlet Gas Temperature, °F	1,500	1,500	1,500
System Horsepower	250	450	675
Equipment Cost, $			
A. Collector	18,850	24,210	33,140
B. Auxiliaries	27,950	76,440	80,760
C. Gas Conditioning Equipment	11,050	15,265	19,177
D. Waste Equipment	-	-	-
E. Other	6,800	11,200	17,200
Total	64,650	127,115	150,277
Installation Cost, $			
A. Grass-Roots	25,000	45,000	65,000
B. Add-On*	--	--	--
Expected Life, Years	10	10	10
Operating and Maintenance $/year	2,800	3,300	3,800

Figure 20

Cost of Wet Scrubbers

for Sweating Furnaces

(High Efficiency)

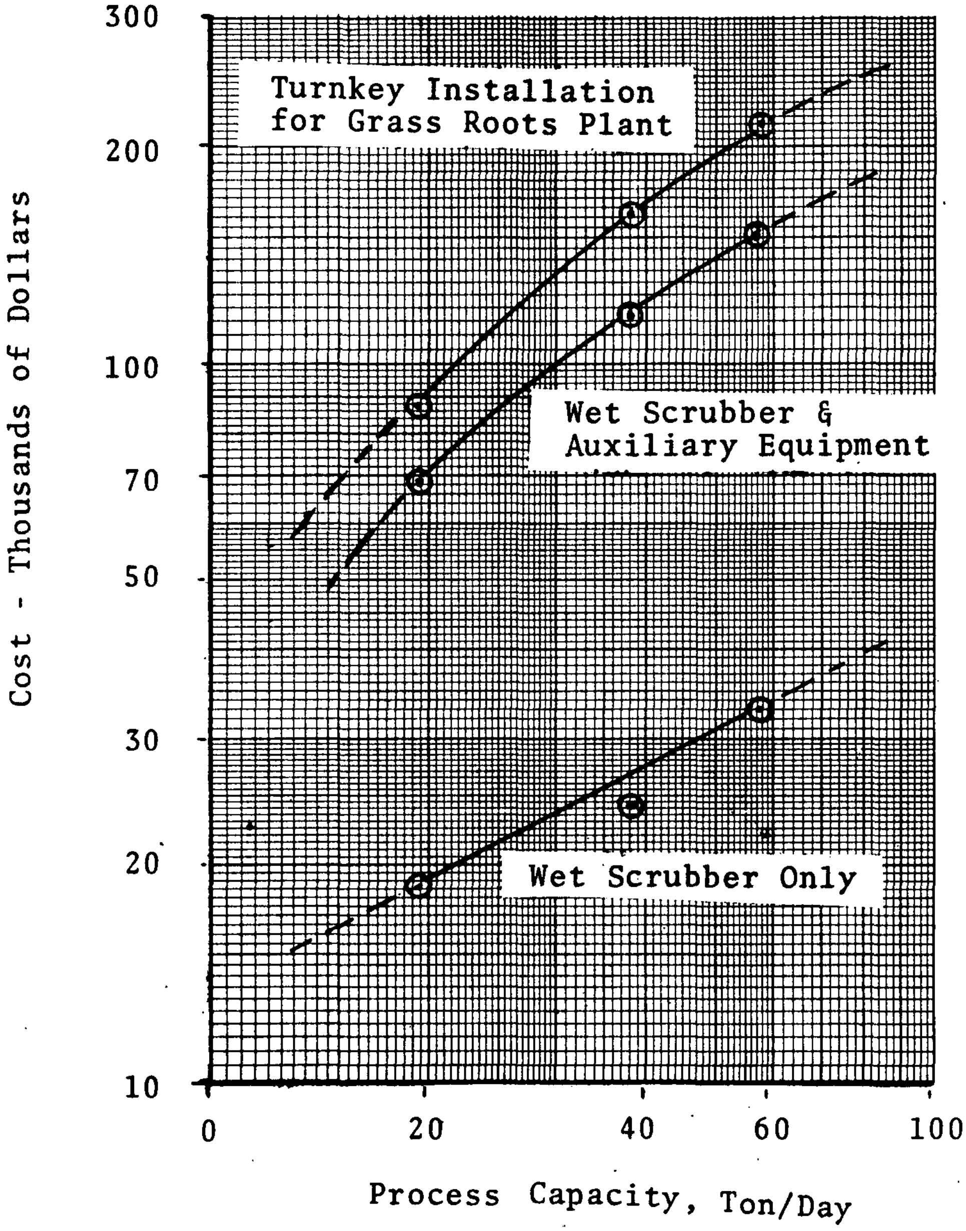


Table 50

Comparison of Total Costs for

Wet Scrubbers and Fabric Collectors

For Sweating Furnaces

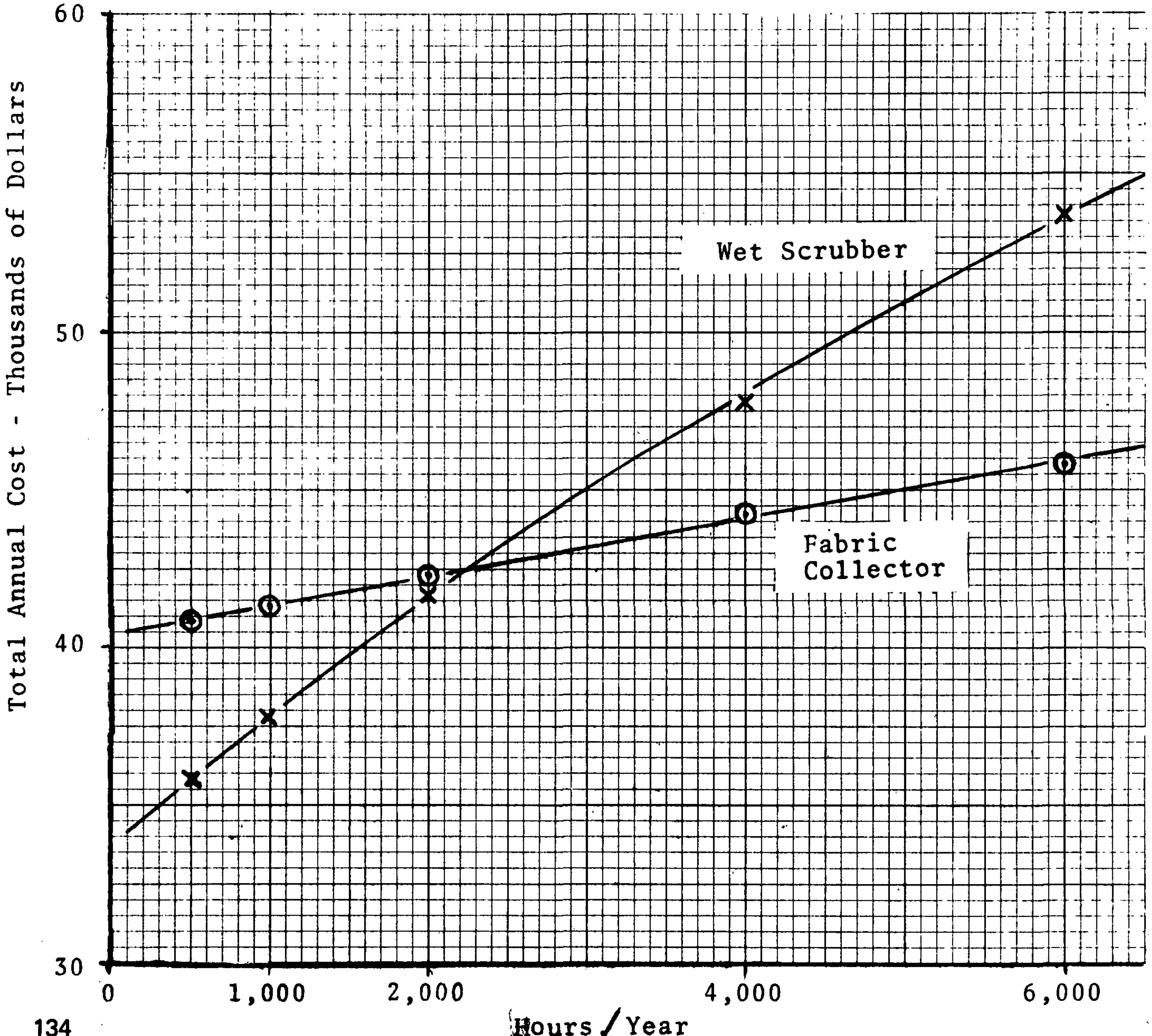
Basis: 38.4 Ton/Day Furnace (Lead)
10% Yearly Cost of Capital
0.01 $/kw-hr Cost of Power
25 Year Life for Fabric; 10 Year for Scrubber

Operating Hours/Year	500	1,000	2,000	4,000	6,000
Fabric Collector					
First Cost	←		(173,420)		→
Annual Capital	32,719	32,719	32,719	32,719	32,719
Parts & Labor	7,776	7,776	7,776	7,776	7,776
Horsepower	440	880	1,760	3,520	5,280
Total	40,935	41,375	42,215	44,015	45,775
Wet Scrubber					
First Cost	←		(159,115)		→
Annual Capital	30,700	30,700	30,700	30,700	30,700
Parts & Labor	3,230	3,230	3,230	3,230	3,230
Horsepower	1,975	3,950	7,900	13,825	19,750
Total	35,905	37,880	41,830	47,755	53,680

Figure 21

Comparison of Abatement Equipment Costs

For Sweating Furnaces



5. AIR POLLUTION CONTROL FOR LEAD REVERBERATORY FURNACES

a. PROCESS DESCRIPTION

1) MANUFACTURING ASPECTS

Reverberatory furnaces are used in a number of ways in the processing of lead scrap metal for reclaim. The furnace is merely a device for heating the contents by direct contact with the products of combustion of oil or gas burners, and by radiation from the hot walls to the contents of the furnace. Whether there is any significant potential air contamination produced depends to a large extent upon the use to which the furnace is put. Several of the uses of reverberatory furnaces in a secondary lead processing plant are:

a) burnout
b) sweating
c) melting
d) purification.

BURNOUT

The burnout operation is not strictly a smelting process, but rather involves the incineration of materials which may be present in scrap metal such as plastics, rubber insulation, wood, paper and other combustible materials. When a reverberatory furnace is used for burnout operations, the air pollution control equipment requirements are similar to those for any other incineration device. That is, the furnace must be provided with sufficient time at temperature to burn any combustible vapors released during the incineration process. If not, a smoke will be produced. The smoke may exceed the visible opacity regulations in force in the area, or may produce grain loadings in excess of the allowable emission limit. If this is the case, it will be necessary to install a thermal afterburner to oxidize the combustible material. This subject falls more strictly in the category of treatment of incineration equipment than smelting equipment, however. Burnout operations may also involve the decomposition of halogen-containing plastic materials. Polyvinyl chloride wire insulation and Teflon are examples of combustible materials which release halogen acids when they are burned. These materials are toxic and are objectionable on the basis of odor when emitted into the atmosphere in significant quantities. Burnout operations which involve substantial quantities of halogen-containing plastics should be equipped with an afterburner-scrubber combination in which the scrubber is used to absorb the halogen acids into a water stream.

SWEATING

Lead sweating operations, in which lead is separated from a mixture of materials, many of which have higher melting points than lead, is covered in detail in another section of this report. The air pollution problems related to lead sweating are mainly associated with the incidental burnout of combustible materials during sweating, with the entrainment of dusty materials in the flue gas, and with SO_x produced from batteries.

MELTING

Reverberatory furnaces may be used to melt lead pigs or ingots for casting. This process is more commonly carried out in indirect heated furnaces such as electrical or gas fired crucibles. The melting of lead does not, in itself, involve any significant air pollution problem. The melting point of lead alloys is relatively low, and the vapor pressure of metallic lead over the melt is not high enough to make any substantial contribution of vaporized lead to the flue gas leaving the furnace. However, in any melting operation there is the possibility of inclusion of materials which will produce organic or halogen-containing emissions when the furnace temperature is raised to the melting point of lead. The inclusion of any material other than metallic lead in the melting furnace should be considered carefully from the standpoint of the potential air pollutants.

PURIFICATION

The principal use to which reverberatory furnaces are put in secondary lead processing involves the melting and purification of lead by removal of extraneous ingredients. This is the principal process which can be described as "smelting" in the reverberatory furnace. It is to this process the remainder of this discussion will be directed.

RAW MATERIALS AND PRODUCTS

The reverberatory furnace may be used for the purification of molten lead by oxidation of impurities such as iron, arsenic, antimony, and tin. The furnace may also be used for reduction of lead oxide drosses, etc. In the case of primary smelting, only the oxidation process is carried out in the reverberatory furnace with the reduction generally done in a lead blast furnace. Many secondary smelters do not operate a blast furnace, and may carry out both operations in the same reverberatory furnace. The charge stock for such smelting operations may be molten lead from a blast furnace in which lead oxide has been reduced by reaction with carbon or coke, or it may be lead ingots cast during a sweating operation conducted in a separate reverberatory sweating furnace. It is not uncommon that burnout, sweating, and smelting operations are carried out sequentially in the same reverberatory furnace. Some raw scrap material may be of sufficient high purity to charge directly to the reverberatory furnace for purification.

Throughout the remainder of this discussion, it will be presumed that the principal purpose of the reverberatory furnace smelting operation is the removal of oxidizable impurities as drosses. The many alternative problems with respect to air pollution, which arise when materials such as plastics, oils, etc. are charged incidentally, must be treated separately.

The reverberatory furnace may be charged with molten lead from the cupola on a continuous basis. In this case, air blowing to oxidize metal impurities is done either intermittently or continuously. The metal dross is removed by slagging intermittently. The molten metal product is removed from the furnace by tapping it into molds on an intermittent basis.

Solid lead scrap may be charged continuously to the reverberatory furnace. Items of scrap lead such as battery plates, lead pipe, cable sheathing, etc. can be hand fed through charging doors, or fed continuously on conveyors. Here again, the air blowing and drossing can be either intermittent or continuous. Casting of the product is ordinarily intermittent.

In the case where solid lead scrap is charged directly to the furnace, it is customary to start the charge by piling a small amount of solid charge material on the hearth and gradually raising the furnace temperature until the material becomes partially melted. As a molten bath is formed on the hearth, additional scrap is added and product is removed when the melt level is sufficiently high.

Lead product is ordinarily classified as hard, semi-soft or soft according to the amount of impurities it contains. Soft lead ordinarily requires fluxing in a crucible furnace and cannot be produced economically in the reverberatory furnace. Semi-soft lead containing between 0.3 and 0.4% antimony and up to 0.05% copper is commonly produced by the reverberatory furnace.

Although the melting point of pure lead is on the order of 625°F, temperatures exceeding 2000°F are used for the purification of lead in the reverberatory furnace. These higher temperatures are required principally to bring about the reaction between the metallic impurities and the oxygen sparged into the metal bath. If lead oxide drosses are charged to the reverberatory furnace, it is necessary to add a reducing agent such as granular carbon to the bath to reduce the lead oxide to metallic lead.

FURNACE EQUIPMENT

The lead reverberatory furnace is constructed of fire brick and refractory materials. The materials of construction need not be particularly resistant to temperature, but the chemical reactivity of the metal drosses is high, and the refractory linings must withstand the continual contact with drosses and slag.

Ordinarily, the furnace is kept as tight as possible to limit the infiltration of air through charging doors, slagging openings and inspection ports. This minimizes the amount of fuel required to heat the leakage. Ideally, only the flue gases produced by the burner system and air blown through the melt to remove impurities would be vented from the furnace through a dust collection system. In cases where substantial quantities of organic material are present in the charge, it is necessary to allow for infiltration of air to burn the organic vapors generated in the furnace and prevent smoking.

Leakage of air into the furnace is generally avoided by operating with the pressure inside the furnace nearly equal to atmospheric pressure. This balanced draft situation results in a minimum of infiltration, but may cause the furnace to "spill" combustion products out through open doors or inspection ports. In order to prevent serious discharge of contaminants into the foundry, hoods are usually provided over these openings. As the hoods capture the fumes which leave the furnace when the doors are opened, the ventilating air from the hoods must be treated in the air pollution control device also. There is generally no requirement for hooding the metal pouring spout through which the molten product is tapped into molds.

A flow diagram of the reverberatory furnace with a typical gas cooling system is shown in Figure 22. This furnace is designed in such a way that combustible vapors generated in the furnace are incinerated before leaving the furnace. For this reason, no separate incineration device is shown. In the case of the fabric filter installation sketched in Figure 22, the combustion products are cooled to a limited extent by mixing with ambient air drawn through the ventilating hoods. Further cooling is necessary to protect the fabric filter from damage due to high gas temperature. This cooling is provided partly by a section of duct work arranged in a serpentine configuration which exposes a great deal of outside surface area to the atmosphere. This serves to drop the gas temperature to the level of about 1000-500°F. In some cases, sufficient cooling surface is provided to bring the gas temperature all the way down to the range acceptable for Dacron bags (around 270°F). In larger installations, it is less expensive to provide some dilution air to do the final cooling.

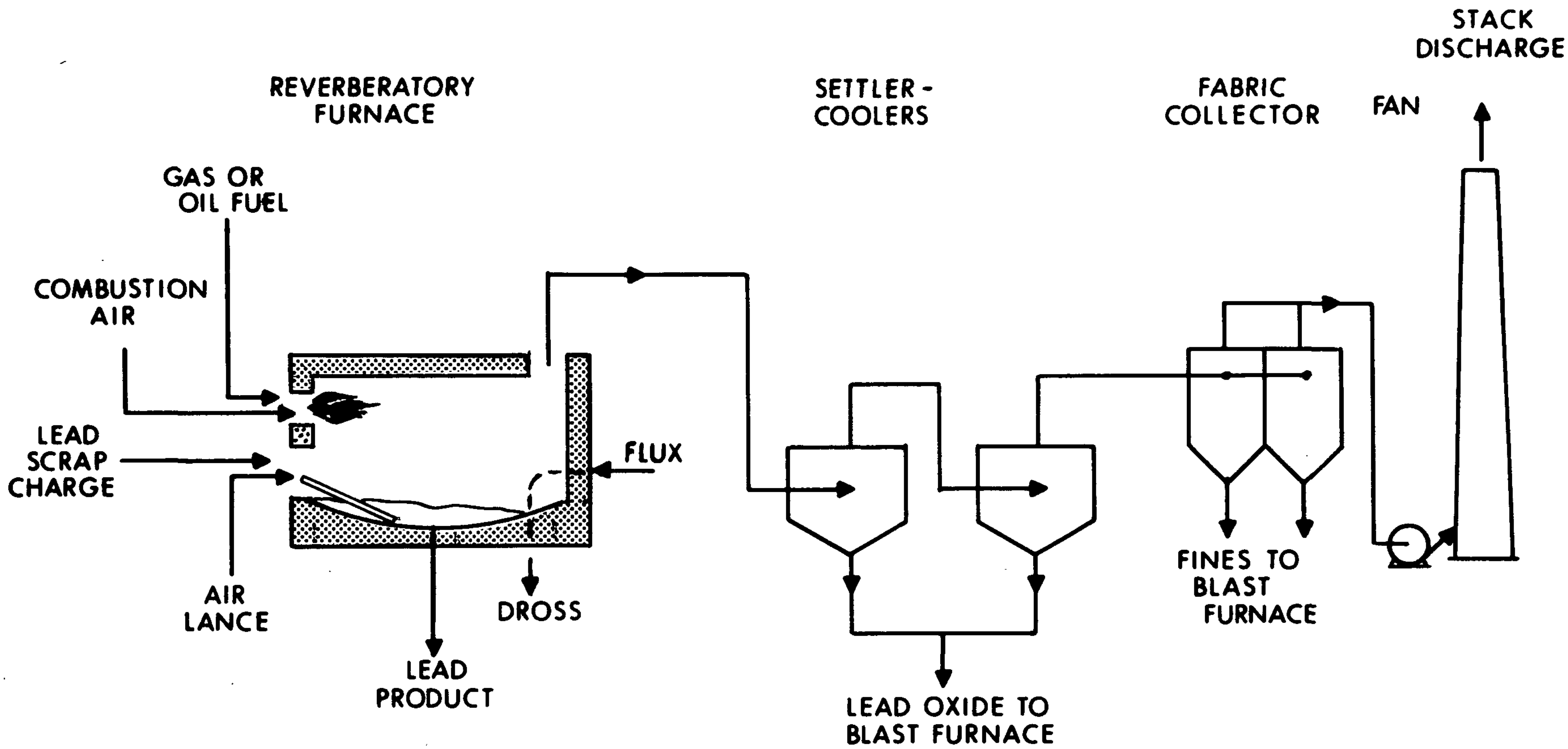


Figure 22

Process Flow Sketch for Lead Reverberatory Furnace

In the arrangement shown in Figure 22, sufficient dilution air is added to bring the gas temperature to 270°F, and also to provide an emergency quench arrangement to drop the temperature even lower in the event that the furnace temperature control does not limit the temperature properly.

In many installations, the U-tube cooler arrangement is replaced by a large diameter cyclone which functions in exactly the same way with regard to cooling the flue gas, but also serves as a "knock-out" chamber in which large particulate materials settle. The large cyclone has the advantage that any heavy materials carried over from the reverberatory furnace can settle out before reaching the fabric filter, and any burning carbon or metal particles can be dropped from the gas stream before reaching the filter. This is important in protecting the combustible filter fabric from ignition.

An alternative arrangement of air pollution control equipment is shown in Figure 23. Here, the gas leaving the reverberatory furnace and the ventilating hoods is carried to a quench chamber where water is used to drop the temperature to a reasonable level so that carbon steel duct work can be used between the quench chamber and the scrubber. Quench chambers are generally unsatisfactory as pretreating devices for fabric filters because of the possibility that the water supply will cool the gas stream excessively and saturate it with water. Saturated gas will very likely wet the filter cake collected on a fabric filter and cause a "blinding" condition which will prevent the proper ventilation of the furnace. With wet scrubbers there is no equivalent situation. A tank for caustic addition is provided for SO_2 scrubbing in Figure 23.

When either a fabric filter or a scrubber is provided for collection of the particulate emission from a reverberatory furnace, it is necessary to furnish a fan with sufficient horsepower to pump the gas through the air pollution device at a high enough volume to ventilate the furnace properly. For a fabric filter the necessary pressure is only a few inches of water column. Wet scrubbers, however, require fans with relatively high pressure drops on the order of 50-60 inches water column in order to collect the very fine particulate material generated by oxidizing impurities in the molten lead. When fans are installed that have the capability of moving large quantities of air, it is usually necessary to provide some sort of draft control at the furnace to prevent over-ventilating, as well as to insure that adequate ventilation will be obtained. In the simplest case, this consists of a barometric damper located after the cooling surface for a fabric filter installation, and between the reverberatory furnace and the quench chamber for a wet scrubbing system.

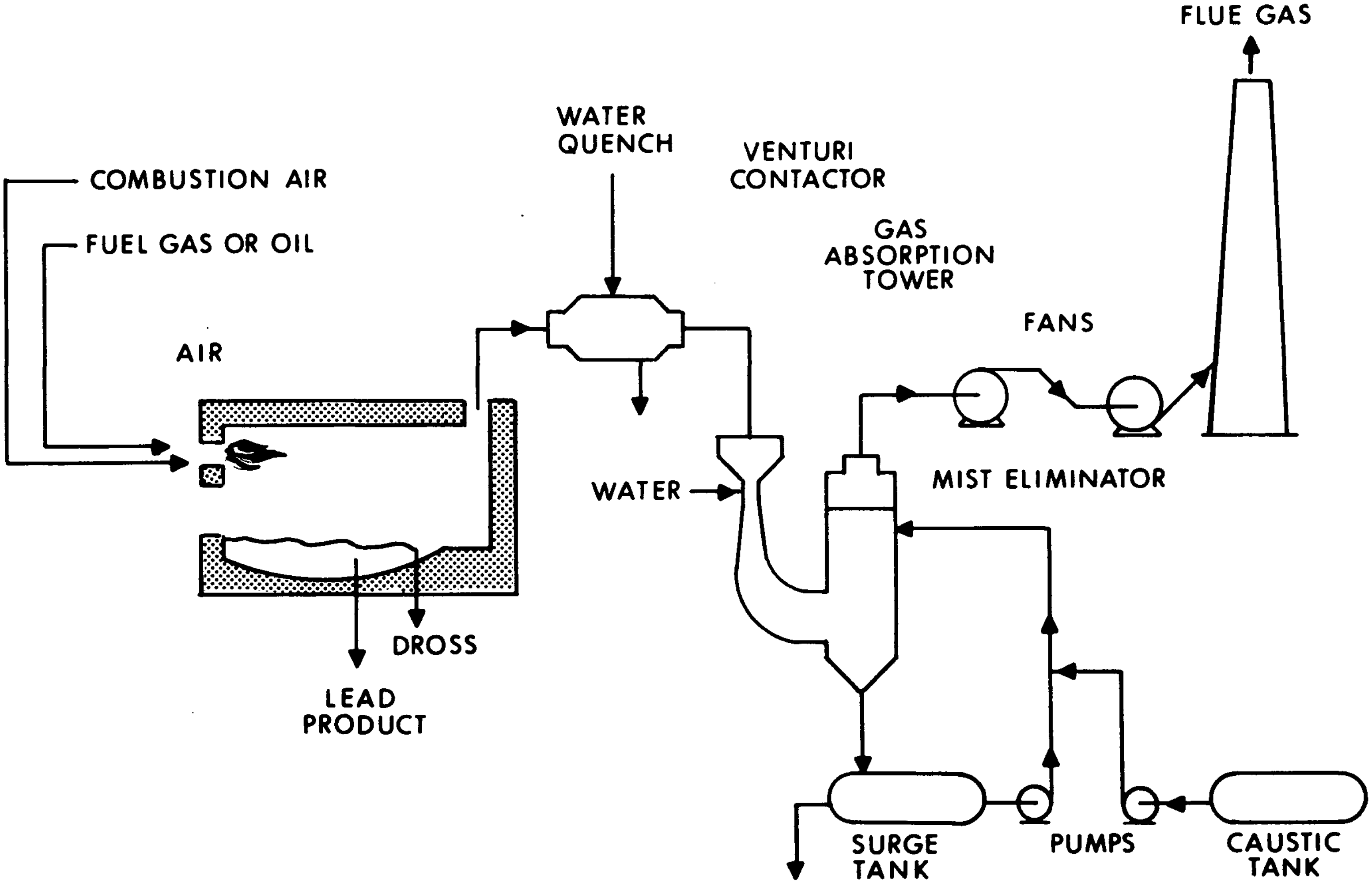


Figure 23

Process Flow Sketch for Lead Reverberatory Furnace with Wet Scrubber

2) CONTROL EQUIPMENT

The principal problem associated with the operation of reverberatory furnaces for lead smelting is the emission of inorganic particulate matter. This consists of the oxides of metal impurities such as iron, antimony, etc. and lead oxide itself. The former are oxidized in the molten bath and rise to the surface as drosses. They are mechanically entrained in the flue gas stream either by the action of the sparge gas or by contact with the flue gas itself. The lead is ordinarily vaporized from the surface of the melt into the flue gas, and reacts there with the residual oxygen to produce lead oxide. In addition to these metallic oxides, there may be oxides of sulfur introduced as lead sulfate or sulfuric acid with used lead storage batteries, organic materials from the vaporization and partial combustion of plastics, oils, etc., and halogen acids produced by the decomposition of PVC plastics and Teflon.

In order to provide a system that will be satisfactory in all respects, it is necessary to establish the total gas flow rate, the composition of the gas stream, and the nature and level of the contaminants. Each of these will be considered in some detail in the following paragraphs.

The most important single variable in sizing air pollution control equipment is the flowing volume of the gas stream which must be accommodated. Because of the many factors which contribute to the volume of gas required for adequate ventilation and cooling of the effluent from reverberatory furnaces, it is imperative that a measurement of the gas flow using accepted flow measuring technique (such as contained in the Industrial Gas Cleaning Institute publication WS-1) be used to measure the gas volume. For preliminary estimate of the gas flow – such as might be used for sizing equipment for budgetary estimates – the volume of the flue gas and ventilating air for hoods may be approximated. Four or five ACFM at 270°F per pound of metal melted per hour is a good first approximation. However, it should be borne in mind that poorly sealed furnaces, or furnaces with unusually large hooded areas may use several times as much air to provide adequate ventilation. A first estimate of the grain loading can be made by using the "emission factor" quoted by the National Air Pollution Control Administration for lead reverberatory furnaces. This is given as 154 pounds of metal per ton of charge. The rates of emission of organic materials and other contaminants such as SO_2, HCl and HF can only be estimated from the rates at which the precursor materials can be charged to the furnace. It is not recommended that equipment specifications be based on such estimates, but rather on a source test performed by accepted methods.

AIR POLLUTION CONTROL EQUIPMENT TYPES

Strictly speaking, the air pollution control equipment for a reverberatory furnace should consist of an afterburner if any organic material is put into the furnace, and a particulate collection device if the furnace is used for refining of lead by oxidizing other metallic impurities. However, the afterburning is most frequently accomplished in the reverberatory furnace proper. This is accomplished by preventing excessive leakage of air into the furnace, and introducing controlled amounts of oxygen either as excess air to the gas or oil burners, or in a separate series of vent ports.

Particulate collection equipment is generally divided into four classifications:

1. Mechanical dust collectors
2. Electrostatic precipitators
3. Fabric filters
4. Wet scrubbers

The mechanical dust collectors do not have good efficiency on the submicron particulate matter emitted in lead smelting, and they cannot be used alone to solve the particular air pollution problem. However, they are sometimes used in series with one of the other collection devices where the cyclone does a crude separation of the largest particulate matter, and the cyclone walls serve to cool the gas stream by transferring some of the heat to ambient air.

ELECTROSTATIC PRECIPITATORS

Electrostatic precipitators can be used for the collection of lead fume from reverberatory furnaces, but two circumstances make the precipitator an unlikely choice. The first of these involves the high minimum cost of electrostatic precipitators. The minimum cost of a small precipitator is likely to be considerably higher than the cost of either a fabric filter or wet scrubber for a lead reverberatory furnace of nominal size. In some large installations, the gas flow rate may be high enough to make a precipitator installation economical. However, the optimum performance of electrostatic precipitators requires that the electrical *resistivity* of the dust be within a narrow range of values. The lead oxide dust does not fall within this range without the addition of a chemical conditioning agent to the gas stream. For these reasons, electrostatic precipitators are not likely to find wide use on reverberatory furnaces.

FABRIC FILTERS

Fabric filtration has been the principal mechanism for particulate control from reverberatory furnaces. This is due to a combination of circumstances. The fabric filter is inherently a very high efficiency device. Even when filtering submicron particulate materials where the dust particle size is much smaller than the opening in the fabric weave, the fabric collects particles by electrostatic attraction to build a filter cake of very small pore size and then collects the submicron material nearly perfectly. In addition, the fabric filter is a dry collection device, and the lead oxide collected is in suitable form for return to a blast furnace or reverberatory furnace for reduction to elemental lead.

The important variables in selection of fabric filters are (1) gas to cloth ratio, (2) fabric material and (3) bag arrangement. In general, the cost of a fabric filter increases nearly in proportion to the amount of bag surface it contains. For this reason, the smallest possible surface area is the lowest in first costs. This indicates that the highest ratio of gas to cloth should be the most economical in first costs. While this is true, the performance of fabric filters with respect to fabric life, freedom from plugging problems, etc., is best when the velocity of gas passing through the filter medium is very low. In general, the installation will be more economical in the long run if a relatively low gas to cloth ratio is used. Installations with one square foot of cloth for every two ACFM of gas (2/1 gas/cloth ratio) have proven satisfactory. For best long term performance, a filter ratio of 1 CFM per square foot of fabric is recommended.

Several fabrics can perform satisfactorily in the atmosphere generated by a reverberatory furnace if the temperature is low enough. In most existing installations, Dacron bags have been found to provide the best compromise between cost, temperature resistance, and good life characteristics. The Dacron bags may be operated at temperatures up to 300°F. However, deterioration is very rapid if the bag temperature limit is exceeded. For this reason, it is wise to design the gas conditioning system to reduce the temperature to a considerably lower level during normal operating conditions. Temperatures of 200-250°F are recommended, and design temperatures up to 270°F should be acceptable. In addition to the normal cooling by dilution with cold air, dilution with cold air plus direct heat exchange, or through heat exchange alone, an emergency quench system should be provided to bleed cold air into the system in large quantities if the temperature control mechanism fails.

WET SCRUBBERS

Wet scrubbers are capable of providing the high efficiency required on the submicron fraction of the reverberatory furnace fume but in order to achieve very high collection efficiency, high levels of energy input are required. In most cases this is done by taking a high pressure drop across a Venturi throat or orifice through which the water used for scrubbing is passed concurrently with the gas. Pressure differences on the order of 30-100 inches of water column are required in order to provide good clean-up for the smelting operation. In addition to the large energy input (which may require two 50-500 horsepower motors), the use of water for scrubbing introduces some corrosion problems. SO_2 in the gas stream is absorbed in water to form dilute sulfurous acid (H_2SO_3), which makes any water that is recycled to the scrubber very acidic. Without chemical treatment, the pH of the recirculated scrubbing water is likely to reach a level of about 2.0. This will attack most ordinary steel construction, so it is necessary to add lime, caustic soda or some similar chemical conditioner to the water to minimize corrosion and prevent discharge of very acidic water to the sewer system or to a natural body of water.

The caustic chemicals might cost several hundred dollars per day. For example, if the SO_2 content of the gases from a large furnace is 5000 ppm and the flow rate averages 14,200 SCFM (20,000 ACFM @ 270°F), the SO_2 discharge rate is 71 SCFM. Neutralization of this much SO_2 with caustic requires about 15 pounds of caustic addition per minute. At a cost of 4c/lb, this amounts to $288 per eight hour day.

With neutralization, the corrosive action of the sulfurous acid is reduced but it is ordinarily not desirable to use carbon steel because of the possibility that the chemical addition will be interrupted for short periods during which serious corrosion would take place.

The dust collected by the wet scrubber will usually be in the form of a relatively dilute slurry. Concentrations over 10 wt % solid are not ordinarily produced by scrubbers. If the lead oxide recovered by a wet scrubber is to be recycled, some form of settling must be provided to separate the solid from the water. This is usually done in a settling pond, but mechanical settlers and drum-type filters can be used.

Although scrubbers have disadvantages as compared with fabric filters for this application, there is one circumstance in which the scrubber may be the only piece of equipment capable of providing adequate treatment of the gas stream. If the sulfur content of the charge is relatively high, the SO_2

concentration in the vent gas from the reverberatory furnace may exceed local emission standards, or it may produce a nuisance. In this case, a scrubber designed solely for absorption of SO_2 in an alkaline scrubbing medium can be used to abate the sulfur oxide emission. Here, it is likely that the scrubber would be placed after an existing fabric filter which serves to remove the particulate matter. Caustic soda, soda ash, and other soluble alkaline materials can be used to remove the sulfur oxides from the effluent gas stream in the form of soluble sulfites. With proper neutralization these may be suitable for discharge into the sewage system serving the plant.

It is likely that the local regulations, or good water treating practice, will require some oxidation of the sulfites to sulfates by aeration before the spent scrubbing liquor is discharged into a water course or sewer. Systems for the removal of sulfur oxides are uncommon, and good practice has not yet been established in the secondary smelting industry.

SPECIFIC PROBLEMS

Several problems are associated with lead smelting in reverberatory furnaces that are not common to the secondary smelting industry in general. These are:

(1) emission of lead fumes
(2) sulfur oxide emissions

Metallic fumes generally produce dense, opaque visible plumes which are objectionable because they are unsightly and because they contribute to the level of particulate matter suspended in urban atmosphere. Lead fumes are particularly objectionable because of the toxicity of lead. For this reason, the particulate emission standards in most localities are enforced with more than average diligence when lead oxide is suspected as a principal ingredient in the emission. While lead oxide emissions are not subject to special regulation apart from process weight limitations for particulate matter in general, or opacity regulations, it is likely that lead will be singled out for special regulation as air pollution standards become more severe. For this reason, it is reasonable to install particulate abatement equipment capable of meeting the highest possible standards of performance. Fabric filters generally are conceded to produce collection efficiency greater than 99.5% for submicron fumes of this sort. It is reasonable to install a fabric filter, even if present regulations would permit the use of a wet scrubber at a lower efficiency level.

A second problem peculiar to lead reclaiming is the emission of sulfur oxides. The sulfur compounds are quite common in primary smelting because many metals occur naturally as sulfides. For example, copper and zinc are most commonly mined as the corresponding sulfide, and oxidized in a roasting furnace which produces large quantities of sulfur dioxide. However, metal reclamation processes do not ordinarily involve the sulfide ore. Lead smelting is an exception, in that much of the lead usage in the U.S. is for the production of lead storage batteries. These batteries contain substantial quantities of lead sulfate when they are discarded. In addition to the lead sulfate, there may still be some sulfuric acid present in the battery when the plates are put in to the reverberatory furnace. If the batteries are in mixed scrap which is sweated to produce lead, the sulfate may be released in the sweating process. If the plates are charged directly to the reverberatory furnace, the sulfur oxides will be released there.

The concentration of sulfur oxides may be well within local air pollution abatement standards if the concentration of battery scrap in the charge is low. However, concentrations of 2000-5000 ppm may be attained if the charge consists principally of battery plates. In this circumstance, a wet scrubber may be required for the removal of SO_2 from the gas stream leaving the fabric filter. Most local ordinances will prohibit the discharge of very acidic water into sewers or natural bodies of water, and some method of neutralizing the scrubber water will be required.

In this circumstance, a single wet scrubbing system may serve both the particulate collection and sulfur oxide scrubbing functions. Figure 23 illustrates a combination of scrubbing system with neutralization of the waste water.

b. SPECIFICATIONS AND COSTS

As in previous sections, the costs compiled for lead reverberatory furnaces were based on a standard specification plus two pages written especially for the lead furnace and the particulate collector specified.

FABRIC FILTER

The process description used in the specification is given in Table 51. Operating conditions for the usual three furnace sizes and two efficiency levels are listed in Table 52. The prices quoted are summarized in Table 53.

As is usually the case, a single fabric filter quotation was presented in response to both efficiency levels, on the basis that the fabric filter will ordinarily produce a very high efficiency. The prices are plotted in Figure 24 for ease of interpolation.

Table 51

FABRIC COLLECTOR PROCESS DESCRIPTION
FOR LEAD REVERBERATORY FURNACE SPECIFICATIONS

The fabric filter is to serve a reverberatory furnace used to recover lead from lead oxide, lead scrap, and dross materials. The charge to the furnace will consist of lead scrap, battery plates, and lead dross. The furnace is fired with natural gas.

The air pollution control system is to capture fumes from the furnace flue and from a fume collection hood. These are brought into a single insulated duct. This duct passes horizontally through the building wall at an elevation of 20' above grade. A high surface area "U-tube" cooling section without insulation is provided outside the building, followed by a dilution air damper to reduce the final temperature from 1000°F to 270°F. The filter is to be located on grade adjacent to the building. The fan following the filter will be located on a shed roof 28' above grade, and will discharge into a new 70' stack.

The fabric filter is to operate in such a manner that a single compartment (with no more than one quarter of the total collecting surface area) can be isolated for shaking. The hopper is to have sufficient capacity to hold the dust collected over a 24 hour period without interfering with normal operation of the collector. The dust outlet should be a minimum of 8'0" above grade in order to provide for truck access. The hopper valve is to be included in the quotation.

Dacron tubular bags shall be used with a gas/cloth ratio of 1.0 CFM/FT^2 or less at operating conditions.

Auxiliaries are defined, for purposes of this specification, as:

(1) Fan and drive
(2) Dampers

Table 52

FABRIC FILTER OPERATING CONDITIONS

FOR LEAD REVERBERATORY FURNACE

Three sizes of fabric collectors are to be quoted. While two levels of efficiency are specified, it is expected that a single fabric quotation will be supplied for each size range.

	Small	Medium	Large
Furnace Capacity, ton	10	25	50
Melting Rate, lb/hr	1,000	2,500	5,000
Inlet gas volume, ACFM	5,000	10,000	20,000
Inlet gas temperature, °F	270	270	270
Inlet loading, lb/hr	57	130	260
Case 1 – LA Process Weight			
Outlet loading, lb/hr	2.80	4.64	6.67
Outlet loading, gr/ACF	0.065	0.054	0.039
Efficiency, wt. %	94.6	96.4	97.4
Case 2 – High Efficiency			
Outlet loading, lb/hr	0.43	0.86	1.72
Outlet loading, gr/ACF	0.01	0.01	0.01
Efficiency, wt. %	99.2	99.34	99.34

Table 53

Fabric Collector Cost Data

for Lead Reverberatory Furnaces

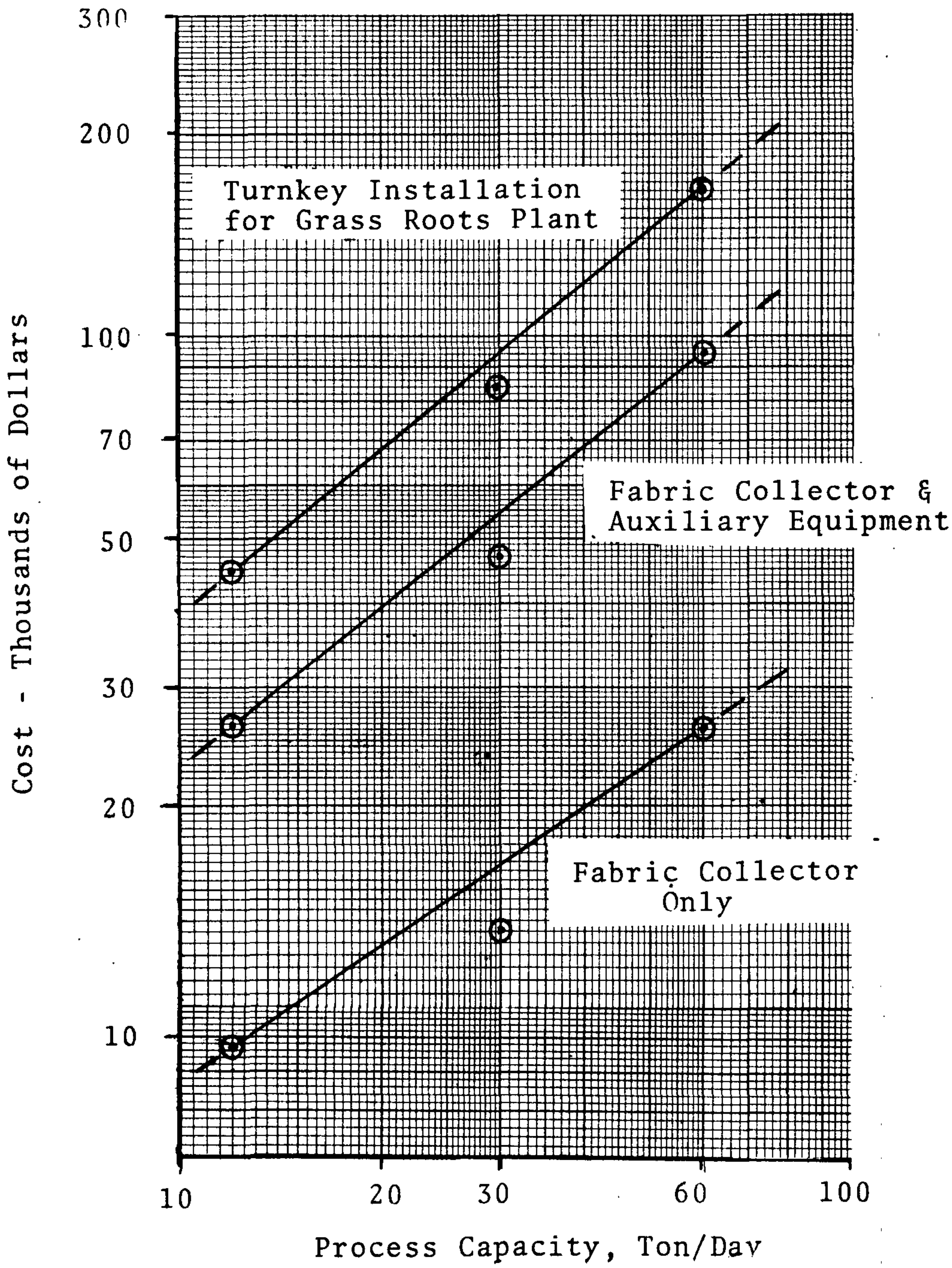
INFORMATION	FABRIC FILTER		
	SMALL	MEDIUM	LARGE
Process Capacity, ton/day	10	25	50
Inlet Gas Volume, ACFM	5,000	10,000	20,000
Efficiency, Wt.%	99.5	99.5	99.5
Controlled Emission, gr/ACF	<0.01	<0.01	<0.01
Type of Charge	← lead scrap and dross →		
Inlet Gas Temperature, F	270	270	270
System Horsepower	15	30	60
Equipment Cost, $			
A. Collector	7,240.00	13,020.00	26,040.00
B. Auxiliaries	4,015.00	5,802.00	11,392.00
C. Gas Conditioning Equipment	14,500.00	29,798.00	58,396.00
D. Waste Equipment			
E. Other			
Total	25,755.00	48,620.00	95,828.00
Installation Cost, $			
A. Grass-Roots	19,320.00	36,475.00	71,875.00
B. Add-On*			
Expected Life, Years	25	25	25
Operating and Maintenance $/year	$2,592.00	$4,536.00	$9,072.00

* Installation costs would be same as grass roots.

Figure 24

Cost of Fabric Collectors for

Lead Reverberatory Furnaces



WET SCRUBBERS

The wet scrubber specifications were written without any reference to SO_2 removal, as this is the most representative of current practice. The specification material is given in Tables 54 and 55. The prices quoted are summarized in Tables 56 and 57 for the LA-Process Weight and High Efficiency cases. Figure 25 is a log - log plot of the cost data for the High Efficiency case.

c. DISCUSSION OF COSTS

There is a first cost advantage in favor of the fabric collector in the smaller size range, which disappears as the gas volume increases. This is because the filter cost increases more nearly in proportion to the gas flow than does the scrubber cost. It is also apparent that the cost of pre-cooling the gas stream for the filter becomes very high for the larger sizes. A more economical design might have resulted if air dilution were used to a greater extent for the larger filter. The horsepower cost associated with the wet scrubber is a significant factor for the larger sizes.

Many of the comments made for the lead cupola apply to the reverberatory furnace, because of the advantages of combining the effluents from these two operations into a single stream to be processed through a fabric filter or scrubber. In particular, the possibility of SO_2 emission control coupled with stringent regulation of lead particulate emissions suggests that combinations of scrubbers and fabric filters may become necessary.

Table 54

WET SCRUBBER PROCESS DESCRIPTION
FOR LEAD REVERBERATORY FURNACE SPECIFICATION

The scrubber is to serve a reverberatory furnace used to recover lead from lead oxide, lead scrap, and dross materials. The furnace is fired with natural gas.

The air pollution control system is to capture fumes from the furnace flue and from a fume collection hood, which are brought into a single insulated duct. This duct passes through the building wall at an elevation 20' above grade. The scrubber is to be located at grade outside the building. The fan will be located after the scrubber on adjacent shed roof approximately 20' above grade, and will discharge into a new 70' stack. The ductwork ahead of the scrubber is to be refractory-lined carbon steel, while the outlet ductwork is to be rubber-lined carbon steel. The scrubber is to be constructed of 304 L stainless steel wherever wetted by the scrubbing liquor.

The external piping and pumps will be of rubber-lined carbon steel or equivalent. The liquor containing the particulate matter is to be discharged into a settling pond within 100' of the scrubber. The scrubber pressure drop shall be no less than 50" wg equivalent energy input for the LA-Process Weight specification and no less than 60" wg pressure drop equivalent energy input for the high efficiency case.

For purposes of this quotation, auxiliaries shall include:

(1) Fan
(2) Pump or pumps
(3) External piping
(4) Controls
(5) Dampers

Table 55

WET SCRUBBER OPERATING CONDITIONS

FOR LEAD REVERBERATORY FURNACE SPECIFICATION

Three sizes of scrubbers are to be quoted for each of two levels of collection efficiency.

	(A) Small	(B) Medium	(C) Large
Furnace Capacity, ton	10	25	50
Melting rate, lb/hr	1,000	2,500	5,000
Inlet gas volume ACFM	5,000	11,800	23,600
Inlet temperature, °F	500	500	500
Inlet loading, lb/hr	52	130	260
Inlet loading, gr/ACF	2.5	2.5	2.5
Outlet gas volume, ACFM	3,500	8,260	16,520
Outlet gas temperature, °F	140	140	140
Case 1 — LA Process Weight			
Outlet loading, lb/hr	2.80	4.64	6.67
Outlet loading, gr/ACF	0.09	0.066	0.047
Efficiency, wt. %	94.6	96.4	97.4
Case 2 — High Efficiency			
Outlet loading, lb/hr	0.30	0.71	1.42
Outlet loading, gr/ACF	0.01	0.01	0.01
Efficiency, wt. %	99.4	99.4	99.4

Table 56

Wet Scrubber Cost Data for

Lead Reverberatory Furnace

(LA–Process Weight)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	10	25	50
Inlet Gas Volume, ACFM	5,000	11,800	23,600
Efficiency, Wt.%	94.6	96.4	97.4
Controlled Emission, gr/ACF	.09	.066	.047
Type of Charge	Process Description		
Inlet Gas Temperature, F	500	500	500
System Horsepower	55	125	250
Equipment Cost, $			
A. Collector	14,200	14,200	17,200
B. Auxiliaries	44,700	41,600	49,600
C. Gas Conditioning Equipment			
D. Waste Equipment			
E. Other			
Total	58,900	55,800	66,900
Installation Cost, $			
A. Grass-Roots	25,800	25,800	27,000
B. Add-On	28,000	28,000	30,000
Expected Life, Years	10	10	10
Operating and Maintenance $/Year	1,000	1,000	1,000

Table 57

Wet Scrubber Cost Data for

Lead Reverberatory Furnace

(High Efficiency)

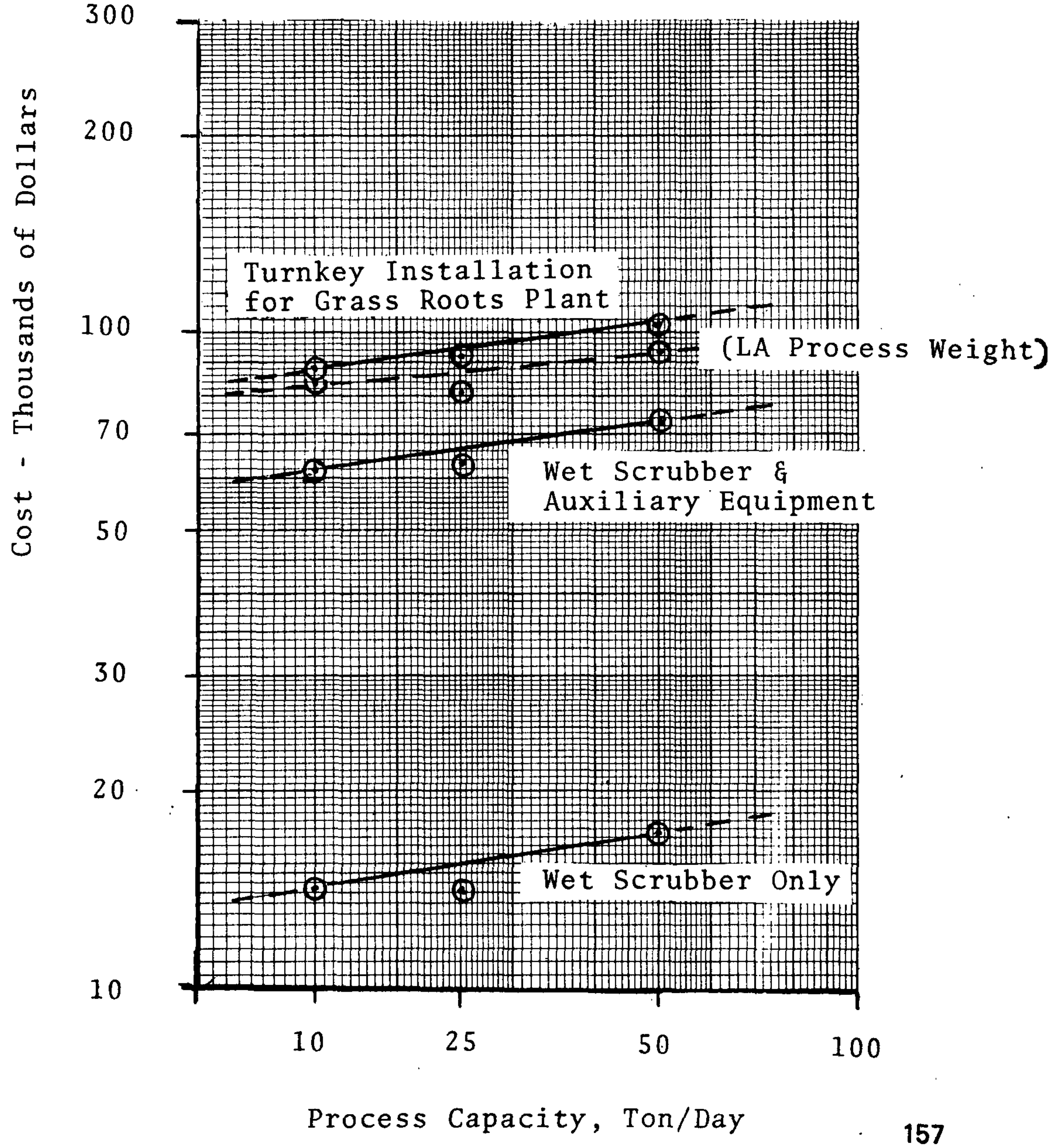
INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	10	25	50
Inlet Gas Volume, ACFM	5,000	11,800	23,600
Efficiency, Wt.%	99.4	99.4	99.4
Controlled Emission, gr/ACF	.01	.01	.01
Type of Charge	Process Description		
Inlet Gas Temperature, F	500	500	500
System Horsepower	65	150	300
Equipment Cost, $			
A. Collector	14,200	14,200	17,200
B. Auxiliaries	48,500	49,600	56,400
C. Gas Conditioning Equipment			
D. Waste Equipment			
E. Other			
Total	62,700	63,800	73,600
Installation Cost, $			
A. Grass-Roots	26,400	26,400	29,000
B. Add-On	29,000	29,000	32,000
Expected Life, Years	10	10	10
Operating and Maintenance $/year	1,000	1,000	1,000

Figure 25

Costs of Wet Scrubbers for

Lead Reverberatory Furnaces

(High Efficiency Case)



6. AIR POLLUTION CONTROL FOR ZINC CALCINATION FURNACES

Prior to this program and through the initial stages of the program, the member companies approached this industrial category on the basis of experience with primary smelting furnaces. As the program proceeded, it became apparent that the calcination operation was quite limited in secondary smelting.

As a result, it was not possible to assemble meaningful information on past installations, costs, and performance for secondary zinc calcining operations. The following discussion is limited to the way "calcination" fits into the secondary zinc smelting business, and the problems which may be encountered in this area. A more complete description of the other processes carried out by secondary zinc smelters is included in the "Air Pollution Engineering Manual" published by NAPCA. These processes include:

1. Zinc Sweating
2. Zinc Melting in
    a. Crucibles
    b. Pot furnaces
    c. Kettles
    d. Reverberatory furnaces
    e. Electric induction furnaces
3. Zinc retorting for
    a. Reduction of zinc oxide
    b. Purification of zinc
4. Burning to produce zinc oxide

a. PROCESS DESCRIPTION

Zinc calcining is the process of heating zinc carbonate ores or secondary zinc materials to drive off gaseous dissociation products which may be detrimental to subsequent treatment or to product use. The process was originally developed to remove water of hydration and carbon dioxide from zinc carbonate ores prior to processing in horizontal retort furnaces.

Mines which once produced zinc carbonate ores are now depleted and alternate methods of treating oxidized ores have been developed. Therefore, calcination practices in the secondary zinc industry are now limited to a few applications in which chlorine, fluorine, carbon and other unwanted contaminants are removed from zinc oxide.

The calcination of carbonate ores is similar to a drying operation with temperatures ranging from 750 °C for zinc minerals to 1470°C for gangue minerals. Up to 30 percent of the ore's original weight is given off as carbon dioxide and water as described by the following chemical equation:

$$ZnCO_3 \cdot x\,(H_2O) \xrightarrow{T>500^\circ F} ZnO + CO_2 + (H_2O)$$

PAST PRACTICE

The process was originally carried out in circular brick kilns about 10 feet in diameter and 20 feet high which were capable of treating approximately 40 tons of ore per day using 2 to 4 tons of fuel. Ore and fuel were charged in alternate layers and combustion air was admitted through tuyeres around the base. The shaft furnace, in which the charge was heated from external fireboxes, was also used because it resulted in a product free from fuel ash.

Circular brick kilns and shaft furnaces were superseded by rotary kilns. These rotary kilns consisted of a horizontally inclined steel cylinder sloped 2 to 4 percent of its length. The kilns were supported on rollers and rotated via a pinion drive and large wheel attached to the shell of the kiln. Crude zinc oxide was passed countercurrently to the heating gases. Fume and dust were pulled through the kiln to a dust collection system using an induced draft fan. The collection systems consisted of a mechanical collector/cooler and a baghouse or an electrostatic precipitator.

Present Uses of Calcination

The few companies that continue to utilize calcination methods on zinc materials have established that the multiple-hearth rabbling furnace is the most satisfactory device for zinc calcination since dust carry-over is low, fuel consumption is not excessive and maintenance costs are minimal. Refractory lined rotary kilns are currently used to treat zinc oxide from fuming operations where de-leading is practiced at temperatures above the generally accepted figure for calcination.

One of the few remaining applications of calcination in the secondary zinc industry is the treatment of zinc oxides from fuming operations. Zinc galvanizing skimmings are melted down to remelt zinc and the fines emanating from the remelt pot are collected and calcined to recover zinc oxide from the zinc ammonium chloride used as a galvanizing flux. The product is used as an additive in fertilizers and cattle feeds and as a raw material for chemical or metallic zinc production.

Very little information has been published recently on zinc calcination processes. C. H. Mathewson describes two foreign applications; one at the Baelen plant of the Societe des Mines et Fonderies de Zinc de la Vieille Montagne and the second at the Flin Flon, Manitoba plant of the Hudson Bay Mining and Smelting Company. At the Baelen plant, 20 tons per day of zinc oxides from slag reduction furnaces are treated in a six-hearth wedge furnace to remove carbon and to complete the oxidation of the constituent elements. The dust carry-over is less than 2 percent, practically all of which is recovered in a standard baghouse. The Flin Flon plant treats 130 tons per day of zinc oxide fume from the slag-fuming plant in two seven-hearth wedge furnaces to remove chlorine, fluorine and sulfur dioxide. The calcined product is used to produce zinc by the electrolytic process.

Air Pollution Control Equipment

Member companies of the Industrial Gas Cleaning Institute have no record of recent gas cleaning installations in the secondary zinc calcining industry. Because so few zinc calcining plants remain in operation in the United States today, it is difficult to obtain data on air pollutants emitted from the process. A detailed discussion of equipment for the recovery of particulates and fume would not be relevant. Zinc oxide particulate emissions are characterized by extremely small particle size. Gaseous emissions will depend on the type of contaminants calcined from the zinc oxide. Operating conditions and material of construction of zinc calcining gas cleaning equipment must be selected with great care in order to minimize corrosion and chemical deterioration inherent with many of these gaseous emissions.

REFERENCES

1. Danielson, John A., "Air Pollution Engineering Manual", NAPCA, Public Health Service Publication No. 999-AP-40

2. Mathewson, C. H., "Zinc – The Metal, Its Alloys and Compounds", Reinhold, N.Y., 1959

3. Pomeroy, J. N. and Crowley, J. E., "Sources and Recovery of Scrap Zinc", Metallurgical Extraction, Circulation 1959

7. AIR POLLUTION CONTROL FOR ALUMINUM CHLORINATION STATIONS

a. PROCESS DESCRIPTION

The secondary smelting of aluminum involves the removal of a variety of impurities, both solid and gaseous. These are removed by the introduction of a flux which reacts chemically with the impurities producing a phase which separates from the hot melt. This discussion is concerned with the use of chlorine as the fluxing agent.

The impurities in the aluminum may consist of "dirt" or solid refractory oxides, gases (typically dissolved hydrogen) or metallic components, such as magnesium which are present as alloying ingredients. The introduction of chlorine by bubbling it through the melt, serves to agitate the bath, and at the same time, combine with the impurities to produce a free vapor or an insoluble dross which will float to the top.

During the fluxing process some of the aluminum reacts with the chlorine to form $AlCl_3$ which is readily sublimed from the melt. This is vented from the furnace as a gas or rapidly hydrolized with the atmospheric moisture present to form solid alumina, Al_2O_3, and hydrogen chloride. The amount of the $AlCl_3$ production depends to a large extent on the amount of magnesium in the melt which competes for the available chlorine producing a $MgCl_2$ dross.

The nearly complete elimination of fumes vented from the furnace which include $AlCl_3$, Al_2O_3, HCl, and unreacted chlorine can be attained in wet scrubbing equipment capable of both high energy impingement of the submicron particulate and absorption of the gaseous components.

1) MANUFACTURING ASPECTS

Furnaces generally used for fluxing are of 20,000 to 200,000 lb. capacity, completely enclosed, but having charging doors, side access doors, and a roof vent used for natural draft ventilation of combustion products and fumes. Gas or oil fired burners are used to melt the charge and maintain temperature, but are normally turned off during chlorination. (Separate reverberatory furnaces may be used for the melting and fluxing steps permitting a semi-continuous operation.) The melting point of the aluminum alloy is approximately 1220°F; however, the melt may be heated to 2000°F and maintained in the molten state during chlorination due to the heat capacity of the refractory lining and molten metal.

The charge material may consist of foundry rejects or mill ends, miscellaneous scrap, or pig aluminum. When the charge contains significant amounts of oil, grease, or paint the problem of the production of a carbonaceous smoke is present which can be treated by controlled oxidation. This problem is not discussed here. Chlorine is normally introduced with carbon lances extending through side ports in the furnace wall. Liquid chlorine is metered into the lance which is submerged beneath the surface of the melt. The bubbling action, produced mechanically, floats the solid impurities to the surface where they are later skimmed as a dross. The chlorine combines with dissolved hydrogen producing HCl which is vented through breeching to the stack. Where separate melting and holding hearths are used, an initial chlorination may take place in the melting hearth to remove the gross impurities prior to transferring the melt to the holding hearth. For this operation, a "wand" consisting of metal tube connected to the chlorine supply is manually extended through one of the doors. The amount of chlorine introduced at this time is normally a small fraction of the total used. Following the chlorination, alloying material may be added to attain the desired metal product.

The amount of chlorine used varies greatly, and is generally dependent on the final magnesium content desired. Removing the last several tenths of a percent of magnesium is a slow process, and large excesses of chlorine are used to speed up the reaction. Chlorine rates may be equivalent to a total chlorine consumption of from 5-40 lbs. per 1000 lbs. of metal over a period of from 20 minutes to several hours. Thus for example, it is possible to add as much as 1000 lbs/hr of chlorine to a 100,000 lb. melt for a period of 4 hours.

Following chlorination, the melt is removed from the furnace through a trough and is cast into pigs, billets or a variety of miscellaneous shapes at a site adjacent to the furnace. The time required for the entire sequence from charging to casting is typically 24 hours. However, it may range from several hours to several days depending on the nature of the overall operation. An overall process flow scheme is sketched in Figure 26.

Nature of Air Pollutants

The introduction of chlorine into an aluminum bath presents some very difficult air handling and fume elimination problems. The vent gases are at temperatures from 500-2000°F, and contain both free chlorine and hydrogen chloride gases. The gases must be quenched prior to scrubbing. This creates metallurgical problems at the hot-cold and gas-liquid interface. The fume generated is composed of sub-micron $AlCl_3$ and Al_2O_3. Hydrogen chloride is

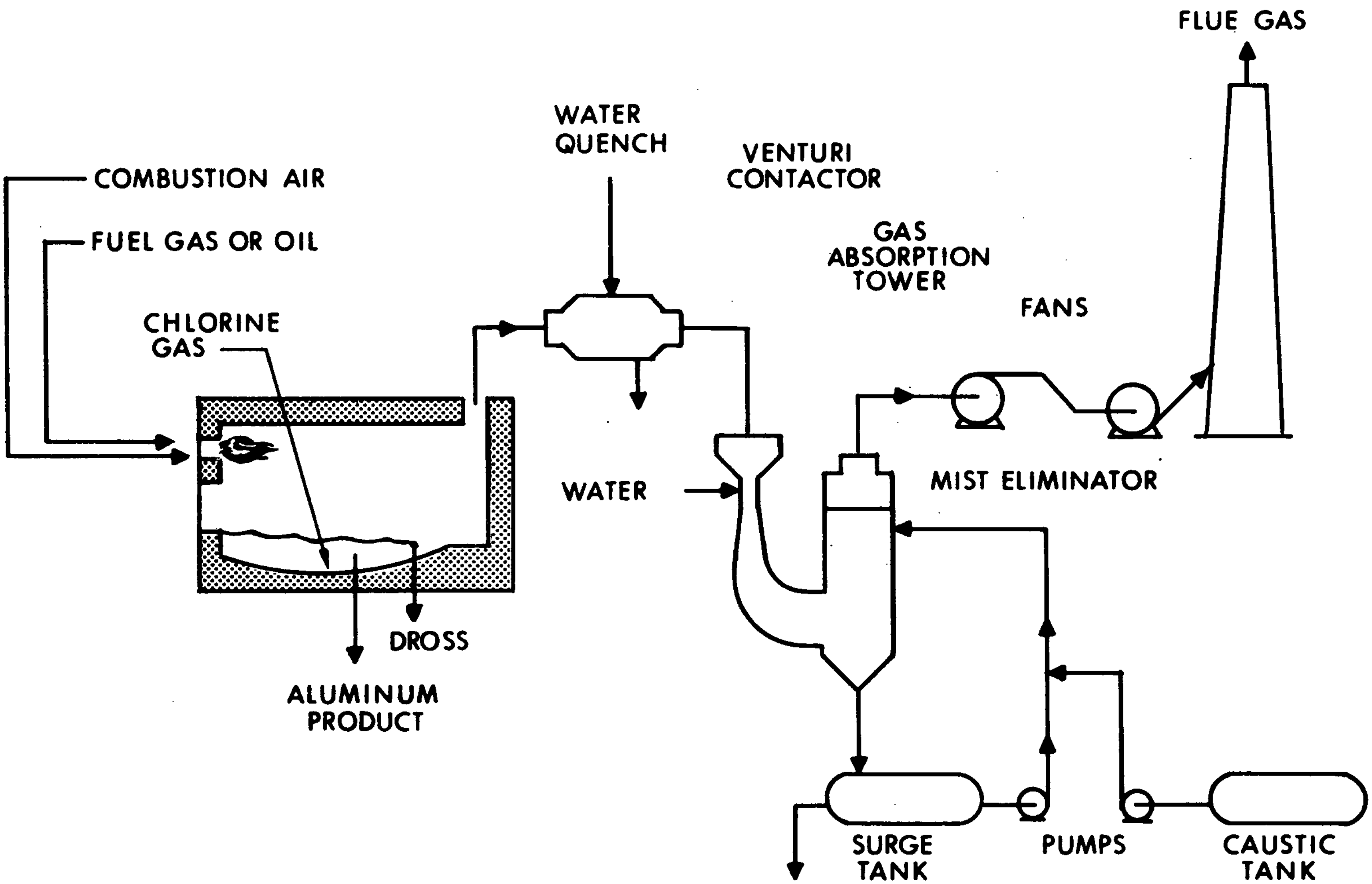


Figure 26

Process Flow Sketch for Aluminum Chlorination Station produced in the furnace and in the quench chamber. This gas along with free unreacted chlorine are in such quantities that a significant amount of gas contaminant must be handled.

2) AIR POLLUTION CONTROL

Submicron $AlCl_3$ and Al_2O_3 produced in the chlorinating furnace requires high pressure drop impaction in a wet scrubbing system. Significant quantities of hydrogen chloride and chlorine require gas absorption using a basic scrubbing liquor, normally NaOH. Therefore a system for storage, mixing, control and disposal of the liquid stream is needed. This equipment is auxiliary to the basic air handling equipment.

A fume control system for the elimination of both particulate and gaseous components can be designed and sized with knowledge of a few basic furnace operating parameters.

Furnace Ventilation Requirements

Furnace vents and stacks are sized to remove the hot combustion gases produced during maximum burner firing. During chlorination, the burners are off and therefore the gas volumes and temperatures are much lower. Calculations based on standard industrial ventilation techniques could be performed where the exact condition of the furnace as regards doors, cracks, temperatures, etc. are known. The best possible method of determining actual ventilation requirement is on-site volumetric measurements taken downstream of a damper which can regulate the flow. This damper should be adjusted to a point where the desired furnace draft is obtained or where the furnace draft is just sufficient to prevent chlorine from escaping through the doors into the room during a period of maximum chlorine usage. The volume measured at this time will be the minimum required. Of course, the temperature should be determined concurrently.

Experience has provided some approximate volume flow rates for various furnace sizes which may be used for estimation or where calculation or measurement is difficult.

Holding Capacity, lbs.	Ventilation Volume, ACFM @ 1000°F
50,000	5,600
100,000	7,500
150,000	9,500
200,000	11,000

The above values may be considered reasonable for a "tight" furnace i.e. with doors closed and with minimum leakage.

Contaminant Identity and Concentration

The major air control problem for chlorine fluxing furnaces is collection of the submicron fume emitted during periods of high chlorine usage and low magnesium content. The particulate entering the vent system may be either $AlCl_3$ or Al_2O_3 (or even some other aluminum compounds). On passing through the cooling chamber the chloride is hydrolized, and it is reasonable to consider all the aluminum entering the scrubber to be the oxide. Therefore, differentiation between various aluminum compounds is an academic question. According to the stoichiometry, a maximum of 47.9 lbs. of Al_2O_3 are produced for each 100 lbs. of chlorine charged. Using this as a basis along with the approximate ventilation requirement given above, it can be shown that the maximum grain loading will be between 1 and 3 gr/SCF/100 lb/hr chlorine usage.

A similar analysis using stoichiometry may be used to calculate maximum HCl emissions.

On-site testing during periods of chlorination will, of course, yield the most reliable loading data. The test procedure of the IGCI with an impinger followed by a fine porosity filter are recommended. The intent is to analyze for total aluminum content through such methods as atomic absorption spectroscopy, and present the results as Al_2O_3 (rather than attempting to differentiate between various aluminum compounds which is a difficult and unrewarding exercise). Quantities of HCl and Cl_2 can also be determined by suitable liquid absorption techniques using wet impingers.

The question of size distribution is again one that becomes academic, and such determinations are always subject to doubt due to procedural difficulties in obtaining the sample. This is true for most submicron material, but is particularly true for Al_2O_3 - $AlCl_3$ mixture since the $AlCl_3$ has a significant vapor pressure even at temperatures below its sublimation point. Therefore, some of the gaseous $AlCl_3$ will be condensing in any collection device defying its size characterization. One of the most useful methods of indicating size is to relate the difficulty of collection by the intended mechanism (in this case impaction wet scrubbing) to a theoretical size. Thus if a 40 inch pressure drop across a Venturi scrubber were required to collect 95% of the Al^{+++} present, this could be related to a fictitious size which may be defined theoretically.

A miniature Venturi contactor has been used for on-site testing, and has been successful in predicting the "apparent" mean size of the submicron particulate present in aluminum fluxing furnace emissions.

The Abatement System

The items of process equipment shown in Figure 26 are discussed below:

a) *Cooling Chamber* – Prior to entering the scrubber, the hot gases must be cooled and saturated to reduce the volume and protect the remainder of the system. Gas temperatures are between 500 - 1500°F, and are rapidly quenched to approximately the adiabatic saturation temperature. Corrosion is severe in the chlorine-free chloride, hot-cold, gas-liquid area of the quench chamber. Typical construction may be of two general types: one is a nickel alloy construction (Ni200, Incoloy 825, or Hastelloy) which resists corrosion, is light in weight, and requires a relatively small space requirement; the second is a refractory acid brick construction which may be reinforced structurally with a rubber lined steel shell.

b) *Venturi Contactor* – The cooled and saturated gases enter the Venturi contactor where the particulate impinges on the atomized water droplets. The Venturi may be constructed of acid and chloride resistant materials, such as nickel alloys or plastic materials. Plastic or rubber coatings must be able to resist flaking, chipping or peeling in the high velocity throat section and are generally not recommended. An atmospheric damper is generally provided at the entrance to the venturi section to permit draft control of the furnace.

c) *Gas Absorption Tower* – Adequate gas-liquid contact must be provided to eliminate HCl and Cl_2. A caustic liquor is generally required to absorb the Cl_2 and also eliminate handling and disposal of acid liquors. The small amounts of particulate passing the Venturi and/or recirculating in the slurry necessitates the tower be of a non-plugging type, either a spray tower or mobile packed bed. The tower construction may be of plastic or rubber lined construction.

d) *Mist Eliminator* – Normally this is integral with the scrubbing tower for the elimination of liquid carryover. Again, it should be of a non-plugging type such as a centrifugal collector.

e) *Fans and Motors* – The possibility of small amounts of carryover and condensation necessitate the use of corrosion resistant materials on all internal parts of the fans. Plastic or rubber coatings on housings are common, and where tip speeds are relatively low can also be used to coat the fan wheel. It is often difficult to specify such low rpm, and stainless steel wheels are necessary for medium ranges up to their top speed limit. (Hastelloy wheels can be used at the higher speeds). General practice is to limit the rpm to, say less than 2000, and connect a number of fans in series to develop the necessary static pressure. An inlet damper and fan drains should be specified.

f) *Stack* – As the existing stack must be used to ventilate the hot combustion product, it is generally unsuitable for the cold and moist scrubber discharge. Plastic or plastic-coated steel is generally used with heights normally just sufficient to rise above roof lines.

g) *Surge Tank* – A tank having 2-3 minutes hold-up time at the existing recirculation rate is desirable. It is, of course, important to maintain enough caustic value in the recirculating system to handle a complete chlorination cycle, and this may be the overriding consideration for sizing the surge tank. Continuous, controlled addition of caustic may eliminate this requirement. Generally the slurry concentration accumulated over a chlorination period is not a factor in tank sizing, but should be investigated.

h) *Recirculation Pump* – Must be of suitable material to handle alkaline and chloride containing liquor.

i) *Caustic Storage Tank* – A 50% sodium hydroxide solution is available from suppliers and this eliminates the necessity of handling and mixing solid material. The solution must be kept above 75°F to prevent freezing, and therefore, provision should be made for external heating of the tank and piping.

j) *Controls* – In addition to the major items of equipment listed above, the system must be ducted and piped to connect the components. A variety of control schemes can be used to insure sufficient addition of caustic to prevent failure due to presence of acidic liquor. pH indication followed by manual or automatic, batch or continuous control is required. Safety electrical interlocks are, of course, necessary to prevent temperature excursions which could damage equipment. In all cases, an emergency bypass to the combustion stack should be provided.

b. SPECIFICATIONS AND COSTS

The aluminum chlorination application is the only application for which only one type of air pollution control equipment was considered suitable. The high concentration of gaseous hydrogen chloride and chlorine require the use of wet scrubbing to conform to good air pollution control practice.

Although it is possible to provide good control by using a scrubber in combination with a fabric filter or electrostatic precipitator, such combinations are likely to be less economical. The specifications furnished the equipment manufacturers to serve as a basis for their bid prices are written around a scrubber alone.

The process description submitted as a part of the specification for the scrubber installation is shown in Table 58. The operating conditions for purposes of this quotation are summarized in Table 59. As in each of the previous cases, the complete specification can be reproduced by inserting the material in these two tables in the Sample Specification given in Appendix IV.

The equipment and installation costs submitted in response to these specifications are summarized in Table 60 and Table 61. The former covers a particulate emission regulation equivalent to the LA-Process Weight regulation, while the latter produces a high particulate collection efficiency. There is likely to be a noticeable particulate residual plume after the water plume has dispersed in the lower efficiency case, whereas there should be little visible emission other than water in the high efficiency case.

Both of the specifications are based on removal of particulate matter. This is because the control of the submicron fume produced by the chlorine fluxing operation is much more difficult than the absorption of HCl and Cl_2 in the alkaline liquor. Ordinarily either scrubber will produce good gas absorption (over 99% efficiency) for the gaseous contaminants, and this need not be specified separately.

Table 58

WET SCRUBBER PROCESS DESCRIPTION FOR

ALUMINUM CHLORINATION STATION SPECIFICATION

The aluminum chlorine fluxing furnace is used to produce a variety of alloy castings. Charging stock is clean (non-oily) scrap consisting of mill ends, shavings, and miscellaneous scrap extrusions of varying magnesium content. End product will have a magnesium content of from 0.1 – 0.5 wt. % magnesium. Past experience has indicated that maximum chlorine consumption is 20 lb. per 1000 lbs. of melt in a 2 hour period.

The furnace operation is such that a normal cycle lasts 24 hours – from charging to casting. On an average 5 drops are made per week. Chlorination is performed in the holding hearth with carbon lances inserted through ports located on the sides of the furnace. Chlorination is not performed during furnace firing.

The furnace is vented through a port located at the middle of one side through a 30 ft. run of horizontal breeching to an 85' stack located outside of the building. At the stack area is a 40' x 40' area available for new equipment installation, for which road access for truck-size deliveries is available. A concrete slab designed for loads of 500 psi covers the entire area. Electric power, steam, gas, and an abundant fresh water supply are available to the area. Sanitary sewage will accept process water in the range of pH 4-10 providing that solids content is less than 1% by weight.

Wet scrubbing equipment is required to reduce particulate and gaseous emissions to a level according to local regulations and the attached table of operation. All materials of construction to be consistent with the materials handled i.e., hot, wet, chlorine and chloride, caustic, slurry, etc. Bids should include the following equipment:

(1) Quench chamber for cooling hot gases

(2) Wet scrubber including a venturi type contactor, a non-plugging gas absorption tower, and mist eliminator

(3) Fans and motors to develop necessary static pressure. Fans shall be selected which will operate at less than 2000 rpm and will be arranged in series.

(4) 85' self-supporting stack

(5) Recirculating tank

(6) 50% caustic storage tank

(7) Interconnecting ductwork and piping for all equipment furnished. Ductwork shall begin at furnace-stack breeching

(8) Appropriate control: dampers, valves, motors, controllers, pH, safety interlocks, etc.

With the exception of the scrubber proper, the above items are to be treated as auxiliaries for quotation purposes.

Table 59

WET SCRUBBER OPERATING CONDITIONS FOR

ALUMINUM CHLORINATION STATION SPECIFICATION

Separate quotations are to be made for the following three conditions, and for each efficiency level specified.

	Small	Medium	Large
Furnace capacity, lb.	30,000	60,000	200,000
Melting rate, lb/hr	1,250	2,500	8,333
Inlet gas volume, ACFM	4,800	6,000	11,200
Inlet gas temp., °F	1,000	1,000	1,000
Inlet loading, lb/hr	150	300	1,000
Inlet loading, gr/ACF	3.65	5.84	10.4
Outlet gas volume, ACFM	2,560	3,200	6,000
Outlet temperature, °F	150	150	150
Case 1 – LA Process Weight			
Outlet loading, lb/hr	3.19	4.64	8.93
Outlet loading, gr/ACF	0.15	0.17	0.19
Efficiency, wt. %	97.9	98.5	99.0
Case 2 – High Efficiency			
Outlet loading, lb/hr	0.44	0.55	1.03
Outlet loading, gr/ACF	0.02	0.02	0.02
Efficiency, wt. %	99.7	99.8	99.9

Table 60

Wet Scrubber Cost Data for

Aluminum Chlorination Station

(LA—Process Weight)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	15	30	100
Inlet Gas Volume, ACFM	4,800	6,000	11,200
Efficiency, Wt.% (For Particulates)**	97.9	98.5	99.0
Controlled Emission, gr/ACF(Part.)**	0.15	0.17	0.19
Type of Charge	Misc. Scrap Al (non-oily)		
Inlet Gas Temperature, F	1,000	1,000	1,000
System Horsepower	40	60	120
Equipment Cost, $			
A. Collector	14,000	15,800	21,600
B. Auxiliaries	40,000	47,500	69,000
C. Gas Conditioning Equipment *	3,900	4,300	6,100
D. Waste Equipment	-	-	-
E. Other	6,100	8,100	12,000
Total	64,000	75,700	108,700
Installation Cost, $.			
A. Grass-Roots	58,000	66,000	90,000
B. Add-On	78,000	88,000	120,000
Expected Life, Years	10	10	10
Operating and Maintenance, $/year			
Caustic	5,000	10,000	34,000
Labor	6,000	6,000	6,000
Parts	3,200	3,800	5,500

* Spray Cooler

** HCl and Cl_2 Efficiencies are expected to be 99+% with 5% caustic liquor.

Table 61

Wet Scrubber Cost Data for

Aluminum Chlorination Station

(High Efficiency)

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	15	30	100
Inlet Gas Volume, ACFM	4,800	6,000	11,200
Efficiency, Wt.% (For Particulates)**	99.7	99.8	99.9
Controlled Emission, gr/ACF (Part.)**	0.02	0.02	0.02
Type of Charge	Misc. Scrap Al (non-oily)		
Inlet Gas Temperature, F	1,000	1,000	1,000
System Horsepower	70	100	210
Equipment Cost, $			
A. Collector	14,000	15,800	21,600
B. Auxiliaries	49,300	58,500	85,000
C. Gas Conditioning Equipment *	3,900	4,300	6,100
D. Waste Equipment	-	-	-
E. Other 50% Caustic tank & pump	6,100	8,100	12,000
Total	73,300	86,700	124,700
Installation Cost, $			
A. Grass-Roots	60,000	68,500	93,000
B. Add-On	80,000	90,500	123,000
Expected Life, Years	10	10	10
Operating and Maintenance, $/year			
Caustic	5,000	10,000	34,000
Labor	6,000	6,000	6,000
Parts	3,665	4,335	6,235

* Spray Cooler

** Note: HCl and Cl_2 Efficiencies are expected to be 99+% with 5 wt.% caustic liquor.

c. SUMMARY COMMENTS

The prices quoted for each of the two cases are plotted in Figures 27 and 28. It is apparent that the cost of the equipment and installation does not increase sharply as the efficiency level increases. The power cost does go up with increasing efficiency because the pressure drop is increased significantly.

It is interesting to note that the horsepower requirement is high, as is the usual case for high energy scrubbers, but that the contribution this makes to the overall operating cost is nominal because it only operates for about 20 hours per week. The annual cost may be estimated for the high efficiency 100 ton unit on the basis of 1c/kw-hr and 85% motor efficiency as follows:

$$210 \text{ HP} \times .746 \times 20 \times 52 \times \$.01 = \$1628.00/\text{year}$$

Both the chemical and replacement parts costs exceed this figure by a substantial margin.

In particular, the chemical cost is high. The consumption of caustic is in direct proportion to the chlorine gas excess over the amount required to react magnesium and other metals out of the solution. It is apparent that any action which reduces the chlorine usage will also reduce the caustic consumption.

The ratio of system cost to scrubber cost is usually high for chemical scrubbing systems. For the high efficiency, 100 ton installation, the *system equipment* cost is five times the bare scrubber cost. On an installed basis, the system cost is nearly ten times the cost of the scrubber.

Another significant item in the turnkey cost figures is the difference in installation cost estimated for an add-on system as opposed to a new, or "grass roots" smelter. There isn't enough room for convenient installation of a scrubbing system in most secondary smelting plants. The additional cost involved in locating fans, scrubbers, tanks, etc. far away from the furnace, or on rooftop is indicated by the roughly $20,000 additional cost to install the system in an existing plant.

Figure 27

Wet Scrubber Cost Data for

Aluminum Chlorination Stations

(LA–Process Weight)

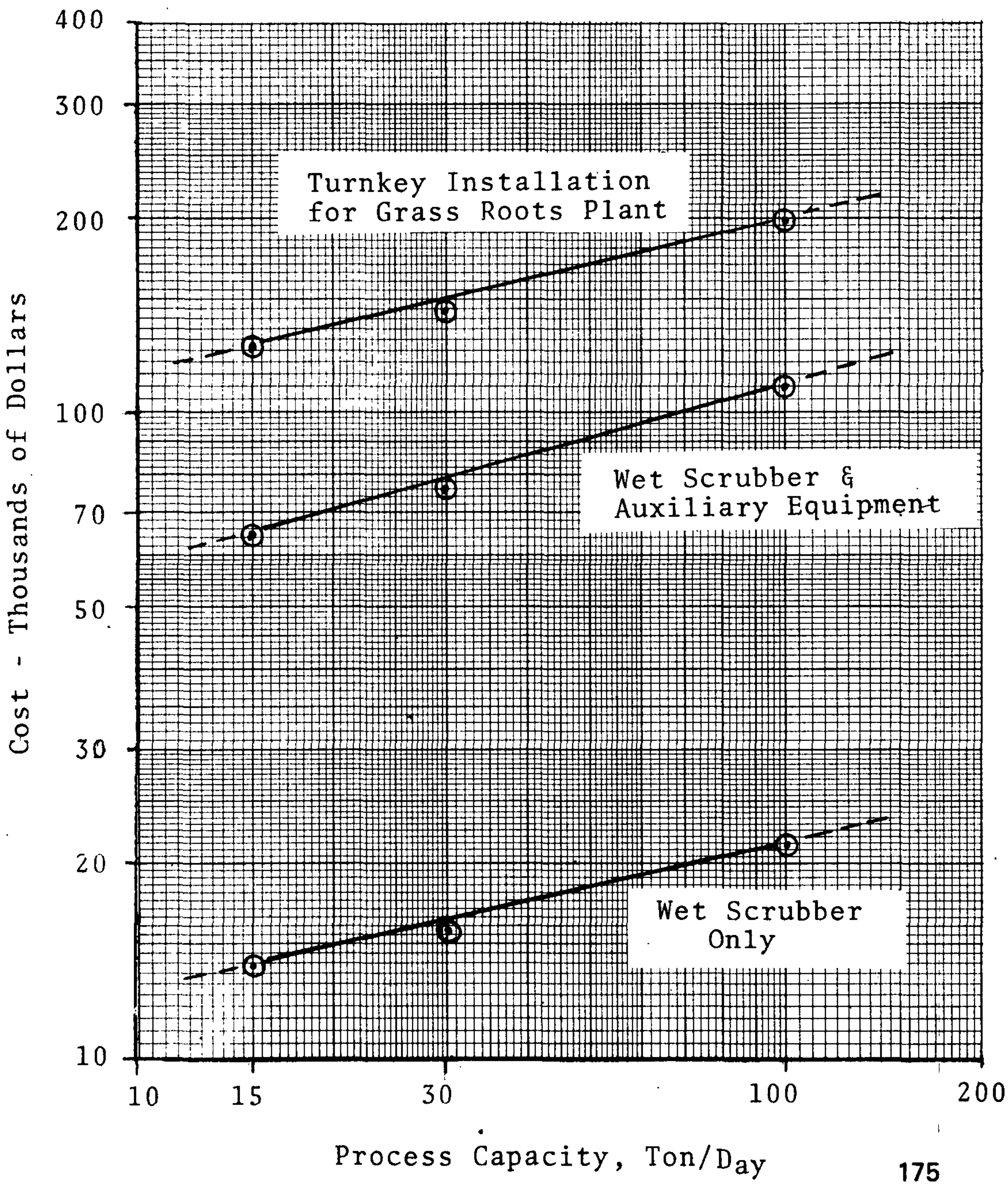
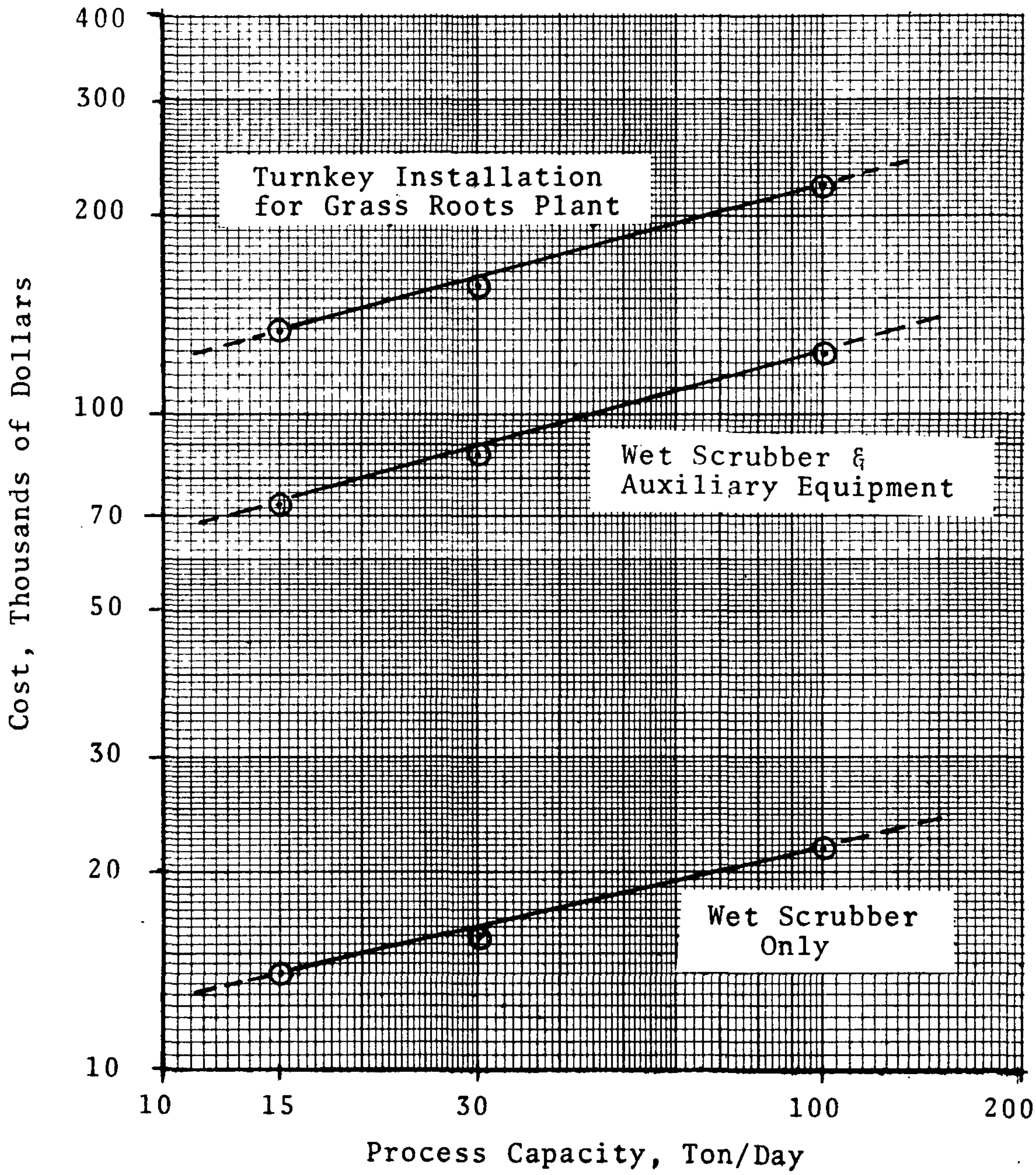


Figure 28

Wet Scrubber Cost Data for
Aluminum Chlorination Stations

(High Efficiency)



C. DISCUSSION OF COSTS

For each of the areas covered, with the exception of zinc calcination, the cost estimates presented by the IGCI member companies form a reasonably complete and consistent pattern.

1. COMPARISON OF INSTALLED COSTS

The first costs may be generalized in two ways. The ventilation rate specified in this study can be taken as a good estimate of the "proper" rate for furnaces of various sizes. The cost of air pollution control equipment can be read from the appropriate data plot as a function of furnace capacity. Or, the costs may be generalized in terms of the cost per CFM of gas treated. This provides the best basis for estimating costs but requires knowledge of the flue gas rate for a particular furnace.

Both bases have been used to generalize capital costs collected in this study. The two cautions suggested in previous sections must be repeated:

(1) Only very rough estimates of capital cost should be based on the "cost – furnace size" relationships given here, for the ventilation requirement may vary greatly from one furnace to another, even though both have the same rated capacity.

(2) Capital costs based on actual gas flows are approximate at best. Quotations from reputable manufacturers of equipment or competent air pollution engineering specialists should be used in estimating the cost of a particular installation.

COST VS. FURNACE SIZE

The "cost – furnace" size relationship is illustrated in the log–log plots included in Section B. This relationship may be written mathematically as:

$$COST = k\,(SIZE)^{x}$$

where:

COST = cost of installation in dollars

k = constant

SIZE = furnace size (usually in ton/day)

x = exponent

The costs obtained in Section B have been generalized to fit this equation by assuming that a straight line (on log - log paper) between the "small" furnace and the "large" one is an adequate representation of the conditions in between. For most of the equipment types, this is a good approximation.

The calculations were made for the constant and exponent in the cost equation for three cases in each application area:

(1) Collector Only

(2) Total Equipment

(3) Total Installed Cost (new plant basis)

The "collector only" case represents the bare piece of control equipment; a wet scrubber, fabric filter or precipitator, with no auxiliaries whatever. It is usually impossible to use such a piece of equipment without the installation of auxiliaries such as fans, pumps, dust handling conveyor, etc.

The cost of the "total equipment" includes the collector and those items specified as auxiliaries in the descriptions written in Section B. It does not include such things as foundations, ductwork, etc.

The "total installed cost" or turnkey cost represents the price a contractor would ordinarily charge for a complete installation, with all incidentals such as start up supervision included. For this study, the "grass–roots" cost was used. This represents the cost which is associated with installation of equipment without the space limitations and possible interferences with installation that are characteristic of back-fit of equipment into an existing plant.

This is not because the back-fit problems are less important than the air pollution problems in existing plants. The choice was made only because of the difficulty in setting meaningful ground rules as to how difficult a situation should be assumed in the back-fit or "add-on" quotes. Some of the manufacturers quoted no difference between the grass roots and add-on installations. Others assumed a significant problem with "shoe horning" equipment into an existing plant.

In general, the cost of add-on installations will exceed those for the same equipment in a new plant. Differences of 20% additional for add-on installations over the grass roots case are typical.

The calculated values for use in the cost equation are given in the following tables:

Table 62 Table 63	Rotary Lime Kilns
Table 66	Brass/Bronze Reverberatory Furnaces
Table 68	Lead Cupolas
Table 70	Sweating Furnaces
Table 72	Lead Reverberatory Furnaces
Table 74	Aluminum Chlorination Stations

The rate of increase of cost with size is lower than generally assumed for capital equipment. That is, while most installations are assumed to increase in cost with the 0.6 power of size, the equipment covered here usually followed a lower "power rule". This was particularly true for the electrostatic precipitators. These are applied to lime kilns at the lower end of their economical size range. Reducing the size of a very small precipitator does not appear to reduce the cost much.

The exception to the generalization about low exponents are the wet scrubbers. These are simple when built on a very small scale, and become more complex as they get larger. These have an exponent of about 0.8 for the rotary lime kiln scrubber. However, the total installed costs fit the generalization well.

One index often used in making budgetary estimates is the ratio of total equipment cost to collector cost, or of turnkey cost to collector cost. These ratios are helpful because of the ease with which "collector only" costs can be estimated, and the difficulty in obtaining good estimates of the turnkey cost. For each of the tables listed, these ratios have been calculated and tabulated.

COSTS PER CFM

Costs of equipment and installation are often quoted as a number of dollars per CFM. For electrical precipitators and fabric filters, it is customary for the manufacturers to use the ACFM at the collector inlet as the basis for this index, while wet scrubber manufacturers use the saturated ACFM at the scrubber outlet.

In order to put this figure into a consistent form for comparison of the costs, the cost/SCFM has been used in this section. The ratios quoted can be converted to an ACFM basis by multiplying \$/ACFM = (\$/SCFM) (530/T + 460) where T is the gas temperature in degrees F at the collector inlet. Scrubber manufacturers should be given the gas conditions (including moisture content) at the scrubber inlet when they are asked for price information. They will calculate the wet gas volume at the scrubber outlet to use in sizing the scrubber.

The cost/SCFM ratios for the application areas covered in this report are given in the following tables:

Table 64 Table 65	Rotary Lime Kilns
Table 67	Brass/Bronze Reverberatory Furnaces
Table 69	Lead Cupolas
Table 71	Sweating Furnaces
Table 73	Lead Reverberatory Furnaces
Table 75	Aluminum Chlorination Stations

Table 62

Derived Cost Indicies for Rotary Lime Kilns

(Precipitator)

COLLECTOR TYPE	K*	X*	B/A **	C/A**	C/B**
ELECTROSTATIC PRECIP. HIGH EFFICIENCY					
COLLECTOR ONLY(A)	16501	.294	-	-	-
TOTAL EQUIPMENT(B)	20577	.395	-	-	-
TURNKEY(C)	26138	.437	-	-	-
SMALL (24500 ACFM)	-	-	2.028	3.155	1.556
MEDIUM(59500 ACFM)	-	-	2.286	3.660	1.601
LARGE (105000 ACFM)	-	-	2.332	3.846	1.649
ELECTROSTATIC PRECIP LA-PROCESS WEIGHT					
COLLECTOR ONLY(A)	7393	.398	-	-	-
TOTAL EQUIPMENT(B)	12257	.462	-	-	-
TURNKEY(C)	14978	.514	-	-	-
SMALL (24500 ACFM)	-	-	2.250	3.546	1.576
MEDIUM(59500 ACFM)	-	-	2.430	3.995	1.644
LARGE (105000 ACFM)	-	-	2.456	4.165	1.696

* For use in equation COST = K · (SIZE, ton/day)^X

** B/A = Cost of total equipment/cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 63

Derived Cost Indicies for Rotary Lime Kilns

(Fabric Collector and Scrubber)

COLLECTOR TYPE	K*	X*	B/A **	C/A**	C/B**
FABRIC COLLECTOR					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	4760	.500	-	-	-
TOTAL EQUIPMENT(B)	10131	.463	-	-	-
TURNKEY(C)	20016	.444	-	-	-
SMALL (20000 ACFM)	-	-	1.783	3.206	1.798
MEDIUM(50000 ACFM)	-	-	1.738	3.062	1.762
LARGE (90000 ACFM)	-	-	1.695	2.966	1.750
WET SCRUBBER					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	270	.822	-	-	-
TOTAL EQUIPMENT(B)	837	.691	-	-	-
TURNKEY(C)	5977	.517	-	-	-
SMALL (35000 ACFM)	-	-	1.647	5.066	3.076
MEDIUM(85000 ACFM)	-	-	1.488	4.058	2.727
LARGE (150000 ACFM)	-	-	1.374	3.318	2.415
WET SCRUBBER					
LA-PROCESS WEIGHT					
COLLECTOR ONLY(A)	115	.856	-	-	-
TOTAL EQUIPMENT(B)	267	.872	-	-	-
TURNKEY(C)	5158	.557	-	-	-
SMALL (35000 ACFM)	-	-	2.507	10.549	4.208
MEDIUM(85000 ACFM)	-	-	2.280	8.364	3.668
LARGE (150000 ACFM)	-	-	2.564	6.966	2.717

* For use in equation COST = K · (SIZE, ton/day)^X

** B/A = Cost of total equipment/Cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 64

Cost per SCFM* for Rotary Lime Kilns

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
ELECTROSTATIC PRECIP. HIGH EFFICIENCY			
GAS FLOW, SCFM	11194	27185	47974
COLLECTOR ONLY	6.09	2.92	2.14
TOTAL EQUIPMENT	12.35	6.68	4.98
TURNKEY**	19.22	10.69	8.22
ELECTROSTATIC PRECIP LA-PROCESS WEIGHT			
GAS FLOW, SCFM	11194	27185	47974
COLLECTOR ONLY	4.52	2.38	1.83
TOTAL EQUIPMENT	10.17	5.78	4.50
TURNKEY **	16.03	9.49	7.63

*BASED ON SCFM (AT 70F, INCLUDING H2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

Table 65

Cost per SCFM* for Rotary Lime Kilns

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
FABRIC COLLECTOR			
HIGH EFFICIENCY			
GAS FLOW, SCFM	10495	26238	47228
COLLECTOR ONLY	5.07	2.87	2.26
TOTAL EQUIPMENT	9.05	4.98	3.82
TURNKEY**	16.27	8.78	6.69
WET SCRUBBER			
HIGH EFFICIENCY			
GAS FLOW, SCFM	11175	27139	47892
COLLECTOR ONLY	1.28	.95	.93
TOTAL EQUIPMENT	2.11	1.41	1.28
TURNKEY**	6.48	3.86	3.10
WET SCRUBBER			
LA-PROCESS WEIGHT			
GAS FLOW, SCFM	11175	27139	47892
COLLECTOR ONLY	.64	.48	.49
TOTAL EQUIPMENT	1.62	1.10	1.26
TURNKEY**	6.80	4.04	3.43

*BASED ON SCFM (AT 70F, INCLUDING H2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

Table 66

Derived Cost Indicies for Brass/Bronze Reverberatory Furnaces

COLLECTOR TYPE	K*	X*	B/A**	C/A**	C/B**
FABRIC COLLECTOR					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	2969	.431	-	-	-
TOTAL EQUIPMENT(B)	6094	.460	-	-	-
TURNKEY(C)	13085	.419	-	-	-
SMALL (2200 ACFM)	-	-	2.236	4.255	1.903
MEDIUM(5500 ACFM)	-	-	2.199	4.190	1.905
LARGE (8250 ACFM)	-	-	2.327	4.186	1.799
WET SCRUBBER					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	614	.712	-	-	-
TOTAL EQUIPMENT(B)	7792	.424	-	-	-
TURNKEY(C)	25164	.426	-	-	-
SMALL (3320 ACFM)	-	-	5.362	17.389	3.243
MEDIUM(8150 ACFM)	-	-	3.537	11.483	3.246
LARGE (12200 ACFM)	-	-	3.598	11.691	3.250
WET SCRUBBER					
LA-PROCESS WEIGHT					
COLLECTOR ONLY(A)	567	.728	-	-	-
TOTAL EQUIPMENT(B)	5491	.449	-	-	-
TURNKEY(C)	50475	.101	-	-	-
SMALL (3320 ACFM)	-	-	4.193	13.586	3.240
MEDIUM(8150 ACFM)	-	-	3.257	10.568	3.244
LARGE (12200 ACFM)	-	-	2.845	5.691	2.000

* For use in equation $COST = K \cdot (SIZE, ton/day)^X$

** B/A = Cost of total equipment/Cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 67

Cost per SCFM* for Brass/Bronze Reverberatory Furnaces

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
FABRIC COLLECTOR			
HIGH EFFICIENCY			
GAS FLOW, SCFM	1597	3993	5990
COLLECTOR ONLY	6.76	3.87	3.28
TOTAL EQUIPMENT	15.12	8.52	7.63
TURNKEY**	28.77	16.23	13.72
WET SCRUBBER			
HIGH EFFICIENCY			
GAS FLOW, SCFM	715	1756	2628
COLLECTOR ONLY	7.24	5.68	5.29
TOTAL EQUIPMENT	38.83	20.11	19.03
TURNKEY**	125.93	65.27	61.83
WET SCRUBBER			
LA-PROCESS WEIGHT			
GAS FLOW, SCFM	715	1756	2628
COLLECTOR ONLY	7.03	5.63	5.25
TOTAL EQUIPMENT	29.45	18.35	14.93
TURNKEY**	95.44	59.52	29.87

*BASED ON SCFM (AT 70F, INCLUDING H2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

Table 68

Derived Cost Indicies for Lead Cupolas

COLLECTOR TYPE	K*	X*	B/A**	C/A**	C/B**
FABRIC COLLECTOR					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	3437	.512	-	-	-
TOTAL EQUIPMENT(B)	5136	.482	-	-	-
TURNKEY(C)	9046	.488	-	-	-
SMALL (5000 ACFM)	-	-	1.387	2.483	1.790
MEDIUM(10000 ACFM)	-	-	1.400	2.531	1.808
LARGE (20000 ACFM)	-	-	1.329	2.401	1.807
WET SCRUBBER					
HIGH EFFECIENCY					
COLLECTOR ONLY(A)	528	.706	-	-	-
TOTAL EQUIPMENT(B)	12109	.320	-	-	-
TURNKEY(C)	39460	.319	-	-	-
SMALL (3675 ACFM)	-	-	8.785	28.589	3.254
MEDIUM(7350 ACFM)	-	-	6.905	22.687	3.286
LARGE (14700 ACFM)	-	-	5.064	16.465	3.252
WET SCRUBBER					
LA-PROCESS WEIGHT					
COLLECTOR ONLY(A)	502	.706	-	-	-
TOTAL EQUIPMENT(B)	7197	.404	-	-	-
TURNKEY(C)	23455	.403	-	-	-
SMALL (3675 ACFM)	-	-	6.774	22.016	3.250
MEDIUM(7350 ACFM)	-	-	5.930	19.239	3.244
LARGE (14700 ACFM)	-	-	4.405	14.291	3.245

* For use in equation COST = K · (SIZE, ton/day)^X

** B/A = Cost of total equipment/Cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 69

Cost per SCFM* for Lead Cupolas

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
FABRIC COLLECTOR			
HIGH EFFICIENCY			
GAS FLOW, SCFM	3630	7260	14521
COLLECTOR ONLY	3.38	2.32	1.75
TOTAL EQUIPMENT	4.68	3.24	2.33
TURNKEY **	8.38	5.86	4.21
WET SCRUBBER			
HIGH EFFECIENCY			
GAS FLOW, SCFM	2029	4058	8116
COLLECTOR ONLY	1.50	1.04	1.03
TOTAL EQUIPMENT	13.21	7.18	5.21
TURNKEY**	42.98	23.59	16.94
WET SCRUBBER			
LA-PROCESS WEIGHT			
GAS FLOW, SCFM	2029	4058	8116
COLLECTOR ONLY	1.43	.99	.98
TOTAL EQUIPMENT	9.68	5.88	4.31
TURNKEY**	31.47	19.06	13.98

*BASED ON SCFM (AT 70F, INCLUDING H2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

Table 70

Derived Cost Indicies for Sweating Furnaces

COLLECTOR TYPE	K*	X*	B/A**	C/A**	C/B**
FABRIC COLLECTOR					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	1124	.892	-	-	-
TOTAL EQUIPMENT(B)	5006	.948	-	-	-
TURNKEY(C)	8760	.948	-	-	-
SMALL (15400 ACFM)	-	-	5.253	9.194	1.750
MEDIUM(30800 ACFM)	-	-	5.618	9.832	1.750
LARGE (46200 ACFM)	-	-	5.586	9.776	1.750
WET SCRUBBER					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	4133	.514	-	-	-
TOTAL EQUIPMENT(B)	6688	.768	-	-	-
TURNKEY(C)	8497	.797	-	-	-
SMALL (42500 ACFM)	-	-	3.430	4.756	1.387
MEDIUM(85000 ACFM)	-	-	4.819	6.678	1.386
LARGE (127500 ACFM)	-	-	4.535	6.496	1.433

* For use in equation COST = K · (SIZE, ton/day)^X

** B/A = Cost of total equipment/Cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 71

Cost per SCFM* for Sweating Furnaces

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
FABRIC COLLECTOR			
HIGH EFFICIENCY			
GAS FLOW, SCFM	11496	22992	34487
COLLECTOR ONLY	1.36	1.21	1.21
TOTAL EQUIPMENT	7.16	6.80	6.76
TURNKEY**	12.54	11.91	11.84
WET SCRUBBER			
HIGH EFFICIENCY			
GAS FLOW, SCFM	11492	22985	34477
COLLECTOR ONLY	1.64	1.05	.96
TOTAL EQUIPMENT	5.63	5.08	4.36
TURNKEY**	7.80	7.03	6.24

*BASED ON SCFM (AT 70F, INCLUDING H_2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

Table 72

Derived Cost Indicies for Lead Reverberatory Furnaces

COLLECTOR TYPE	K*	X*	B/A**	C/A**	C/B**
FABRIC COLLECTOR					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	1160	.795	-	-	-
TOTAL EQUIPMENT(B)	3931	.816	-	-	-
TURNKEY(C)	6880	.816	-	-	-
SMALL (5000 ACFM)	-	-	3.557	6.226	1.750
MEDIUM(10000 ACFM)	-	-	3.734	6.536	1.750
LARGE (20000 ACFM)	-	-	3.680	6.440	1.750
WET SCRUBBER					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	10794	.119	-	-	-
TOTAL EQUIPMENT(B)	49851	.100	-	-	-
TURNKEY(C)	72815	.088	-	-	-
SMALL (5000 ACFM)	-	-	4.415	6.275	1.421
MEDIUM(11800 ACFM)	-	-	4.493	6.352	1.414
LARGE (23600 ACFM)	-	-	4.279	5.965	1.394
WET SCRUBBER					
LA-PROCESS WEIGHT					
COLLECTOR ONLY(A)	7528	.269	-	-	-
TOTAL EQUIPMENT(B)	34273	.330	-	-	-
TURNKEY(C)	66078	.305	-	-	-
SMALL (5000 ACFM)	-	-	5.236	9.521	1.819
MEDIUM(11800 ACFM)	-	-	5.487	9.823	1.790
LARGE (23600 ACFM)	-	-	5.773	10.079	1.746

* For use in equation $COST = K \cdot (SIZE, ton/day)^X$

** B/A = Cost of total equipment/Cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 73

Cost per SCFM* for Lead Reverberatory Furnaces

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
FABRIC COLLECTOR			
HIGH EFFICIENCY			
GAS FLOW, SCFM	3630	7260	14521
COLLECTOR ONLY	1.99	1.79	1.79
TOTAL EQUIPMENT	7.09	6.70	6.60
TURNKEY**	12.42	11.72	11.55
WET SCRUBBER			
HIGH EFFICIENCY			
GAS FLOW, SCFM	2760	6515	13029
COLLECTOR ONLY	5.14	2.18	1.32
TOTAL EQUIPMENT	22.71	9.79	5.65
TURNKEY**	32.28	13.85	7.87
WET SCRUBBER			
LA-PROCESS WEIGHT			
GAS FLOW, SCFM	2760	6515	13029
COLLECTOR ONLY	5.07	2.43	1.66
TOTAL EQUIPMENT	26.55	13.31	9.57
TURNKEY**	48.29	23.82	16.71

*BASED ON SCFM (AT 70F, INCLUDING H2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

Table 74

Derived Cost Indicies for Aluminum Chlorination Stations

COLLECTOR TYPE	K*	X*	B/A**	C/A**	C/B**
WET SCRUBBER					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	7539	.229	-	-	-
TOTAL EQUIPMENT(B)	34332	.280	-	-	-
TURNKEY(C)	66182	.259	-	-	-
SMALL (4800 ACFM)	-	-	5.236	9.521	1.819
MEDIUM(6000 ACFM)	-	-	5.487	9.823	1.790
LARGE (11200 ACFM)	-	-	5.773	10.079	1.746
WET SCRUBBER					
LA-PROCESS WEIGHT					
COLLECTOR ONLY(A)	7539	.229	-	-	-
TOTAL EQUIPMENT(B)	30047	.279	-	-	-
TURNKEY(C)	60809	.257	-	-	-
SMALL (4800 ACFM)	-	-	4.571	8.714	1.906
MEDIUM(6000 ACFM)	-	-	4.791	8.968	1.872
LARGE (11200 ACFM)	-	-	5.032	9.199	1.828

* For use in equation COST = K · $(\text{SIZE, ton/day})^X$

** B/A = Cost of total equipment/Cost of collector only

C/A = Turnkey cost/Cost of collector only

C/B = Turnkey cost/Cost of total equipment

Table 75

Cost per SCFM* for Aluminum Chlorination

COLLECTOR TYPE	SMALL	MEDIUM	LARGE
WET SCRUBBER			
HIGH EFFICIENCY			
GAS FLOW, SCFM	1742	2178	4066
COLLECTOR ONLY	8.03	7.25	5.31
TOTAL EQUIPMENT	42.07	39.81	30.67
TURNKEY**	76.50	71.26	53.54
WET SCRUBBER			
LA-PROCESS WEIGHT			
GAS FLOW, SCFM	1742	2178	4066
COLLECTOR ONLY	8.03	7.25	5.31
TOTAL EQUIPMENT	36.73	34.76	26.74
TURNKEY**	70.02	65.06	48.87

*BASED ON SCFM (AT 70F, INCLUDING H2O) AT COLLECTOR INLET
**FOR GRASS ROOTS INSTALLATION

2. DISCUSSION OF OPERATING COSTS

Several examples of cost calculations were made in Section B using the total annual cost of an air pollution control installation as the total of:

(a) Capital Charges (including depreciation, taxes and insurance)

(b) Utilities

(c) Maintenance Materials

(d) Maintenance Labor

The first cost of equipment is often considered to the exclusion of the long term cost of owning and operating a system. In order to make a good estimate of the total annual cost, each of the items listed must be considered.

(a) *Capital Charges* may be figured according to the normal practice of the user of the equipment. One method, used in Section B, is as follows. The total annual capital charge is the sum of

(1) the current interest rate on borrowed money, i.e. (say 10% per year)

(2) the sinking fund depreciation charge, S

$$S = \frac{P/n}{(1 + i)^n - 1}$$

S = sinking fund depreciation charge, $/year

P = initial cost, $

i = interest rate (fraction)

n = number of years life

(3) an allowance for taxes and insurance (say 3% per year)

For precipitators and fabric collectors *which are free of corrosion problems,* the most often quoted life for the equipment was 25 years. Scrubbers, on the other hand, were usually quoted at ten years expected life.

(b) *Utilities Costs* consist mainly of the costs of running the fans that overcome the pressure loss through the collector, plus minor costs for pump drives, solids handling equipment, and precipitator power supply.

In the case of fabric filters and scrubbers the utilities cost may be estimated on the basis of quoted system horsepower as illustrated in Section B for the rotary lime kilns and lead/aluminum sweating furnaces.

Fan horsepower is set by the gas flow rate through the fan and the pressure loss. It may be approximated by:

$$BHP = \frac{F \times \Delta P}{33{,}000 \times E} \left(\frac{62.4}{12}\right)$$

where:

BHP = Brake horsepower

F = Flow, ACFM

ΔP = Pressure loss, in wg

E = Fan Efficiency

The horsepower requirement was quoted by the manufacturers of the equipment in Section B. Average figures are listed for each application for the high efficiency case below:

	ESP	Fabric Filter	Wet Scrubber
Rotary Lime Kiln	40.5	150	140
Brass/Bronze Reverb.	–	48	90
Lead Cupola	–	34	98
Sweating Furnace	–	100	450
Lead Reverb.	–	30	150
Zinc Calcination Furnace	–	–	–
Aluminum Chlor.	–	–	100

These may be scaled up or down in direct ratio to the size of the installation for estimating purposes.

(c) *Maintenance Materials* are relatively minor for electrical precipitators and are nominal for scrubbers. The principal item in this category is the cost of replacement bags for fabric collectors. This item is large in comparison to all other maintenance charges against the collectors. It is frequently quoted as the total maintenance charge for fabric filters.

The maintenance charges for bag replacement are a linear function of the size of the installation, while maintenance charges for other parts — fan wheels, for example — should be more nearly proportional to the square root of the size.

The aluminum chlorination station alone among the applications covered here has a chemical consumption cost. This should vary with the amount of unreacted chlorine vented rather than with the furnace capacity. For a rough estimate of chemical costs, all of the chlorine injected may be assumed to leave the furnace as HCl and react with caustic in the scrubber according to:

$$HCl + NaOH \rightarrow NaCl + H_2O$$

This reaction requires almost exactly one pound of caustic per pound of chlorine.

(d) *Maintenance Labor* is nominal for most air pollution control equipment. Routine cleaning and inspection are necessary for good performance of any type of equipment, and should not be overlooked for air pollution control systems. Scrubbers, in particular, require frequent inspection to determine that the nozzles are open and that no plugging or clogging of mist eliminators has taken place. Fan wheels on fans located downstream of scrubbers require especially frequent attention.

Fabric collectors require attention to insure that the bags are intact and shaker or back blow mechanisms functioning properly. While the manhour figure is not broken out in most of the estimates, 80 to 160 hours per year should be sufficient. An allowance of 1/2 hour per bag replacement is adequate.

Wet scrubbers vary in time requirements from nearly "maintenance free" in a lime kiln application to "requiring frequent inspection and cleaning" in aluminum chlorination. Maintenance involves frequently washing out the fans and connecting ductwork, washing out and inspecting the entrainment separator and body of the scrubber and inspecting piping, pumps and tanks for chloride corrosion. Requirements might run as high as 200-400 hours per year for the worst circumstances.

Total of maintenance parts and labor was accumulated below by taking labor cost at $6.00/hr. where labor was broken out separately.

Cost in Dollars per Year

	ESP	Fabric Filter	Wet Scrubber
Rotary Lime Kiln	480	18000	5600
Brass/Bronze Reverb.	–	–	600
Lead Cupola	–	–	600
Lead Alum. Sweat	–	7776	1728
Lead Reverb.	–	4563	–
Aluminum Chlorination	–		6000

The costs given here may be used as first approximations for planned equipment installations. The costs can vary greatly from one plant to another, and final equipment selection decisions should be based on estimated operating costs furnished by a competent manufacturer or engineer.

D. INSTALLATION AND TEST DATA

All of the IGCI member companies were asked to participate in this program by summarizing their past installation data (since January 1, 1960). Also, any performance test information relating actual operation to design conditions was requested. The forms used for this solicitation are shown in Table 76. Detailed instructions for completing them are given in Appendix VI.

Twelve of the member companies actually had installations to report. Of the companies reporting installations, seven were most active in the rotary lime kiln area. The remainder of the application areas were reported by only two or three companies in most cases.

The returns proved quite limited in another respect. For some of the application areas, relatively small, inexpensive fabric filters have been found acceptable. These devices generally perform at a high efficiency level (>99.5%) and produce a clear effluent. For this reason they are often installed without an efficiency guarantee, and accepted without performance tests. In this circumstance, little performance data is obtained. However, the compilation of the installation and test data does provide some interesting insights into the pattern of application, the sizes of the units installed, etc.

In each of the following sections, the data on the forms returned by the member companies is abstracted and discussed. The complete data contained on the forms is given in a table at the end of each section.

1. ROTARY LIME KILNS

More applications were reported for rotary lime kilns than for all the other application areas combined. Table 77 lists the distribution of these applications by year and collector type. Table 78 gives the capacity of the installations in terms of the ACFM at the collector inlet. It was not possible to list these by kiln capacity (in ton/day lime production) because in most of the cases the kiln size was not known by the supplier of the air pollution control equipment. All of the installations and the test data reported are listed in Table 82.

For most of the applications, no test data was secured. There was usually a guaranteed or represented efficiency reported however, and the few test results given indicate performance at, or slightly better than, the represented efficiency. In many cases there was no performance representation, or a relatively conservative one in terms of the known capability of the

Table 76

SOURCE: ____________________

Sample

SUMMARY OF INSTALLATION DATA

Page 1

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT	TYPE OF RAW [1] MATERIAL OR CHARGE	FUEL[2] USED	TYPE[3] COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING GR/ACF		DESIGN EFF. WT. %	IS[4] PLUME VISIBLE
								INLET	OUTLET		

1. The composition of the raw material or charge should be presented on a wt.% basis.
2. The type of fuel used in firing should be presented. Report sulfur and ash content of coal.
3. Describe the type of collector. Examples: Venturi-30" w. c.;Fabric Filter, Orlon Bags;ESP, Area.
4. Is the plume visible after collection? Answer yes or no here. If yes, an explanation as to time span, process step during which plume is visible, etc., should be presented in the remarks column.

Table 76

Sample

SOURCE: ______________________

SUMMARY OF INSTALLATION DATA

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS NOTE 5
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	

5. Remarks which might serve to clarify or enhance the value of the reported data should be presented on a separate sheet with reference numbers indicated in column 15.

Table 77

Number of Rotary Lime Kiln Installations

By Year Placed in Service

Year	Fabric Filters	Wet Scrubbers	ESP	Mechanical	Total
1960	–	2	–	3	5
1961	–	–	–	1	1
1962	3	1	–	–	4
1963	1	2	–	2	5
1964	4	1	–	2	7
1965	1	9	–	3	13
1966	4	5	2	2	13
1967	2	4	–	5	11
1968	–	2	2	2	6
1969	–	2	–	1	3
1970	3	7	1	–	11
Total	18	35	5	21	79*

*NOTE: Table 82 lists 78 installations. Twin precipitators were counted as two installations here, but show as a single entry in Table 82.

Table 78

Total Gas Volume from Rotary Lime Kilns

by Year of Installation

(thousands of ACFM)

Year	Fabric Filters	Wet Scrubbers	ESP	Mechanical Collectors	Total
1960	–	101	–	160	261
1961	–	–	–	91	91
1962	171	65	–	–	236
1963	83	96	–	35	214
1964	200	37	–	56	293
1965	115	389	–	103	607
1966	560	265	294	72	1191
1967	190	213	–	289	692
1968	–	155	237	73	465
1969	–	296	–	36	332
1970	379	416	50	–	845
Total	1698	2033	581	915	5227

Table 79

Efficiency Representations Available From

Equipment Manufacturers for

Rotary Lime Kilns

Year	Fabric Filters	Wet Scrubbers	ESP	Mech-anicals
1960	–	–	–	–
1961	–	–	–	88
1962	99+	95	–	–
1963	99+	99	–	–
1964	99.5	99	–	–
1965	–	99	–	–
1966	–	99	–	96
1967	99+	99.3	–	96
1968	–	99-99.9	99.7	–
1969	–	99.6	–	–
1970	99.5	99-99.6	99.8	–

equipment type. For this reason, neither the average efficiency levels represented or the average performance test results are tabulated. However, a meaningful pattern becomes apparent when the highest efficiency levels for which equipment was being designed are considered. Table 79 lists these efficiencies for each type of equipment for each year covered by this study.

There has been little change in the level of efficiency quoted for *fabric collectors* since 1960. They are most frequently quoted as "99 plus" percent efficient, with the tacit understanding that the efficiency should be close to 100% if the bags are intact. Occasionally the representation is changed to 99.5%, but this does not represent a change in design or expected performance. No tests were run to substantiate the high efficiency of fabric collectors in lime kiln service, but whenever observations of the effluent were made, it was reported to be clear. This indicates an effluent grain loading less than 0.03 gr/ACF or 0.05 gr/SCF.

There has been a relatively flat trend in usage of fabric collectors for lime kilns over the 10 year period.

Wet scrubbers have accounted for more installations than any other type of collector, and nearly as many as all the others combined. The number of installations has increased steadily from year to year with the exception of 1968 and 1969. During these years, little equipment of any kind was installed.

A pattern of efficiency representations apparently started to form in 1960 or 1961. This resulted in scrubber installations with a nominal guaranteed efficiency of 95% in 1962. The efficiency representation increased to 99% in 1963 and 1964, and has risen to about 99.6% for recent installations. Test data substantiates the high efficiencies represented. Frequently the scrubber outlet grain loading is represented rather than an efficiency. An outlet loading "less than 0.05 gr/SCF" is typical. This is a more meaningful representation than the collection efficiency but requires a knowledge of the dust loadings and properties of the dust which may not be available to the manufacturer. Frequently such representations are based on pilot unit operation or experience with similar installations.

Several additional comments are in order with respect to reported scrubber efficiency. Scrubbers, like mechanical collectors, are inherently size-selective. They capture large particles more easily than small ones. For this reason, the inclusion of a mechanical separator, such as a cyclone or settling chamber, in the process ahead of the scrubber will reduce the "efficiency" of the scrubber even though the performance of the system may be improved.

Some of the scrubbers reported in this study had mechanical separation devices ahead of them to reduce the particulate loading, so efficiencies reported are not directly comparable.

Another qualification peculiar to the scrubber performance reported involves the formation of a steam plume. The gases enter the scrubber at a relatively high temperature. They leave at the saturation temperature which is typically between 140 and 170°F, with a high concentration of water vapor. This condenses upon mixing with ambient air to form a steam plume. The steam plume is opaque and may mask a particulate load which would otherwise be visible. The masking effect persists for a short distance as the plume is dispersed into the atmosphere, and hidden particulate matter may become visible as the water plume dissipates. The companies reporting scrubber applications described the plume as "visible" if there was an appearance of particulate solid after dissipation of the steam plume. For most of the scrubber installations there was no visible particulate solid but there was a dense steam plume.

Electrostatic precipitators have been applied to lime kilns to a limited extent. Only four applications are listed for this period. There is no real pattern of efficiency representations, but it appears that the precipitators have been offered for either 99.7% efficiency or less than 0.05 gr/ACF. The average precipitator handled almost twice as much gas as the average scrubber or filter, even though the kiln sizes were comparable.

Mechanical collectors were not considered to be satisfactory devices for lime kilns except in combination with other units. However, 21 installations of mechanical collectors were reported over the 10 year period. These were generally used for smaller gas flows than any of the other equipment types, and they were generally operated at a higher temperature.

Most frequently the mechanical collectors were sold on the basis of an "efficiency curve" which related expected efficiency to the particle size range for the dust. No explicit efficiency was represented. For a few cases the efficiency was established in absolute terms, with 96% as the highest represented.

The application of mechanical collectors apparently reached a peak around 1967 and declined subsequently.

Several tests were run to substantiate performance of the mechanical collectors. From this data, the gas composition and dust properties are listed in

Table 80. One complete precipitator test furnished the dust resistivity listed in Table 81.

Table 82 contains a complete listing of the rotary lime kiln installation data.

Table 80

Properties of Rotary Lime Kiln Dusts

From Mechanical Collector Tests
(All Analyses for Particle Size by Bahco)

Test No.	26	6	22	33	35	35	41	63
Grains/ACF	7.60	5.34	0.94	0.64	2.17	2.40	0.646	–
Particle Size								
> 40 μ	40.0	47.0	89.4	89.4	19.5	23.2	16.5	63.5
< 40 > 30	5.9	6.0	1.4	1.4	8.5	8.8	5.5	5.5
< 30 > 20	7.6	7.0	1.9	1.9	14.0	13.0	11.5	7.0
< 20 > 10	17.5	15.0	2.3	2.3	23.8	19.0	29.5	9.0
< 10 > 5	14.0	9.0	1.6	1.6	16.2	15.0	22.0	6.0
< 5	15.0	16.0	3.4	3.4	18.0	21.0	15.0	9.0
Temp., °F	827	831	650	650	440	440	395	722
ACFM	90843	91718	25000	25000	52800	52800	69600	42511
Gas Comp, Mol %								
N_2		67.1	58.3	58.5	72.9	–	59.0	65.4
O_2		7.5	5.1	5.1	14.8	–	10.2	11.9
CO_2		18.6	14.4	14.4	7.9	–	9.4	12.3
H_2O		6.8	22.2	22.0	4.4	–	21.4	10.4
Specific Gravity	2.77	2.74	NA	2.9	3.02-3.08	3.02-3.08	2.72	2.73
Fuel Used	NA	NA	NA	CO Gas	CO Gas	CO Gas	Nat. Gas	NA
Collection Efficiency	88	82	97.0	97.5	92.23	93.87	96.86	95
ΔP in wg	5.0	5.0	5.3	2.6	13	13	–	3.0

Table 81

Electrical Resistivity of Dust

From 50 T/D Rotary Lime Kiln

Inlet Conditions

Temp., °F	530
Flow, ACFM	235,000
Loading gr/ACF	∿ 3.0
Fuel	Natl. Gas

Particle Size Distribution by Bahco,	%
< 40 > 20 μ	23
< 20 > 10 μ	24
< 10 > 5 μ	17
< 5 > 3 μ	7

Resistivity, ohm - cm

at 15% Moisture in Gas		at 25% Moisture in Gas	
°F	R	°F	R
160	2.4×10^{7}	140	5.8×10^{7}
230	7×10^{8}	220	5.6×10^{9}
270	3.4×10^{9}	270	3.7×10^{10}
380	2.3×10^{11}	300	6×10^{10}
450	4.6×10^{11}	370	1.9×10^{11}
		420	2.2×10^{11}
		450	1.0×10^{11}

Table 82

Summary of Installation and Test Data for Rotary Lime Kilns

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) MEASURED DUST LOADING gr/ACF OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
1	NA	Limestone	NA **	Cyclone 2.3" wg	1960	20,200	750	NA	NA	F.E. Curve	NA
2	NA	Limestone and Dolomite	Coal and Oil	Cyclone 1.7-3.3" wg	1960	120,000	600	5.0	NA	F.E. Curve	NA
3	NA	Limestone	NA	Cyclone 2.2-3.1" wg	1960	20,000	750 400	NA	NA	F.E. Curve	NA
4	200	Limestone	NA	Dynamic *** Scrubber	1960	50,700 (NA)*	900 (NA)*	2.81- 2.89	0.071- 0.08	0.2 gr/ACF	NO
5	148	Limestone	NA	Dynamic Scrubber	1960	50,700 (NA)	900 (NA)	2.37- 2.84	0.052- 0.058	0.2 gr/ACF	NO
6	768	Dolomite	NA	Cyclone	1961	90.843 91.718	827 831	7.60 5.34	1.00 1.04	ACT. 88 82	YES

*For wet scrubbers, the second flow and temperature at saturation conditions.

**NA – Is used where data is either "not available" or "not applicable".

***"Dynamic Scrubber" indicates a device with mechanically augmented contacting as in a wetted fan.

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
7	NA	Limestone	Nat'l Gas	Dynamic Scrubber	1962	65,000 (37,000)	1,300 (170)	NA	NA	95	NO
8	225	Limestone	Gas	Fabric Filter	1962	21,300	495	10.0	NA	99+	NO
9	NA	Limestone	NA	Fabric Filter	1962	75,000	550	NA	NA	99+	NO
10	NA	Limestone	NA	Fabric Filter	1962	75,000	550	1.45	NA	99+	NA
11	500	Limestone	Coal	Fabric Filter	1963	83,200	550	4-8	NA	99+	NA
12	NA	Limestone	Nat'l. Gas	Dynamic Scrubber	1963	66,000 (32,500)	1,440 (171)	4.0 (Customer)	NA	0.1 gr/ACF	NO

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
13	NA	Limestone	NA	Cyclone	1963	20,000	600	NA	NA	F.E. Curve	NA
14	NA	Limestone	NA	Scrubber 8"wg	1963	30,000 (NA)	400 (NA)	8	0.036	99	NA
15	NA	NA	Gas	Cyclone	1963	15,000	NA	NA	NA	NA	YES
16	NA	NA	NA	Scrubber 8"wg	1964	37,000 (NA)	500 (NA)	3	0.15	99	NA
17	125	Limestone	Gas	Fabric Filter	1964	16,000	550	3.8	NA	99+	NA
18	125	Limestone	Gas	Fabric Filter	1964	16,000	550	3.8	NA	99+	NA

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
19	600	Limestone	NA	Fabric - Fiberglass, Reverse Air	1964	140,000	550	NA	NA	NA	NO
20	NA	Limestone	Coal	Fabric Filter	1964	28,000	550	0.8	NA	99.5	NA
21	NA	Limestone	NA	Cyclone	1964	25,000	900	NA	NA	F.E. Curve	NA
22	240	Limestone	NA	Cyclone 2.6 - 2.7"wg	1964	30,600 30,750	650 640	0.94 0.64	0.032 0.018	(ACT) 97.0 97.5	YES
23	NA	NA	NA	Scrubber	1965	40,000 (NA)	500 (NA)	NA	0.39	NA	NA
24	NA	NA	NA	Scrubber	1965	100,000 (NA)	600 (NA)	NA	0.05	NA	NA

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
25	NA	NA	NA	Scrubber 8" wg	1965	35,000 (NA)	650 (NA)	NA	0.05 gr/SCF	99	NA
26	500	Limestone	Coal	Fabric-Fiberglass Reverse Air	1965	115,000	550	7.6	NA	NA	NO
27	NA	NA	NA	Scrubber 8" wg	1965	52,000 (NA)	400 (NA)	NA	NA	98.2	NA
28	NA	NA	NA	Scrubber	1965	46,000 (NA)	600 (NA)	2.4	0.05	NA	NA
29	NA	NA	NA	Scrubber 15" wg	1965	29,400 (NA)	450 (NA)	20	0.2	99	NA
30	100	Limestone	Nat'l. Gas	Dynamic Scrubber	1965	52,000 (30,000)	1,050 (150)	NA	NA	NA	NO

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
31	140	Limestone	NA	Dynamic Scrubber	1965	31,000 (22,300)	1.050	10	0.045	NA	NO
32	NA	NA	Gas	Dynamic Scrubber	1965	4,000	NA	NA	NA	NA	YES
33	200	Limestone	CO Gas	Cyclone 2.3-6.0"wg	1965	25,000 Nor. 40,000 Max.	650	1.5	NA	F.E. Curve	NA
34	200	Limestone	CO Gas	Cyclone	1965	25,000 Nor. 40,000 Max.	650	1.5	NA	F.E. Curve	NA
35	200	Limestone	CO Gas	Cyclone 13"wg	1965	52,800	440	2.17 2.40	0.148 0.148	(ACT) 93.23 93.87	YES
36	NA	NA	Nat'l. Gas	Scrubber 15"wg	1966	73,300 (NA)	450 (NA)	20	NA	99.7	NA

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
37	NA	NA	Nat'l. Gas	Scrubber	1966	40,000 (NA)	500 (NA)	15	0.3	NA	NA
38	NA	NA	Oil	Scrubber 13" wg	1966	62,000 (NA)	550 (NA)	20	0.1	99.5	NA
39	NA	NA	Oil	Scrubber 15" wg	1966	48,000 (NA)	550 (NA)	20	0.08	99.7	NA
40	NA	NA	Nat'l. Gas	Scrubber 15" wg	1966	42,900 (NA)	500 (NA)	20	0.1	99.5	NA
41	35	Oyster Shells	Methane	ESP	1966	69,600	395	0.646	0.0207	(ACT) 96.98	YES
42	300	Limestone	NA	ESP	1966	225,000	500	0.8	NA	99.0	NA

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
43	NA	Limestone	NA	Cyclone	1966	36,000 37,000	700 450	NA	NA	Curve	NA
44	NA	Sludge Lime	NA	Cyclone	1966	36,400	300	1,280 #/Min.	NA	96	NA
45	600	Limestone	Coal	Fabric - Fiberglass, Reverse Air	1966	140,000	550	NA	NA	NA	NO
46	600	Limestone	NA	Fabric - Fiberglass, Reverse Air	1966	140,000	550	NA	NA	NA	NO
47	600	Limestone	NA	Fabric - Fiberglass, Reverse Air	1966	140,000	550	NA	NA	NA	NO
48	600	Limestone	NA	Fabric - Fiberglass, Reverse Air	1966	140,000	550	NA	NA	NA	NO

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) MEASURED DUST LOADING gr/ACF OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
49	NA	NA	Oil	Scrubber 10" wg	1967	25,000	450	5.3	0.05	99	NA
50	NA	Limestone	NA	Cyclone 2.8" wg	1967	86,500	600	5-12	NA	F.E. Curve	NA
51	NA	Limestone	NA	Cyclone 2.2" wg	1967	100,000	700	NA	NA	F.E. Curve	NA
52	NA	Limestone	NA	Cyclone 9.6" wg	1967	35,500	300	1,495 #/Min	NA	96.0	NA
53	NA	Limestone	NA	Cyclone 2.5" wg	1967	47,000	600	NA	NA	F.E. Curve	NA
54	NA	Limestone	NA	Cyclone 5.5" wg	1967	20,000	600	NA	NA	F.E. Curve	NA

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF INLET	OUTLET	DESIGN EFF. WT. %	IS PLUME VISIBLE
55	245	Dolomite	Gas	Fabric Filter	1967	50,000	500	2.00	NA	99+	NO
56	600	Limestone	NA	Fabric Filter - Glass; Rev. Air	1967	140,000	550	NA	NA	NA	NO
57	NA	Limestone	Coal High S	Dynamic Scrubber	1967	62,500 (40,300)	700 (154)	4.24 2.83 2.22	0.0306 0.0319 0.0318	99.0	NO
58	NA	Limestone	Coal High S	Dynamic Scrubber	1967	62,500 (40,300)	700 (154)	NA	NA	NA	NO
59	NA	Limestone	Coal High S	Dynamic Scrubber	1967	62,500 (40,300)	700 (154)	NA	NA	NA	NO
60	NA	Limestone	Nat'l. Gas	Dynamic Scrubber	1968	111,000 (54,100)	1,400 (165)	10-20	NA	99.0	NO

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
61	NA	NA	Oil	Scrubber 20" Wg	1968	44,000 (NA)	450 (NA)	20	NA	99.9	NA
62	100*	Limestone	Nat'l. Gas + Coal	ESP (two units)	1968	236,920**	530	3.00**	0.0077**	99.7 99.717** ACT	NO
63	NA	Limestone	NA	Cyclone 3.0" Wg	1968	42,511	722	1.29	0.066	ACT 95.0	YES
64	NA	NA	Gas	Cyclone	1968	30,000	NA	NA	NA	NA	YES
65	NA	Limestone	NA	Cyclone	1969	35.850	740	NA	NA	F.E. Curve	NA
66	NA	NA	Gas	Scrubber 50" Wg	1969	110,000	600	4.4	0.02	99.6	NA

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) MEASURED DUST LOADING gr/ACF OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
67	650	Limestone	Coal, Low S	Dynamic Scrubber	1969	186,000 (98,500)	1,100 (160)	NA	NA	15 gr/ACF in 0.05 gr/ACF out	NO
68	NA	Limestone	Coal Low S	Dynamic Scrubber	1970	63,800 (36,000)	950 (152)	NA	NA	0.05 gr/SCF	NO
69	NA	Limestone	Coal Low S	Dynamic Scrubber	1970	42,500 (24,600)	950 (152)	NA	NA	0.05 gr/SCF	NO
70	NA	Limestone	Nat'l. Gas	Venturi Scrubber 15-20 wg	1970	16,500 (14,250)	430 (132)	NA	0.023 0.0286 gr/SCF	99 on 2μ +	NO
71	NA	Limestone	Coal Low S	Venturi Scrubber 15-20" wg	1970	NA	NA	NA	NA	NA	NO
72	220	Limestone	Nat'l. Gas	Dynamic Scrubber	1970	45,000 (31,200)	550 (136)	NA	NA	NA	NO

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF INLET	OUTLET	DESIGN EFF. WT. %	IS PLUME VISIBLE
73	600	Limestone	30% Coal 70% Gas	Dynamic Scrubber	1970	186,000 (97,000)	1,150 (162)	NA	NA	99.6	NO
74	NA	Limestone	Coal	Fabric Filter	1970	110,000	570	1.83	NA	99+	NA
75	250	Limestone	Gas	ESP	1970	50,000	550	12.0	0.02	99.84	NO
76	NA	Dolomite	Coal	Fabric Filter	1970	255,000	600	2.85	NA	99.5	NO
77	NA	Limestone	NA	Fabric Filter	1970	44,000	550	0.52	NA	99.5	NA
78	NA	NA	Gas	Scrubber	1970	62,400 (NA)	525 (NA)	NA	NA	NA	NA

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	
6	45	45	37.5-44.2	BAHCO	NA	NA	NA	2.775 g	NA	O_2	7.5	Draft
	40	40	2.5-2.8					2.745 g		CO_2	18.6	Loss
	35	35	2.0-3.0							N_2	67.1	5" wg
		30	3.9-3.0									
	30	25	3.1-3.0							H_2O	6.8	
	25	20	4.5-4.0									
	20	15	6.6-5.9									
	15	10	10.9-9.1									
	10	5	14.0-9.0									
	5		15.0-16.0									

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	
		45	16.5-20.0									
35	45	40	3.0-3.2	BAHCO	NA	NA	NA	3.02-		O_2	14.8	
	40	35	4.2-3.4					3.08 sg		CO_2	7.9	
	35	30	4.3-5.4							N_2	72.9	
	30	25	6.0-5.0							H_2O	4.4	
	25	20	8.0-8.0									
	20	15	10.0-8.9									
	15	10	13.8-10.1									
	10	5	16.2-15.0									
	5		18.0-21.0									
		45	14.5									
41	45	40	2.0							O_2	10.2	
	40	35	2.5	BAHCO	NA	NA	NA	2.72 sg		CO_2	9.4	
	35	30	3.0							N_2	59.0	
	30	25	4.8							H_2O	21.4	
	25	20	6.7									
	20	15	10.5									
	15	10	19.0									
	10	5	22.0									
	5		15.0									

Table 82 — continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	
		45	88.5									
22	45	40	0.9	BAHCO	NA	NA	NA			O^2	5.1	
	40	35	0.6							CO_2	14.4	
	35	30	0.8							N_2	58.3	
	30	25	0.7							H_2O	22.2	
	25	20	1.2									
	20	15	1.1									
	15	10	1.2									
	10	5	1.6									
	5		3.4									
		45	88.5									
33	45	40	0.9	BAHCO	NA	NA	NA	2.9 sg		O_2	5.1	
	40	35	0.6							CO_2	14.4	
	35	30	0.8									
	30	25	0.7							N_2	58.5	
	25	20	1.2							H_2O	22.0	
	20	15	1.1									
	15	10	1.2									
	10	5	1.6									
	5		3.4									

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	
57	NA	NA	NA	NA	NA	NA	NA		NA	O_2 CO_2 N_2	0.7 24.3 59.7	
										H_2O	15.3	
60	20 11	11 0	50 50	By Customer	NA	NA	NA	$CaCO_3$ CaO	50 50			
62	40 20 10	20 10 5	23 24 17	Standard Screens Composite	$2.4x10^7$ $7 x 10^8$ $3.4x10^9$ $2.3x10^{11}$	160 230 270 380	15% Moisture	NA	NA	NA	NA	
	5	3	7	9 Tests	$4.6x10^{11}$ $5.8x10^7$ $5.6x10^9$ $3.7x10^{10}$ $6 x10^{10}$	450 150 220 270 300						
					$1.9x10^{11}$ $2.2x10^{11}$ $1.0x10^{11}$	370 420 450						

Table 82 – continued

Summary of Installation and Test Data for Rotary Lime Kilns

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	
63		45	61.0	BAHCO	NA	NA	NA	2.73 sg		O_2	11.9	
	45	40	2.5							CO_2	12.3	
	40	35	2.5							N_2	65.4	
	35	30	3.0							H_2O		
	30	25	3.1									
	25	20	3.9									
	20	15	4.0									
	15	10	5.0									
	10	5	6.0									
	5		9.0									
		25	80.2									
73	25	10	10.8	Customer Analysis								
	10	4	4.3									
	4	1	2.9									
	1		1.8									

2. Brass/Bronze Reverberatory Furnaces

A total of 16 applications of equipment was reported in this area. Of these, all but seven were fabric collectors. These were ordinarily not sold for specified efficiency level, although several were represented to be 99.9 percent efficient. These ordinarily functioned well enough to provide a clear effluent and no efficiency tests were run. Orlon or Dacron bags were used in all of the installations except one which had a 550°F operating temperature and used glass bags.

Two Venturi type scrubbers were installed. One was designed for 28" wg and had a reported efficiency of 99.32% on a furnace charging dross containing lead, zinc and soldering alloys. The other operated at 35" wg and showed only 92.5% collection efficiency. The discrepancy here lies in the loadings at the scrubber inlet, which was almost 10 times as high on the furnace for which the 99+% efficiency was obtained. This is apparently due to the mechanical entrainment of large quantities of the dross which carried over into the scrubber. The two produced effluents of nearly equal grain loading (0.045 and 0.039 gr/ACF) with the higher pressure drop producing the lower outlet grain loading. These values may be compared with the grain loading specified for the "high efficiency" case in Section B, which called for 0.01 gr/ACF on brass/bronze reverberatory furnaces for good stack appearance. Both scrubbers were reported to operate with no visible plume other than the steam plume, however.

Three dynamic scrubbers and one dynamic mechanical collector were also installed. No performance specifications were reported for any of these, nor were any tests run to establish performance. One of the four was reported to produce a clear stack. The other three were all reported to leave a visible particulate plume in addition to any plume due to water condensation.

Two of the fabric collectors were reported to have visible plumes. One of these was due to failure of the cooling system which caused bag damage. The other fabric collector installations were all reported to produce a clear effluent.

All of the collected installation data are summarized in Table 83.

Table 83

Summary of Installation and Test Data for Brass/Bronze Reverberatory Furnaces

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
1	20	Brass/Bronze Scrap	Oil	Dynamic Scrubber	1960	36,000	NA	NA	NA	NA	YES
2	30	Brass/Bronze Scrap	Gas	Dynamic Scrubber	1960	30,000	NA	NA	NA	NA	NO
3	10	Brass/Bronze Scrap	Oil	Dynamic Scrubber	1963	12,000	NA	NA	NA	NA	YES
4	20 T/D (total 2 furn.)	Copper Scrap	#5 Oil	Fabric Filter - Orlon, Shaker	1965	18,000	250	NA	NA	NA	YES*
5	72 T/D Charge	Copper Scrap	NA	Fabric Filter - Dacron Shaker	1965	30,000	275	NA	NA	NA	NO
6	NA	Copper Scrap	NA	Fabric-Glass, Sonic & Reverse Air	1965	31,500	550	NA	NA	NA	NO

Table 83 — continued

Summary of Installation and Test Data for Brass/Bronze Reverberatory Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
7	NA	NA	NA	Fabric - Orlon Shaker Type	1967	38,000	250	NA	NA	NA	YES
8	50	Brass/Bronze Scrap	Gas	Venturi Scrubber	1967	4,000	306	NA	NA	99.6	NO
9	5	Brass/Bronze Scrap	Oil	Dynamic Mechanical	1967	2,500	NA	NA	NA	NA	YES
10	75 to 100 T/D	Scrap Radiators	#5 Oil or Gas	Fabric - Acrylic, Shaker	1968	81,000	260	NA	NA	99.9+	NO
11	NA	NA	NA	Fabric - Dacron, Shaker	1968	24,000	250	NA	NA	99.9+	NO
12		Zinc and Copper	Oil	Fabric - Acrylic, Shaker	1968	41,000	250	0.01	NA	99.9+	NO

Table 83 — continued

Summary of Installation and Test Data for Brass/Bronze Reverberatory Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING /ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
13	NA	Dross Containing Lead, Zinc + Soldering Alloy	Gas	Venturi Scrubber 28"wg	1968	50,000 (30,000)	340 (120)	4	0.045	NA	NO
14	100	Brass/Bronze Scrap	Gas	Fabric Filter	1969	10,000	250	NA	NA	99.9	NO
15	NA	NA	Oil & Gas	Fabric-Orlon Shaker	1970	53,000	250	NA	NA	99.9	NA
16	10	Brass Scrap	Nat'l. Gas	Venturi Scrubber 35"wg	1970	15,000 (12,000)	1,200 (160)	0.418	0.039	ACT 92.5	NO

3. Lead Cupolas

Four manufacturers reported a total of 11 installations in this area, as indicated in Table 84. All but one were fabric collectors. These were represented to be 99.85% efficient, 99.9+% efficient, or no representation was made at all. No tests were run, but the effluent was reported to have no visible plume in eight of the 10 cases, and the stack appearance was not available in the other two. The single wet scrubber was of the "wet dynamic" type and was reported to have an efficiency of 87.5%. This stack was reported to have a visible plume.

Four of the installations were reported to serve gas flows far in excess of that generated by a single cupola, and probably represent a single collector installed to handle a variety of furnaces ventilated through a common stack.

Lead Reverberatory Furnaces

Three companies reported a total of 17 installations over the 10 year period from 1960 to 1970. The complete tabulation is given in Table 86. These were all fabric collectors, most of which used Orlon bags. Temperatures were all below 275°F, with only one below 230°F. The average size was 18,000 ACFM, but some of the installations were sized to include a blast furnace, sweating furnace, or other equipment in addition to the reverberatory furnace.

Efficiencies were represented to be 99.85 or 99.9+ wherever a representation was made. All the stacks were reported to be clear where there was a record of a stack observation.

Table 84

Summary of Installation Data for Lead Cupolas

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING GR/ACF INLET	(8b) MEASURED DUST LOADING GR/ACF OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
1	NA	NA	NA	Fabric Shaker Orlon	1961	350,000	200	NA	NA	99.9+	NO
2	28.3	NA	NA	Fabric Shaker Acrylic	1964	14,680	250	NA	NA	99.9+	NO
3	NA	NA	NA	Automatic Shaker Orlon	1964	40,000	250	NA	NA	NA	NO
4	NA	NA	NA	Intermit-tent Shaker Type Orlon	1964	3,800	250	NA	NA	NA	NO
5	NA	NA	NA	Fabric Shaker Fiberglass	1965	100,000	350	NA	NA	99.9+	NO
6	5	Lead Dross Battery Plates Coke & Slag	Soft Coal	Dynamic Scrubber	1965	8,000	700	4.3	0.54	87.5	YES

Table 84 – continued

Summary of Installation Data for Lead Cupolas

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING GR/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
7	NA	NA	NA	Fabric Shaker Filtron Tubes	1967	450,000	230	NA	NA	99.9+	NO
8	NA	NA	NA	Fabric Shaker Filtron Tubes	1967	450,000	230	NA	NA	99.9+	NO
9	NA	NA	NA	Fabric Shaker Orlon	1969	22,500	275	NA	NA	99.9+	NO
10	NA	NA	NA	Fabric	1970	23,000	200°F.	NA	NA	99.85	NA
11	NA	NA	NA	Fabric	1970	16,000	120°F.	NA	NA	99.85	NA

4. Lead/Aluminum Sweating Furnaces

Table 85 is a compilation of all of the installations reported by the IGCI member companies.

A total of 18 installations were made by three companies. The furnace usage was designated as follows:

	Fabric	Wet	Total
Lead Sweating	6	–	6
Aluminum Sweating	6	–	6
Lead/Aluminum Sweating	–	6	6
	12	6	18

The fabric collectors were most frequently represented as "99.9+" percent efficient, while the scrubbers were all represented to be 98% efficient. No test data was available for any of the installations.

Several of the lead sweating fabric collectors were represented to serve more than one furnace. The inclusion of reverberatory furnaces and cupolas in the same gas handling system is common for fabric collector installations in lead smelting plants. The scrubbers were apparently special purpose devices tailored to a single furnace.

Table 85

Summary of Installation Data for Sweating Furnaces

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr/ACF INLET	(8b) MEASURED DUST LOADING gr/ACF OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
1	NA	NA (lead)	NA	Fabric Repressured Fiberglass	1960	10,000	500	NA	NA	99.9+	NO
2	NA	NA (lead)	NA	Fabric - Shaker Type with Orlon	1964	40,000	250	NA	NA	NA	NO
3	NA	NA (lead)	NA	Fabric - Intermittent Shaker Type w/Orlon	1964	3,800	250	NA	NA	NA	NO
4	NA	NA (lead)	NA	Fabric - Shaker Filtron	1967	450,000	230	NA	NA	99.9+	NO
5	NA	NA (lead)	NA	Fabric-Shaker Dacron	1967	7,000	NA	NA	NA	99.9+	NO
6	NA	Lead Scrap	NA	Fabric	1967	25,000	250	NA	NA	99.85	NA

Table 85 — continued

Summary of Installation Data for Sweating Furnaces

(1) TEST NO.	(2) CAP. OF UNIT T/D	(3) TYPE OF RAW MATERIAL OR CHARGE	(4) FUEL USED	(5) TYPE COLLECTOR	(5a) YEAR PLACED IN SERVICE	(6) GAS VOLUME ACFM	(7) INLET TEMP. °F	(8a) MEASURED DUST LOADING gr./ACF INLET	(8b) OUTLET	(9) DESIGN EFF. WT. %	(10) IS PLUME VISIBLE
7	NA	NA	NA	Fabric Shaker Orlon	1962	14,000	320	10.0	NA	99.9+	NO
8	NA	NA	NA	Fabric Shaker Orlon	1964	30,000	NA	2.0	NA	99.9+	NO
9	NA	NA	NA	Fabric Shaker Fire Ret. Tubes	1968	14,112	150	NA	NA	99.9+	NO
10	NA	NA	NA	Fabric Shaker Cot.Sateen	1969	40,000	160	NA	NA	99.9+	NO
11	NA	NA (aluminum)	Nat.Gas/ #2 Oil Standby	Automatic Shaker Dacron	1970	37,500	250	NA	NA	NA	NO
12	NA	NA (aluminum)	Nat.Gas #2Oil Standby	Automatic Shaker Dacron	1970	32,500	250	NA	NA	NA	NO

Table 85 — continued

Summary of Installation Data for Sweating Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
13	48	Non Ferrous Metal (Aluminum & Lead Scrap)	Nat. Gas	Venturi Scrubber 9" wg	1968	20,000	1,600	1.0	NA	98.0	NA
14	48	Non Ferrous Metal (Scrap)	Nat. Gas	Venturi Scrubber 9" wg	1968	20,000	1,600	1.0	NA	98.0	NA
15	48	Non Ferrous Metal (Scrap)	Nat. Gas	Venturi Scrubber 9" wg	1968	20,000	1,600	1.0	NA	98.0	NA
16	48	Non Ferrous Metal (Scrap)	Nat. Gas	Venturi Scrubber 9" wg	1968	20,000	1,600	1.0	NA	98.0	NA
17	48	Non Ferrous Metal (Scrap)	Nat. Gas	Venturi Scrubber 9" wg	1969	20,000	1,600	1.0	NA	98.0	NA
18	48	Non Ferrous Metal (Scrap)	Nat. Gas	Venturi Scrubber 9" wg	1969	20,000	1,600	1.0	NA	98.0	NA

Table 86

Summary of Installation Data for Lead Reverberatory Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING ./ACF INLET	OUTLET	DESIGN EFF. WT. %	IS PLUME VISIBLE
1	700	Junk Batteries & by-products tin	NA	Fabric Shaker Orlon	1961	12,000	250	NA	NA	99.9+	NO
2	NA	NA	NA	Fabric Shaker Orlon	1963	25,000	260	NA	NA	99.9+	NO
3	NA	NA	Nat. Gas	Fabric Shaker Orlon	1963	4,920	250	8.4 mg/M^3	NA	99.9+	NO
4	342	NA	Nat. Gas	Fabric Shaker Orlon	1963	12,500	275	NA	NA	99.9+	NO
5	NA	NA	Oil	Fabric Shaker Orlon	1964	30,000	250	NA	NA	99.9+	NO
6	NA	NA	NA	Automatic Shaker Orlon	1964	40,000	250	NA	NA	NA	NO

Table 86 — continued

Summary of Installation Data for Lead Reverberatory Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
7	NA	NA	NA		1963	8,000	NA	NA	NA	99.85	NA
8	NA	NA	NA	Fabric Shaker Acrylic	1965	12,000	250	NA	NA	99.9+	NO
9	118	NA	40 gal. per hr. #2 Fuel Oil	Fabric Shaker Orlon	1965	22,500	250	NA	NA	99.9+	NO
10	NA	NA	NA	Fabric Shaker Cotton Sateen	1967	5,000	180	(very light)		99.9+	NO
11	106-120	0 NA	30 gal. per hr. #5 Fuel Oil	Fabric Shaker Filtron	1967	15,000	250	NA	NA	99.9+	NO
12	NA	NA	3 each---- NA	Fabric Shaker Orlon	1967	15,000	260	NA	NA	99.9+	NO

Table 86 — continued

Summary of Installation Data for Lead Reverberatory Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
13	NA	NA 2 each------	NA	Fabric Shaker Orlon	1967	20,000	260	NA	NA	99.9+	NO
14	NA	NA	NA	Automatic Shaker Orlon	1967	19,000	230	NA	NA	NA	NO
15	NA	NA	NA	Automatic Shaker Orlon	1969	40,000	230	NA	NA	NA	NO
16	NA	NA	NA	Fabric	1970	6,000	120	NA	NA	99.85	NA
17	NA	NA	NA	Fabric Shaker Orlon	1970	18,000	275	NA	NA	99.9+	NO

5. Zinc Calcination Furnace

Although little information regarding the calcination of secondary zinc oxide was uncovered, five applications of fabric collectors on "zinc kilns" were reported. No information was available with regard to the process other than the gas flow and temperature. In fact, even the gas flow was not reported for one of the five.

For each application, the gas temperature was limited to the range where Dacron bags are generally suitable if there is no acid condensation problem. The efficiency was specified as 99.85% or 99.9+% by the manufacturer in each case. These applications are listed in Table 87.

Table 87

Summary of Installation Data for Zinc Calcination Furnaces

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING gr/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE
								INLET	OUTLET		
1	NA	NA	NA	Fabric	1960	10,300	230	NA	NA	99.85	NA
2	NA	NA	NA	Fabric Tubes fur. by Customer	1965	450,000	250	NA	NA	99.9+	NO
3	NA	NA	NA	Fabric	1966	10,000	275	NA	NA	99.85	NA
4	NA	NA	NA	Fabric	1967	NA	NA	NA	NA	99.85	NA
5	NA	NA	Nat. Gas	Fabric Tubes fur. by Customer	1969	30,000	260	30	NA	99.9+	NO

6. Aluminum Chlorination Station

Four manufacturers reported installation of a total of six systems for chlorination of secondary aluminum. The scrubbers and results obtained varied widely from one application to another.

Three of the scrubbers were of the "mobile packing" variety, in which plastic spheres or glass marbles serve as the packing. These varied from 25" wg to 55" wg, with efficiencies as follows:

Δ P in wg	E.%
25	96
30	99
55	99.1 to 99.8

The efficiency varied with grain loading at the scrubber inlet, as well as with pressure drop, indicating that the scrubbers were most effective on the particulate material where the concentration was high.

The other three installations were Venturi scrubbers operating at 14 to 45" wg. These showed outlet grain loadings lower than the mobile packed scrubbers, but the only efficiencies reported are 90-95 and 95%, which is lower than for the mobile packed scrubbers. This appears to relate to the very low inlet grain loading for the Venturi scrubber, however, rather than to the performance characteristics of Venturis. Very low inlet loadings are more typical of primary chlorination than secondary.

The installation data reported is given in Table 88.

Table 88

Summary of Installation Data for Aluminum Chlorination Stations

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT T/D	TYPE OF RAW MATERIAL OR CHARGE	FUEL USED	TYPE COLLECTOR	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING GR/ACF INLET	OUTLET	DESIGN EFF. WT. %	IS PLUME VISIBLE
1	37.5	Scrap Aluminum Chlorine Rate NA	NA, probably Nat. Gas	Scrubber @30" w c	1964	NA (1600)	810 (82°)	50	0.5	ACT 99	YES
2	28.5	Scrap Aluminum, 750 lb/hr chlorine (Producing Alloy 380Z3)	Nat. Gas	Scrubber @25" w c	1965	NA (2000)	NA (135°)	12.	0.5	ACT 96	YES
3	NA	Secondary Scrap and Chlorine	Gas	Venturi & Precooler 29" wg	1967-1968	15,000 (9,000)	800 (140)	-	0.05	-	NO
4	45	Chlorination in Secondary Aluminum Smelter	Nat. Gas	3-Bed Hi-Energy Wet Scrubber	1968	5,000 to 6,230	138° Scrubber Outlet Temp. 98°F	2.79 to 11.80 Avg. 6.70	0.0046 to 0.084 Avg. 0.0342	ACT 99.1% to 99.8%	Barely Visible
5	NA	NA	NA	Wet Scrubber 14" ΔP	1969	3,000	120	NA	NA	90-95%	NO
6	50	Mill ends, pig aluminum-210 lb/hr. Cl_2 (Producing Alloy 3003)	Nat. Gas	Scrubber (Venturi) @45" w c	1969	(2500)	(175)	1.5	0.07	95 ACT 95	NO

VI. CONCLUSIONS AND RECOMMENDATION

The data collected and reported substantiate several conclusions:

A. All of the applications covered can be treated adequately with conventional air pollution control equipment.

B. Electrostatic precipitators are currently limited to the lime kiln application by the economics of small precipitators relative to fabric collectors or scrubbers.

C. Fabric collectors are acceptable for all the applications except aluminum chlorination.

D. Wet scrubbers are acceptable for all of the applications, but are less frequently used for fine fumes in secondary smelting than fabric collectors.

E. Wet scrubbers must be used for aluminum chlorination stations.

F. Mechanical collectors are not adequate for good pollution control in any of the areas, although they are often used as precleaners.

In addition to these generalizations with respect to the data presented, several conclusions were drawn regarding the program organization and scope:

A. The combination of the rotary lime kiln application area with the secondary smelting areas detracts from the continuity of the report. The data might be more easily read and interpreted if these two areas were reported separately.

B. The several smelting areas covered do not embrace all secondary smelting operations. For example, zinc sweating, various crucible operations, etc. were omitted. The value of the data would be enhanced by filling these gaps at some future time.

C. The program organization employed was effective in achieving the goals set up. That is, the data in possession of the member companies was obtained in a cooperative atmosphere which would not ordinarily exist if a contractor other than IGCI was assigned to collect it.

D. The combination of Coordinating Engineer – Project Director – member company participants provided a good distribution of work load.

E. The ability of the member companies to produce information of the type required here varied in accord with how closely the functions relate to normal business practice. The various information producing functions are listed in accord with the ease of production (as judged by the Coordinating Engineer and Project Director):

Bid Prices – easiest
Specifications
Narratives
Data on old installations
Non-routine clerical or statistical work – most difficult

F. The installation and test data was limited by the lack of air pollution control in the secondary metals area. If an industrial area were chosen for a similar study which was more generally serviced by the air pollution control equipment manufacturers, the information would be more complete and detailed than that contained in this report. Examples of such industrial areas are:

Paper mills
Utility power generation
Rock products
Primary Metals

APPENDIX I

Program Planning & Execution

PROGRAM PLANNING AND EXECUTION

The initial work on this program was aimed toward providing a suitable work plan and subdivision of the functions among the IGCI member companies, the Executive Secretary, various IGCI committees and the Coordinating Engineer.

Program execution began during the first week in July, which was used by members of the IGCI Government Relations Committee to interview candidates for employment as Coordinating Engineer. Several candidates were considered, all of whom were formerly associated with member companies, but no longer have any affiliation with either member companies or with IGCI.On the basis of these interviews, L. C. Hardison of Air Resources, Inc. in Palatine, Illinois was selected. Herbert R. Herington, Executive Secretary of IGCI, was named Project Director.

Division of Functions

The Project Director, Coordinating Engineer and Government Relations Committee agreed upon a division of work among the parties involved, which was followed during the course of the program. This division is as follows:

1. Drafting of reports, forms, instructions, etc., plus technical editing of all material - Coordinating Engineer (L. C. Hardison)

2. Preparation of mailings, correspondence with member companies, preparation of material in final form – IGCI Project Director (Herbert R. Herington)

3. Approval of all technical material to be made available for publication, general review and approval of program progress, and selection of member companies for preparation of narrative descriptions and bid price data – Engineering Standards Committee (Harry Krockta, Chairman)

4. Basic Program direction – Government Relations Committee, (Hugh Mullen, Chairman) with Project Director, Herbert R. Herington.

This working arrangement was put into effect during the second week of July, with the preparation of the Work Plan Draft.

The Work Plan Draft was prepared by L. C. Hardison after a review of the pertinent contract documents and conferences with Hugh Mullen for the Government Relations Committee and Project Director Herington.

The draft was reviewed by the members of the IGCI Engineering Standards Committee and revised after comments were received. The final draft was prepared by the Coordinating Engineer and the Project Director, and submitted to NAPCA on July 31, 1970.

Subdivision of the Program

In order to complete the work in the scheduled time period, it was necessary to carry out some of the steps in each of the three categories simultaneously. A work plan was drawn up which treated the three categories as separate projects insofar as possible in order to operate them in parallel throughout the 6-month period of the project. The work plan centers around detailed calendars of events in each of the three areas.

Some necessary interrelations were taken into account. For example, three companies were selected as most qualified to prepare narrative descriptions of the processes. These were adjudged most likely to be best qualified to prepare bid prices. Some of the schedule dates in the work plan were adjusted so that they were the same in each of the parallel programs.

Preparation of the Narratives

The preparation of a concise narrative description of the process, the types of gas cleaning equipment applicable, and the technical problems inherent in the application was done by an individual employee of a member company.

Several steps were taken to assist the individual in each case in preparing an authoritative and readable document. As a preliminary step, a brief survey of applicable literature was made by the Coordinating Engineer, and references were furnished the company selected for preparation of the narrative. A general outline was furnished each participating company in order to avoid omissions and secure some consistency in form.

All of the IGCI member companies known to have applications in the process area in question were solicited to determine their degree of interest prior to selecting the companies most qualified. From among those exhibiting significant interest, the three deemed most qualified by the members of the

IGCI Engineering Standards Committee were selected to participate in a predraft seminar to cover the process in question with the Coordinating Engineer. The representatives of the three companies selected chose one of their employees to prepare the draft of the narrative, along with a flow diagram.

The draft was edited by the Coordinating Engineer and the final draft reviewed with the Engineering Standards Committee prior to submission.

A detailed schedule of the steps in this process is given on the following page.

Compilation and Tabulation of Installation and Test Data

The requirements of NAPCA as described in the contract documents were followed as closely as possible in this area. However, the data forms were revised considerably by the Coordinating Engineer, with NAPCA concurrence, during the course of the project.

The detailed steps in the process of review, issue, retrieval and compilation are given on the following page.

Detailed Calendar for Narratives

No. of Event	Name of Event	WORK DONE BY Coor. Engr.	Ex. Sec.	Engr. Stds.	Memb.	Other	PROJECTED COMPLETION DATE	ACTUAL DATE
N-1	Literature survey of applicable general articles.	X					7-31	7-31
N-2	List Member Companies cross referenced with known areas of application.	X	X				7-31	7-31
N-3	Solicit member companies for level of interest (0-10 scale)		X				7-31	7-31
N-4	Prepare list of member companies indicating interest for review by Engr. Stds. Comm.	X	X				8-18	8-18
N-5	Select three companies in each category			X			8-18	8-18
N-6	Schedule meetings of representatives in 9 areas	X	X				8-18	8-18
N-7	Hold meetings	X			X		9-15	9-3
N-8	Prepare drafts of narratives				X		9-30	10-20
N-9	Review drafts	X					10-15	11-5
N-10	Distribute drafts to other participating member companies		X				10-20	11-11
N-11	Comment on drafts				X		10-30	11-15
N-12	Review & Consolidate	X					11-15	11-19
N-13	Final Draft Review			X			11-20	12-17
N-14	Print and Distribute		X				11-30	12-31

Detailed Calendar for Forms

No. of Event	Name of Event	WORK DONE BY Coor. Engr.	Ex. Sec.	Engr. Stds.	Memb.	Other	PROJECTED COMPLETION DATE	ACTUAL DATE
F-1	Propose forms for submission to members	X	X				7-31	7-31
F-2	Review with Chrm. of Engr. Stds. Comm.	X	X	X			7-31	7-31
F-3	Distribute to members		X				8-15	8-8
F-4	Receive returns and followup on non-return	X	X				9-15	11-16*
F-5	Edit returns	X					9-31	11-16
F-6	Make statistical averages as required	X					10-5	11-16
F-7	Prepare in final form for typing	X					10-30	11-18
F-8	Final review			X			11-15	12-17
F-9	Print and distribute		X				11-30	12-31

*Date of receipt of last form

Solicitation and Tabulation of Bid Prices for Systems

This section comprises the most difficult and probably the most significant part of the project. Several of the steps involved are discussed in the following paragraphs.

Emission standards for each application were selected. In the case of the LA-Process Weight * limitation, the problem was relatively simple. For the high efficiency specification, a relationship between particle size distribution, grain loading, plume depth and the visible threshold was investigated. This relationship has not been established for the sources involved here. An arbitrary definition was proposed at a meeting between IGCI and the NAPCA Project Officer on August 12, and accepted. This is discussed in more detail in the Technical Data Section of the Report.

Specification form exerts a significant influence on the contractor's price, particularly when equipment is to perform to a specification such as "the stack shall be clear". For this reason it was important that each company preparing a specification worked to a common set of standards. This required a high degree of unanimity among the member companies on the form of the specification.

In order to minimize the time required in completing this section of the program, the Coordinating Engineer drafted a general specification to apply to all of the processes, which was reviewed by the Engineering Standards Committee and all the participants.

In the preparation of the bid prices, companies chosen as most qualified by the Engineering Standards Committee were brought together to discuss the specifications (this meeting coincided with the seminar described in connection with writing the process narratives), after which the Engineering Standards Committee reviewed the specifications. The three companies each prepared prices for two levels of abatement and three sizes of process. The required information from the bid forms was entered on the appropriate summary form by the Coordinating Engineer without reference to the name of the firm submitting the proposal.

The results were submitted to the Engineering Standards Committee for final approval. A detailed listing of the steps involved in this process, and a tentative completion date for each step is given on the following page.

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*Air Pollution Control District County of Los Angeles Rule 54. See Appendix III.

Detailed Calendar for Price Quotes

No. of Event	Name of Event	WORK DONE BY: Coor. Engr.	Ex. Sec.	Engr. Stds.	Memb.	Other	PROJECTED COMPLETION DATE	ACTUAL DATE
P-1	Obtain pertinent sections of LA-APCD process weight standard	X					7-31	7-31
P-2	Establish approximate basis for weight emission at "clear stack" condition, for review by Engr. Stds.	X					7-31	7-31
P-3	Prepare uniform specification for system for review by Engr. Stds.	X					8-15	8-15
P-4	Prepare form sheets for installation data and	X					8-15	8-15
P-5	Review with Engr. Stds.	X	X	X			8-18	8-18
P-6	Submit to companies selected for narratives		X				8-30	9-3
P-7	Prepare cost estimates				X		9-30	11-15
P-8	Receive completed estimates	X					9-30	11-15
P-9	Review and edit results	X					10-15	11-19
P-10	Approve or revise			X			10-30	11-19
P-11	Put in final form	X					11-15	12-17
P-12	Print & distribute		X				11-30	12-31

*Date of receipt of last estimate

INDUSTRIAL GAS CLEANING INSTITUTE, INC.

I.G.C.I. H.E.W. CONTRACT SURVEY

DEADLINE IS APRIL 24

Since 1960, we have sold the following number of installations of gas cleaning equipment in the following applications:

1. Lime industry
   a. Rotary lime kiln (not including lime sludge kilns)

      Number sold since January 1, 1960 ____________

2. Secondary non-ferrous metallurgical industry

	Number sold since January 1, 1960
a. Brass reverberatory furnace	____________
b. Lead cupola (blast furnace)	____________
c. Lead sweating furnace	____________
d. Lead reverberatory furnace	____________
e. Zinc calcining kiln	____________
f. Aluminum sweating furnace	____________
g. Aluminum Chlorination station	____________
h. Bronze reverberatory furnace	____________

Keep one copy and send one copy by April 24 to:

Mr. Hugh Mullen
Buell Engineering Co., Inc.
253 North Fourth St.
Lebanon, Pa. 17042

Name ____________________

Company ____________________

Date ____________________

INDUSTRIAL GAS CLEANING INSTITUTE, INC.

NAPCA CONTRACT INTEREST SURVEY

Please indicate your company's interest in participating in each of the following areas with respect to each type of equipment using a scale from 0 - 10, with

0 = no interest whatsoever
10 = very strong interest

Area	Interest Level: Elec.Precip.	Fabric	Wet Scrubbers
1a Rotary Lime Kiln			
2a Brass Reverberatory Furnace			
2b Lead Cupola			
2c Lead Sweating Furnace			
2d Lead Reverberatory Furnace			
2e Zinc Calcining Kiln			
2f Aluminum Sweating Furnace			
2g Aluminum Chlorination station			
2h Bronze Reverberatory Furnace			

Signed ______________________

Company ______________________

DEADLINE - JULY 28, 1970

MAIL TO:

H. R. Herington
P. O. Box 448
Rye, N. Y. 10580

APPENDIX II

Detailed Instructions for Preparing Specifications

DETAILED INSTRUCTIONS FOR PREPARING SPECIFICATIONS

The I.G.C.I. as the contractor is to furnish NAPCA with an analysis of cost requirements for collection systems that can meet two levels of abatement:

1) The LA-APCD Process Weight Regulation
2) An arbitrary outlet grain loading as shown in the attached Table I.

The second specification represents a higher efficiency level than the LA-APCD process weight regulation. While these numbers are frequently at or below the visible threshold, they do not define conditions at which a clear stack can be obtained.

Three sizes or capacities are to be figured for each of the collection systems involved. This means that the specification given to a member company for preparation of a bid price must contain enough information to define six cases like this:

SMALL	MEDIUM	LARGE
LOW EFF.	LOW EFF.	LOW EFF.
SMALL	MEDIUM	LARGE
HIGH EFF.	HIGH EFF.	HIGH EFF.

The six cases are to be repeated for each collector type applicable to the industrial area. The I.G.C.I. Engineering Standards Committee has agreed upon the types of equipment applicable to each area as shown in the attached Table II.

(There are 20 combinations of equipment type and application areas which should require 120 separate quotations from the 9 application groups.)

In order to provide a uniform basis to each of the companies participating in the bid price preparation, it is recommended that this application group prepare a complete specification for the equipment, consisting of the following items:

1. Scope
2. Process Description
3. Operating Conditions
4. Process Performance Guarantee
5. General Conditions

For most cases, a single set of specifications will suffice for items 1, 4 and 5 above, regardless of the equipment type or application area. The Engineering Standards Committee has approved the wording of the sections of the sample specification attached for use in this way. These are given page numbers 1, 2, 5 and 6.

Page 3, to be written by the application group, should contain:

(1) A simple description of the equipment that is included, covering the basic collector and items such as:

a) type of fabric (for fabric collectors)
b) bag cleaning method (for fabric collectors)
c) materials of construction (for wet scrubbers)

(2) A concise definition of items that are to be included in the auxiliary equipment cost such as:

a) fans
b) dampers
c) pumps

(3) A brief description of the circumstances involved in installation of the equipment.

Page 4, to be written by the application group, should summarize the operating conditions to which the equipment is to be designed and for which operating costs are to be developed. The following items should be specified for each of three sizes:

a) Process capacity in appropriate units
b) Inlet gas volume to the collector in ACFM
c) Inlet temperature, ^{o}F.
d) Inlet contaminant loading
e) Efficiency, wt %
f) Controlled, or outlet contaminant loading
g) Outlet temperature (if different from inlet)

h) Outlet gas volume, ACFM (if different from inlet)
i) Type of charge fed to the furnace: - dirty, oily, scrap, shavings, volatile metals, etc.

Any additional information which will add clarity to the cost estimates should be included.

TABLE I

DEFINITION OF OUTLET GRAIN LOADINGS FOR

SECOND EFFICIENCY LEVEL BIDS

		Outlet Loading gr/ACF
1-a	Rotary Lime Kilns	0.03
2-a	Brass Reverberatory Furnaces	0.01
b	Lead Cupola	0.03
c	Lead Sweating Furnace	0.03
d	Lead Reverberatory Furnace	0.01
e	Zinc Calciner	0.01
f	Aluminum Sweating Furnace	0.03
g	Aluminum Chlorination Station	0.02
h	Bronze Reverberatory Furnace	0.03

TABLE II

DEFINITION OF COLLECTOR TYPES APPLICABLE TO VARIOUS INDUSTRIAL AREAS

Collector Type	1a Lime Kiln	2a Brass Reverb.	2b Lead Cupola	2c Lead Sweat.	2d Lead Reverb.	2e Zinc Calcin.	2f Alum. Sweat.	2g Alum. Chlor.	2h Bronze Reverb.
Electrostatic Precipitator	Yes	No*	No*	No*	Yes	Yes	No*	No	No*
Fabric Collector	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Wet Scrubber	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Note that Electrostatic Precipitators are not applicable to these areas only because the sources are too small to make precipitator application economical under ordinary circumstances.

APPENDIX III

Rule 54 of the Air Pollution Control District of Los Angeles County

Air Pollution Control District
County of Los Angeles

RULES AND REGULATIONS

December 4, 1969

434 South San Pedro Street, Los Angeles, California, 90013
MA 9-4711

Rule 54. Dust and Fumes

A person shall not discharge in any one hour from any source whatsoever dust or fumes in total quantities in excess of the amount shown in the following table: (see next page)

To use the following table, take the process weight per hour as such is defined in Rule 2(j).* Then find this figure on the table, opposite which is the maximum number of pounds of contaminants which may be discharged into the atmosphere in any one hour. As an example, if A has a process which emits contaminants into the atmosphere and which process takes 3 hours to complete, he will divide the weight of all materials in the specific process, in this example, 1,500 lbs. by 3 giving a process weight per hour of 500 lbs. The table shows that A may not discharge more than 1.77 lbs. in any one hour during the process. Where the process weight per hour falls between figures in the left hand column, the exact weight of permitted discharge may be interpolated.

---

* Rule 2 (j). Process Weight Per Hour. "Process Weight" is the total weight of all materials introduced into any specific process which process may cause any discharge into the atmosphere. Solid fuels charged will be considered as part of the process weight, but liquid and gaseous fuels and combustion air will not. "The Process Weight Per Hour" will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof, excluding any time during which the equipment is idle.

(k). Dusts. "Dusts" are minute solid particles released into the air by natural forces or by mechanical processes such as crushing, grinding, milling, drilling, demolishing, shoveling, conveying, covering, bagging, sweeping, etc.

(l). Condensed Fumes. "Condensed Fumes" are minute solid particles generated by the condensation of vapors from solid matter after volatilization from the molten state, or may be generated by sublimation, distillation, calcination, or chemical reaction, when these processes create air-borne particles.

TABLE

*Process Wt/hr(lbs)	Maximum Weight Disch/hr(lbs)	*Process Wt/hr(lbs)	Maximum Weight Disch/hr(lbs)
50	.24	3400	5.44
100	.46	3500	5.52
150	.66	3600	5.61
200	.85	3700	5.69
250	1.03	3800	5.77
300	1.20	3900	5.85
350	1.35	4000	5.93
400	1.50	4100	6.01
450	1.63	4200	6.08
500	1.77	4300	6.15
550	1.89	4400	6.22
600	2.01	4500	6.30
650	2.12	4600	6.37
700	2.24	4700	6.45
750	2.34	4800	6.52
800	2.43	4900	6.60
850	2.53	5000	6.67
900	2.62	5500	7.03
950	2.72	6000	7.37
1000	2.80	6500	7.71
1100	2.97	7000	8.05
1200	3.12	7500	8.39
1300	3.26	8000	8.71
1400	3.40	8500	9.03
1500	3.54	9000	9.36
1600	3.66	9500	9.67
1700	3.79	10000	10.0
1800	3.91	11000	10.63
1900	4.03	12000	11.28
2000	4.14	13000	11.89
2100	4.24	14000	12.50
2200	4.34	15000	13.13
2300	4.44	16000	13.74
2400	4.55	17000	14.36
2500	4.64	18000	14.97
2600	4.74	19000	15.58
2700	4.84	20000	16.19
2800	4.92	30000	22.22
2900	5.02	40000	28.3
3000	5.10	50000	34.3
3100	5.18	60000	40.0
3200	5.27	or	
3300	5.36	more	

*See Definition in Rule 2(j).

APPENDIX IV

Sample Specification for Air Pollution Abatement Equipment

Specifications for Abatement Equipment

1. SCOPE

A. This specification covers vendor requirements for a ______________________________ to serve as the principal abatement device in a secondary smelting process. The intent of the specification is to describe the service as thoroughly as possible so as to secure vendor's proposal for equipment which is suitable in every respect for the service intended. Basic information is tabulated on pages 2, 3 and 4. The vendor should specify any of the performance characteristics which cannot be guaranteed without samples of process effluent.

B. The vendor shall supply all labor, materials, equipment, and services to furnish one _________________________ together with the following auxiliaries:

1. All ladders, platforms, and other accessways to provide convenient access to all points requiring observation or maintenance.

2. Foundation bolts as required.

3. Six (6) sets of drawings, instructions, spare parts list, etc., pertinent to the above.

The vendor shall not include in his base bid the following:

1. Erection

2. Foundation

3. External piping

4. Pumps

5. Fans (if not an internal part of the collector)

6. Dust or slurry handling systems

C. The vendor shall furnish the equipment FOB point of manufacture, and shall furnish as a part of this project competent supervision of the erection, which shall be by others.

D. Vendor shall furnish the following drawings, etc., as a minimum:

1. With his proposal:
   a. Plan and elevation showing general arrangement.
   b. Typical details of collector internals proposed.
   c. Data relating to projected performance with respect to pressure drop, gas absorption efficiency and particulate removal efficiency to gas and liquor flows.

2. Upon receipt of order:
   a. Proposed schedule of design and delivery.

3. Within 60 days of order:
   a. Complete drawings of equipment for approval by customer.
   b. 30 days prior to shipment:
      1) Certified drawings of equipment, six sets
      2) Installation instructions, six sets
      3) Starting and operating instructions, six sets
      4) Maintenance instructions and recommended spare parts lists, six sets

E. The design and construction of the collector and auxiliaries shall conform to the general conditions given on page 6, and to good engineering practice.

2. PROCESS DESCRIPTION

The scrubber is to handle the exhaust gas from a rotary lime kiln fired by natural gas. The filter will be used to remove limestone and lime dust from the exhaust gas. The rotary kiln is fed with ¼" to ½" limestone. There is no preheater on the kiln and the feed end of the kiln is equipped with a dust fall-out chamber. The dust chamber is followed by a wet scrubber with pre-cooling sprays or saturation chamber as required. Such pre-cooling equipment is to be located at the discharge from the fall-out chamber, and must cool the ductwork to a maximum of 550°F. It will be considered as an integral part of the scrubber for this quotation.

The exhaust gas will be brought from the precooling section to a point twenty feet outside the building where a fan will be located. (The fan outlet is five (5) feet above grade.) The scrubber will be located in an area beyond the fan. The area is free of space limitations. The scrubber is to be designed to withstand the full discharge pressure developed by the fan.

The scrubber is to operate in such a manner as to continuously attain the efficiency levels specified in the following section.

The scrubber shall have a conical bottom designed to avoid the collection of sediment or deposits. Liquor effluent is to be piped to a recirculation tank from which the recirculation pump takes suction. Fresh makeup water is to be added to the system at this point. Discharge from the recirculation pump is to be partially returned to the scrubber and part withdrawn to a slurry settling basin to be provided by the customer. The slurry withdrawal is to be set to maintain about 10 weight percent solids when the kiln is operating at design capacity.

The scrubber and external piping are to be constructed of carbon steel. Packing glands are to be flushed with fresh water to prevent binding of the seals.

For purposes of this quotation, the following is to be considered auxiliary equipment:

(1) pumps and reservoir
(2) fan
(3) external piping
(4) controls

3. OPERATING CONDITIONS

Three sizes of scrubbers are to be quoted for each of two levels of efficiency.

	(A) Small	(B) Medium	(C) Large
Furnace capacity, ton	125	250	500
Production rate, lb/hr	10,400	20,800	41,600
Process weight rate, lb/hr	18,700	37,400	74,800
Inlet gas volume, ACFM	35,000	85,000	150,000
Inlet gas temperature, ^{o}F	1,200	1,200	1,200
Inlet loading, lb/hr	815	1,960	3,500
Inlet loading, gr/ACF	2.82	2.69	2.72
Outlet gas volume, ACFM	19,000	46,000	81,000
Outlet gas temperature, ^{o}F	164	164	164

Case 1 - LA Process Weight

Outlet loading, #/hr	15.40	26.7	40
Outlet loading, gr/ACF	0.094	0.068	0.058
Efficiency, wt %	98.1	98.6	98.9

Case 2 - High Efficiency

Outlet loading, #/hr	4.89	11.85	20.8
Outlet loading, gr/ACF	0.03	0.03	0.03
Efficiency, wt %	99.4	99.4	99.4

4. PROCESS PERFORMANCE GUARANTEE

A. The ______________________ will be guaranteed to reduce the particulate and/or gas contaminant loadings as indicated in the service description.

B. Performance test will be conducted in accordance with I.G.C.I. test methods where applicable.

C. Testing shall be conducted at a time mutually agreeable to the customer and the vendor.

D. The cost of the performance test is to be included in vendor's proposal as an alternate.

E. In the event the ______________________ fails to comply with the guarantee at the specified design conditions, the vendor shall make every effort to correct any defect expeditiously at his own expense. Subsequent retesting to obtain a satisfactory result shall be at the vendor's expense.

5. GENERAL CONDITIONS

A. Materials and Workmanship

Only new materials of the best quality shall be used in the manufacture of items covered by this specification. Workmanship shall be of high quality and performed by competent workmen.

B. Equipment

Equipment not of vendor's manufacture furnished as a part of this collector shall be regarded in every respect as though it were of vendor's original manufacture.

C. Compliance with Applicable Work Standards and Codes

It shall be the responsibility of the vendor to design and manufacture the equipment specified in compliance with the practice specified by applicable codes.

D. Delivery Schedules

1. The vendor shall arrange delivery of equipment under this contract so as to provide for unloading at the job site within a time period specified by the customer. Vendor shall provide for expediting and following shipment of materials to the extent required to comply with delivery specified.

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APPENDIX V

Detailed Instructions for Preparing Bid Price Proposals

INSTRUCTIONS FOR COMPLETING TABLE III

Items (1) through (6): The information requested in items (1) through (6) of Table III is to be taken from the specification.

Item (7): System horsepower is to include the estimated horsepower at design conditions for the fan and pump drivers.

Item (8): Equipment costs are for immediate delivery.

A. The collector is to be figured on a flange-to-flange basis and to include no auxiliaries.

B. The Process Description section of the specification spells out what is to be included as "auxiliaries" in each case.

C. Gas conditioning equipment includes such items as water quench systems, and chemical additive systems for altering flyash resistivity.

D. Waste equipment includes such items as wet scrubber slurry disposal and dry collector solids handling equipment.

E. "Other" can be used for such equipment items as standby or safety equipment, water reservoirs, and chemical storage tanks.

Item (9): Covers the expected difference between the total turnkey cost of the complete system, and the equipment cost listed in item (8). This is to be estimated alternately for a complete new facility (grass roots), and for back-fit into an existing plant (add-on). For purposes of this study, the turnkey prices are to be figured as though the installation were to be made in Milwaukee, Wisconsin where hourly labor rates in the construction trades are near the average for the U. S. A tabulation of an hourly rate index for major U. S. cities, along with a list of the average hourly rates for various trades is attached.

Item (10): The nominal life of the equipment in years is to represent your best estimate of actual service life. This does not constitute a representation which can be applied to any future specific sale, but should be your best estimate for the average life equipment in this kind of service.

Item (11): An estimate of yearly maintenance costs is required here. This should include an estimate of man-hours for service, plus a dollar figure for replacement parts, etc.

NOTE: Please use one form for the high efficiency case, and another for the low efficiency case.

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INDUSTRIAL GAS CLEANING INSTITUTE, INC.

August 24, 1970

TO: Participants in NAPCA Project

FROM: L.C. Hardison, Coordinating Engineer

SUBJECT: Bid Price Proposals for Erection

The contract with NAPCA specifies that turnkey prices are to be submitted and that variations in cost from area to area are to be discussed. Gary Evans, the NAPCA Project Officer, has suggested a relatively simple way of handling this.

Attached is a copy of City Cost Indexes taken from "Building Construction Cost Data, 1970"*. This gives a construction cost index for 90 cities, using 100 as the national average. These are for the building trades, as reported by the U.S. Department of Labor. A copy of the rates by trade is also attached.

While these figures do not take productivity differences into account, it will be acceptable to NAPCA if we choose a base location with a labor index of about 100 (such as Milwaukee, Wisconsin). The variation in labor rate can be discribed by using the "City Cost Index" table. Variations in productivity can be handled by soliciting comments from the companies preparing bid prices as to areas where productivity is likely to be unusually high or low.

L.C. Hardison
Coordinating Engineer

* by Robert Sturgis Godfrey, published by Robert Snow Means Company, Inc. P.O. Box G., Duxbury, Mass. 02332.

Labor rates used in this edition are as listed below for 1970. They are averages of the 30 largest cities in the U.S. as reported by the U.S. Dept. of Labor and are substantially the same as listed by Engineering News-Record. The rates have been rounded out to the nearest 5¢ and include fringe benefits but do not include insurance or taxes.

Trade	1970	1969	1968	1967	1966
Common Building Labor	$5.00	$4.55	$4.10	$3.85	$3.65
Skilled Average	6.85	6.05	5.50	5.15	4.90
Helpers Average	5.15	4.65	4.20	4.00	3.85
Foremen (usually 35¢ over trade)	7.20	6.40	5.85	5.50	5.25
Bricklayers	7.15	6.40	5.85	5.55	5.35
Bricklayers Helpers	5.20	4.70	4.30	4.05	3.95
Carpenters	6.95	6.15	5.40	5.10	4.90
Cement Finishers	6.75	5.90	5.30	5.05	4.85
Electricians	7.50	6.45	5.95	5.60	5.45
Glaziers	6.25	5.50	5.10	4.75	4.60
Hoist Engineers	7.05	5.90	5.40	5.10	4.85
Lathers	6.60	5.95	5.45	5.20	5.05
Marble & Terrazzo Workers	6.45	5.60	5.25	5.05	4.90
Painters, Ordinary	6.20	5.45	5.05	4.75	4.50
Painters, Structural Steel	6.50	5.80	5.30	4.95	4.80
Paperhangers	6.30	5.60	5.15	4.75	4.55
Plasterers	6.60	5.95	5.50	5.15	5.00
Plasterers Helpers	5.30	4.85	4.45	4.15	4.00
Plumbers	7.75	6.90	6.15	5.75	5.55
Power Shovel or Crane Operator	7.20	6.20	5.65	5.35	5.05
Rodmen (Reinforcing)	7.30	6.35	5.80	5.45	5.15
Roofers, Composition	6.30	5.55	5.05	4.75	4.65
Roofers, Tile & Slate	6.35	5.60	5.10	4.85	4.80
Roofers Helpers (Composition)	4.75	4.45	4.00	3.75	3.55
Steamfitters	7.70	6.90	6.10	5.70	5.50
Sprinkler Installers	7.70	6.90	6.10	5.70	5.50
Structural Steel Workers	7.45	6.45	5.90	5.55	5.25
Tile Layers (Floor)	6.50	5.60	5.20	4.90	4.80
Tile Layers Helpers	5.25	4.80	4.35	4.15	4.05
Truck Drivers	5.15	4.60	4.30	3.95	3.65
Welders, Structural Steel	7.15	6.35	5.80	5.45	5.10

(1) CITY COST INDEXES (p. 1)

Tabulated below are average construction cost indexes for 90 major U.S. and Canadian cities. There are two index figures, one for Labor Rates as compared to the 30 major cities with U.S. average of 100, the other for Overall or Total construction costs using 100 as the average for 1969 for the 30 major cities. (Cont'd on next page)

Average 1969 Construction Cost & Labor Indexes						Historical Average	
	Index			Index		Year	Index
City	Labor	Total	City	Labor	Total	1969	100
Albany, N.Y.	98	100	Milwaukee, Wi.	103	108	1968	91
Albuquerque, N.M.	86	95	Minneapolis, Mn.	99	98	1967	86
Amarillo, Tx.	87	84	Mobile, Al.	94	90	1966	83
Anchorage, Ak.	131	148	Montreal, Cn.	77	89	1965	79
Atlanta, Ga.	88	94	Nashville, Tn.	79	82	1964	78
Baltimore, Md.	90	93	Newark, N.J.	122	109	1963	76
Baton Rouge, La.	83	88	New Haven, Ct.	102	100	1962	74
Birmingham, Al.	79	86	New Orleans, La.	89	95	1961	72
Boston, Ma.	106	103	New York, N.Y.	132	118	1960	71
Bridgeport, Ct.	104	102	Norfolk, Va.	73	77	1959	69
Buffalo, N.Y.	104	107	Oklahoma City, Ok.	82	88	1958	67
Burlington, Vt.	86	90	Omaha, Nb.	90	93	1957	65
Charlotte, N.C.	70	75	Philadelphia, Pa.	106	101	1956	63
Chattanooga, Tn.	81	84	Phoenix, Az.	101	97	1955	59
Chicago, Ill.	107	103	Pittsburgh, Pa.	110	106	1954	58
Cincinnati, Oh.	108	104	Portland, Me.	82	87	1953	57
Cleveland, Oh.	121	112	Portland, Or.	102	103	1952	55
Columbus, Oh.	106	99	Providence, R.I.	98	97	1951	53
Dallas, Tx.	86	89	Richmond, Va.	76	79	1950	49
Dayton, Oh.	100	103	Rochester, N.Y.	110	107	1949	48
Denver, Co.	94	91	Rockford, Ill.	109	109	1948	48
Des Moines, Ia.	93	96	Sacramento, Ca.	117	110	1947	43
Detroit, Mi.	117	111	St. Louis, Mo.	110	103	1946	35
Edmonton, Cn.	80	83	Salt Lake City, Ut.	93	95	1945	30
El Paso, Tx.	77	83	San Antonio, Tx.	82	82	1944	29
Erie, Pa.	98	99	San Diego, Ca.	111	107	1943	29
Evansville, In.	93	97	San Francisco, Ca.	124	109	1942	28
Grand Rapids, Mi.	103	99	Savannah, Ga.	72	77	1941	25
Harrisburg, Pa.	90	92	Scranton, Pa.	94	96	1940	24
Hartford, Ct.	104	100	Seattle, Wa.	104	99	1939	23
Honolulu, Hi.	99	109	Shreveport, La.	82	89	1938	23
Houston, Tx.	92	89	South Bend, In.	99	97	1937	23
Indianapolis, In.	97	98	Spokane, Wa.	101	100	1936	20
Jackson, Ms.	73	75	Springfield, Ma.	99	97	1935	20
Jacksonville, Fl.	78	79	Syracuse, N.Y.	105	103	1934	20
Kansas City, Mo.	94	93	Tampa, Fl.	81	84	1933	18
Knoxville, Tn.	82	82	Toledo, Oh.	105	105	1932	17
Las Vegas, Nv.	115	107	Toronto, Cn.	84	93	1931	20
Little Rock, Ar.	78	81	Trenton, N.J.	114	103	1930	22
Los Angeles, Ca.	113	102	Tulsa, Ok.	85	89	1929	23
Louisville, Ky.	92	93	Vancouver, Cn.	81	91	1928	23
Madison, Wi.	95	98	Washington, D.C.	98	94	1927	23
Manchester, N.H.	89	92	Wichita, Ks.	85	90	1926	23
Memphis, Tn.	83	82	Winnipeg, Cn.	62	82	1925	23
Miami, Fl.	98	94	Youngstown, Oh.	107	106	1924	23

APPENDIX VI

Detailed Instructions for Listing Installations

INDUSTRIAL GAS CLEANING INSTITUTE, INC.

National Association of Manufacturers of Industrial Gas Cleaning Equipment

IGCI

HERBERT R. HERINGTON
Executive Secretary

Box 448, Rye, N. Y. 10580

Telephone: Area Code 914
WOodbine 7-7044

August 8, 1970

TO: All Corporate Representatives

FROM: L. C. Hardison, Coordinating Engineer

SUBJECT: Summary of Installation Data

The NAPCA contract with I.G.C.I. specifies that the member companies prepare, for each of the sources below, a listing of all the installations made since January 1, 1960, and all the pertinent test data in the I.G.C.I. members' files. The sources to be included in this tabulation are:

1. Lime Industry (not including pulp or paper mill applications)
   a. Rotary lime kiln

2. Secondary non-ferrous metallurgical industry
   a. Brass reverberatory furnace
   b. Lead cupola (blast furnace)
   c. Lead sweating furnace
   d. Lead reverberatory furnace
   e. Zinc calcining kiln
   f. Aluminum sweating furnace
   g. Aluminum chlorination station
   h. Bronze reverberatory furnace

All of the material requested is to be listed in Table I. An example entry is included with your copies of the blank forms to assist you in filling them out. Duplicate forms are included so you may retain a copy for your files. In addition, some detailed instructions follow.

Some comments apply generally. An installation consists of all of the equipment installed to process gas from a single source. For example, if two scrubbers are operated in parallel on the gas from an aluminum chlorination station, they should be covered by a single entry. The gas volume, etc., relates to the total flow through both scrubbers.

It has been generally agreed that none of the applications involved in the study can be handled adequately by a mechanical collector alone. However, there are many installations which incorporate a mechanical ahead of a precipitator, scrubber or filter. Where this is the case, please treat the mechanical as a part of the gas cleaning device, and call attention to the tandem arrangement in the "remarks".

Where only a part of the data requested is available, please indicate the information which is not available in your files by entering "NA" in the appropriate space. The same abbreviation may be used to indicate that information called for is not applicable to the installation in question.

Please note that there is no space for the name of your company on the forms. Be sure to attach something to identify the company to the completed forms, but don't put your company name on the forms themselves. Return the completed forms to Herb Herington.

The remainder of the comments and instructions pertain to the individual columns in Table I, which are numbered across the top of the pages.

1. Column 1 is for the purpose of indexing the summary of tests from all of the member companies. Please enter the data serially according to the date the installation was put into service, starting with January 1, 1960 and working toward the present. Number the earliest installation #1, so that the last "Test number" on your form represents the total number of installations your company has made since January 1, 1960. If you wish to use another test number for your own reference, enter it in parenthesis below the sequential numbers.

2. Capacity - The capacity of the source will be presented in appropriate units (tons/day, tons/heat, or tons/hr.). The capacity reported will be the design capacity for the piece of source equipment or the maximum design condition for the collector.

3. Type of raw material or charge - The composition of the raw material or charge will be presented on a percent by weight basis.

4. Fuel Used - The type of fuel used in firing the source equipment will be presented. Sulfur and ash contents for coal and oil will be reported.

5. Type collector and year placed in service - The type of collector will be described (i.e., - venturi- 30" W.G., Fabric Filter - Orlon bags, ESP - collector surface area) and the year placed in service will also be listed.

6. Gas Volume - The gas volume at the design capacity will be presented in acrual cubic feet per minute. For the case of wet scrubbers, the capacity of the source should be reported in ACFM, and the capacity of the scrubber reported in ACFM saturated beneath the hot gas figure.

7. Temperature - The temperature at the collector inlet in ^{o}F will be presented. Where a saturated gas volume is presented for a wet scrubber capacity, the saturation temperature should be given in parenthesis below the hot gas temperature.

8. Measured Grain Loading - The inlet and outlet grain loadings, at the collector, measured by a source test, will be presented in grains per ACF.

9. Design Efficiency - The design collection efficiency for the collector will be presented. The measured or test efficiency of the collector, calculated from the grain loadings in column 8, should be entered in parenthesis below the Design Efficiency.

10. Plume Visibility - Is plume visible after collection? Answer yes or no. If yes, an explanation as to % opacity, time span, and process step during which plume is visible (i.e., charging, melting, pouring), should be presented on the remarks sheet, and referenced in column 15. See p. 4.

11. Particle size distribution and method - The particle size distribution and the method of measurement will be presented.

12. Dust Resistivity and method of measurement - The contractor shall present information on the dust resistivity (ohm - cm) and the temperature (^{o}F) at which the measurement was made. The method of measurement, laboratory or in situ, shall also

be presented. The dust resistivity measurement is applicable only to precipitator installations, but should be reported, if known, regardless of the type of collector installed.

13. Chemical composition of particles - The chemical composition of the particles on a percent by weight basis shall be presented.

14. Chemical composition of gas stream - The chemical composition of the gas stream on a percent by volume basis shall be presented.

15. Any remarks which might serve to clarify or enhance the value of the reported data should be presented on a separate sheet with reference numbers indicated in column 15. For example, a mechanical collector is frequently included in a scrubber or filter application. This pertinent fact should be clearly indicated in the "remarks".

LCH:js

Addendum:

Item No. 10: For wet scrubbers only:
If the plume appears to consist wholly of condensed water vapor, answer "no" in column 10, and note in the remarks that there was a visible steam plume.

TABLE I page 2 SOURCE:____________________

SUMMARY OF INSTALLATION DATA

(1)	(11)				(12)			(13)		(14)		(15)
TEST NO.	PARTICLE SIZE μ		WT.% IN RANGE	METHOD OF ANALYSIS	RESISTIVITY OHM-CM		METHOD OF ANALYSIS	CHEMICAL COMP. OF PARTICLES		CHEMICAL COMP. OF GAS		REMARKS NOTE 5
	<	>			RESIST.	TEMP.F		COMP.	WT.%	COMP.	VOL.%	

5. Remarks which might serve to clarify or enhance the value of the reported data should be presented on a separate sheet with reference numbers indicated in column 15.

TABLE I SOURCE: ____________

SUMMARY OF INSTALLATION DATA

(1)	(2)	(3)	(4)	(5)	(5a)	(6)	(7)	(8a)	(8b)	(9)	(10)
TEST NO.	CAP. OF UNIT	TYPE OF RAW MATERIAL OR CHARGE[1]	FUEL USED[2]	TYPE COLLECTOR[3]	YEAR PLACED IN SERVICE	GAS VOLUME ACFM	INLET TEMP. °F	MEASURED DUST LOADING GR/ACF		DESIGN EFF. WT. %	IS PLUME VISIBLE[4]
								INLET	OUTLET		

1. The composition of the raw material or charge should be presented on a wt.% basis.
2. The type of fuel used in firing should be presented. Report sulfur and ash content of coal.
3. Describe the type of collector. Examples: Venturi-30" w. c.;Fabric Filter, Orlon Bags;ESP, Area.
4. Is the plume visible after collection? Answer yes or no here. If yes, an explanation as to time span, process step during which plume is visible, etc., should be presented in the remarks column.

APPENDIX VII

List of IGCI Publications

APPENDIX VII

LIST OF IGCI PUBLICATIONS

"Test Procedure for Gas Scrubbers"	(WS-1)
"Terminology for Electrostatic Precipitators"	(E-P 1)
"Procedure for Determination of Velocity and Gas Flow Rate" (Electrostatic Precipitators Div.)	(E-P 2)
"Criteria for Performance Guarantee Determinations" (Electrostatic Precipitators Div.)	(E-P 3)
"Evaluation Bid Form" (Electrostatic Precipitators Div.)	(E-P 4)
"Information Required for the Preparation of Bidding Specifications for Electrostatic Precipitators"	(E-P 5)
"Pilot Electrostatic Precipitators"	(E-P 6)
"Gas Flow Model Studies"	(E-P 7)
"Cyclonic Mechanical Dust Collector Criteria" (Mechanical Collectors Div.)	(M-2)
"Gravity, Louver and Dynamic Mechanical Collector Criteria"	(M-3)
"Gaseous Emissions Equipment: Product Definitions and Illustrations" (Gaseous Control Div.)	(G-1)
"Fundamentals of Fabric Collectors and Glossary of Terms"	(F-2)
"Operation and Maintenance of Fabric Collectors"	(F-3)