AIR POLLUTION CONTROL TECHNOLOGY AND COSTS IN NINE SELECTED AREAS

INDUSTRIAL GAS CLEANING INSTITUTE, INC.
STAMFORD, CONNECTICUT

I G C I

THE CLEAN AIR PEOPLE

INDUSTRIAL GAS CLEANING INSTITUTE, INC.

P.O. BOX 1333, STAMFORD, CONN. 06904

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AIR POLLUTION CONTROL TECHNOLOGY AND COSTS IN NINE SELECTED AREAS

FINAL REPORT

(Submitted September 30, 1972)

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Prepared for

The Environmental Protection Agency

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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.

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I. INTRODUCTION

The Industrial Gas Cleaning Institute (IGCI) is an association of manufacturers of industrial gas cleaning equipment. Under this contract, members of the IGCI collected and formalized information on air pollution control for sixteen processes in nine industrial areas:

1. Rendering
2. Asphalt Batch Plants
3. Petroleum Refining
4. BOF Steelmaking
5. Coal Cleaning
6. Brick and Tile Kilns
7. Primary Copper Smelting
8. Kraft Pulp Industry Bark Boilers
9. Ferroalloy Furnaces

This report includes a completed narrative description of each area, describing the processes and air pollution abatement methods in use. In addition, specifications for abatement equipment have been written for large and small processes, and for two levels of air pollution control. These specifications were submitted to three member companies active in furnishing equipment to the industry involved. The capital and operating cost data prepared for each process were summarized and average costs are included in this report.

In addition, correlations were made between process size, gas flow and abatement cost where meaningful relationships appeared to exist.

II. TECHNICAL DATA

This section contains all of the data collected relative to process descriptions, air pollution requirements, specifications and capital and operating costs for abatement equipment. Narrative material was generated by the combined efforts of Air Resources, Inc. personnel acting as editors and coordinators for the program, and the most qualified personnel of the member companies active in the field. The cost data, however, is entirely the product of the member companies judged most qualified. These companies prepared cost estimates independently of one another. Air Resources, Inc. consolidated the data and edited it with regard to format only.

A. General Description

The format chosen for presentation of the material collected groups all of the information pertaining to a given industrial area in a single section of the report. The final summary section describes the findings in general terms, and contains generalizations of cost factors common to all the areas covered.

1. FORMAT

There are nine sections, each covering one of the industrial areas. For each area, the following format is used:

1. Description of the Process
    a. Manufacturing or Production Aspects
    b. Air Pollution Control Equipment
2. Specifications and Costs
    a. Electrostatic Precipitators
        (1) Specifications
        (2) Capital Costs
        (3) Operating Costs

   b. Wet Scrubbers

   c. Fabric Collectors

   d. Other

3. Summary Comments

This material is not presented in outline form, nor is each item necessarily included for each process area.

2. SELECTION OF APPLICABLE EQUIPMENT TYPES

Most of the processes covered by this report require abatement devices for the control of particulate emission. These devices include:

Electrostatic Precipitators

Wet Scrubbers

Fabric Collectors

Mechanical (Cyclonic) Collectors

One of the processes — rendering — has little need for particulate control, but requires instead the removal of a variety of gaseous materials which give rise to local odor nuisance problems. The devices used for gaseous emission control are:

Wet Scrubbers

Incinerators

Adsorption Units

In general, a given process is amenable to control by one or more of the equipment types, but seldom by all of them. For this reason, a meeting of the Engineering Standards Committee of the Industrial Gas Cleaning Institute was held early in the program for the purpose of selecting the equipment types applicable to each process.

The results of this selection for all nine areas are presented in Table 1. There were several changes in the definition of applicable equipment types after the initial selection. These are made as evidence emerged during the preparation of narratives that a particular process was amenable to control by equipment not previously considered applicable or was not ordinarily controlled by one of the equipment types listed. The changes are discussed in the following paragraphs.

Rendering emissions were considered amenable to control by absorption (wet scrubbing with chemical oxidation of the organic odor precursors) or thermal incineration. The third method of emission control – adsorption – was ruled out because of the presumption that activated carbon or other adsorption beds would plug with the heavier grease-like organic compounds. It was found that one of the companies active in the field has used a combination scrubbing carbon adsorption system for cooker applications. Data on costs for this combination system are presented, but Table 1 does not show adsorption (alone) as a suitable method of control.

Asphalt Batch Plants were considered amenable to control by all three types of particulate control equipment, but electrostatic precipitators were omitted from Table 1 initially because most batch plants are relatively small in terms of gas flow, and usually below the size range in which precipitators are economically applied. However, it was learned during the course of the study that one of the member companies has provided a number of small precipitators for batch plants. In view of this, precipitators were added, and specifications written. Only one company has supplied precipitators for the asphalt industry, however, and no comparative cost data is included.

Petroleum Refining was considered amenable to control by wet scrubbers and precipitators, but no installations of wet scrubbers have been made in the U.S., so they were deleted. However, it was found that mechanical collectors used as "final stage external cyclones" do satisfy most air pollution requirements for plants with normal emission levels, and these were permitted as alternatives to the electrostatic precipitator where they would meet the performance specifications.

BOF Steelmaking was presumed amenable to treatment by wet scrubbers and precipitators, and this was not changed during the course of the program. Closed hood systems were assumed to be limited to wet scrubbing because of the combustion hazard with precipitators.

TABLE 1

PROPOSED TABLE OF APPLICATIONS

	Elect.	Fabric	Wet	Incin-erator	Total Applica-tions
(1) Rendering					
(a) Cookers			X	X	2
(b) Expellers			X	X	2
(c) Room Vents			X	X*	2
(2) Petroleum Refining	X				1
(3) Asphalt Batching	X*	X	X		3
(4) BOF Steel Making					
(a) With CO Burning	X		X		2
(b) Without CO Burning			X		1
(5) Coal Cleaning					
(a) Fluidized Bed Dryer		X**	X		1
(b) Flash Dryer		X**	X**		
(6) Brick and Tile			X	X	2
(7) Copper Smelting					
(a) Reverb., no SO_2 Control	X	X**	X		2
(b) Reverb., with SO_2 Control	X**				
(c) Convertor (or Roaster)	X	X**	X		2
(8) Kraft Mill Bark Boilers	X		X		2
(9) Ferroalloy Furnaces					
(a) Ferrosilicon	X***	X	X		3
(b) Ferrochrome	X***	X	X		3

*These were added during the course of the program.

**These were deleted during the course of the program.

***These were retained through specification writing, but no equipment bids were obtained.

Coal Cleaning was originally described as controlled by both fabric collectors and wet scrubbers. Current practice is limited to wet scrubbers, however. This is related to the difficulty in treating nearly saturated gas streams with fabric collectors. For this reason, fabric collectors were deleted from this section of the study.

Brick and Tile Kilns emit contaminants only when materials such as sulfur, fluorine or organics are present in the clay. Wet scrubbing is the method used for removal of SO_2 and HF, while incineration is useful for removing smoke produced by combustibles in the clay.

Copper Smelting was modified substantially. It was found that no reverberatory furnaces are being treated with fabric collectors so this category was deleted. In addition, no reverberatory furnaces with SO_2 control were found, so this entire category was dropped. Lastly, the roasting furnace was substituted for the converter to obtain costs for conditioning gas to be fed to a sulfuric acid plant.

Kraft Mill Bark Boilers have been treated by both electrostatic precipitators and wet scrubbers. This was not altered during the course of the program.

Ferroalloy Furnaces are difficult to treat adequately, but all three methods have been applied with some degree of success. All three were included at the beginning of the program but only fabric collection was found to be suitable for both types of operation.

3. BASIS FOR SPECIFICATIONS

The degree of reduction of emissions required in a given application will influence the cost significantly for wet scrubbers and electrostatic precipitators. Fabric filters, mechanical collectors and thermal incinerators are, on the other hand, relatively insensitive to the efficiency level specified. In all cases, the cost is directly related to size or gas handling capacity required.

In order to make a meaningful comparison of capital and operating costs, it is necessary to specify the performance level, or degree of reduction of emissions required. For this project, two arbitrary levels of performance were specified:

a) An "intermediate level" which corresponds to the Los Angeles County Air Pollution Control District process weight requirements, and

b) A "high level" of performance which should show little or no subjective evidence of emissions; that is no visible particulate matter, and no detectable odor level.

These levels are arbitrary and should not be used as guides to selection of abatement equipment without a good understanding of the local requirements and any special conditions affecting the emissions from the process.

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. Many of the processes covered by this study are relatively small in terms of total feed rate, and the 40 lb/hr maximum emission level will not be applicable. Others such as catalytic cracking units and BOF furnaces normally operate at high process weights and have a 40 lb/hr emission limit.

A list of allowable emission rates under the LA—Process Weight regulation is given in Table 2. A more detailed version of Rule 54 of the Air Pollution Control District of Los Angeles County is given in Appendix I. This rule was modified during the course of the contract, and the version in effect on July 1, 1971 has been used throughout.

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 3 lists the values assigned by the Engineering Standards Committee to this "High Efficiency" case.

It should be noted that the experience of the member companies over a period of many years has been drawn upon to establish the grain loading figures indicated. Although there has been no single standardized test method used in the past, the methods prescribed by the American Society of Mechanical Engineers and embodied in Power Test Codes 21 and 27 have had the widest use. The "High Efficiency" grain loadings may be presumed to relate to these methods more closely than to others such as the recently developed "EPA sampling train", (Test Method No. 5, Federal Register 12/23/71).

Table 3 shows loadings in gr/ACF because these should correlate better with visibility of the discharge than gr/SCF. Most frequently the measured emissions are reported in gr/SCF and the conversion to gr/ACF should not be overlooked. In order to make this easier, Table 4 has been prepared. This lists various levels of emission in terms of gr/ACF in the left-hand column, and corresponding values of gr/SCF at various stack temperatures.

For the case of rendering equipment, the particulate emission standards do not apply and a basis for odor emission was defined by the committee and reviewed with the Project Officer. This basis is described in the following paragraph.

High efficiency performance has been defined as that which shows little or no subjective evidence of emission. For rendering, the equivalent of a clear stack is an undetectable odor. For this reason the "High Efficiency" level was defined as 1.0 or less odor units at ground level. The Coordinating Engineer specified the stack height and abatement level required to accomplish this. The "LA—Process Weight" does not apply to odors. In order to accomplish the equivalent of this specification, the use of 8.0 o.u./SCF max. at ground level was agreed upon.

TABLE 2

LA–PROCESS WEIGHT AND ALLOWABLE EMISSION

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

*See Definition in Rule 2(j) (Reproduced in Appendix I)

TABLE 3

DEFINITION OF "HIGH EFFICIENCY" PERFORMANCE LEVEL

		Collector Outlet Concentration
(1)	Rendering	1.0 o.u.*/SCF max. instantaneous ground level value (8.0 o.u./SCF max. instantaneous ground level = low efficiency)
(2)	Petroleum Refining	
	Cat Crackers	0.015 gr/ACF
(3)	Asphalt Batch Plants	0.03 gr/ACF
(4)	Coal Dryers	0.03 gr/ACF
(5)	Brick and Tile Kilns	0.005 gr/ACF (for organic particulate)
(6)	Copper Smelting	
	Reverberatory without SO_2 Control	0.015 gr/ACF
	Convertors	0.01 gr/ACF
(7)	Kraft Bark Boilers	0.04 gr/ACF
(8)	Basic Oxygen Furnaces	0.01 gr/ACF
(9)	Ferroalloy Furnaces	0.01 gr/ACF

*"o.u." is the abbreviation for odor unit, or the concentration of an odor precursor just high enough to bring the odor of one SCF of air to the detectable threshold.

TABLE 4

CONVERSION OF LOADINGS FROM gr/ACF to gr/SCF*

gr/ACF	gr/SCF						
	Temperature, °F						
	70	100	200	300	400	500	600
0.005	0.005	0.0053	0.0062	0.0072	0.0081	0.009	0.010
0.0075	0.0075	0.0079	0.0093	0.011	0.012	0.014	0.015
0.01	0.01	0.011	0.012	0.014	0.016	0.018	0.020
0.015	0.015	0.016	0.019	0.021	0.024	0.027	0.030
0.02	0.02	0.021	0.025	0.029	0.032	0.036	0.040
0.025	0.025	0.026	0.031	0.036	0.041	0.045	0.050
0.03	0.03	0.032	0.037	0.043	0.049	0.054	0.060
0.035	0.035	0.037	0.044	0.050	0.057	0.063	0.070
0.04	0.04	0.042	0.050	0.057	0.065	0.073	0.080

*Based upon 70°F, 14.7 psia standard conditions and presumption that emission is also at 14.7 psia. The SCF, as used here, has the same water vapor content as the ACF. This should not be confused with the dry standard volume, or DSCF.

BASIS FOR PREPARING SPECIFICATIONS AND BID PRICES

Several simplifications 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 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 III 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 is given in Appendix II.

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 5 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 6 shows the tabulated hourly rates for various construction trades (based on national averages) which may be useful for this purpose.*

Considerable emphasis was placed on estimation of operating costs. Manufacturers submitting costs for equipment were asked to estimate the operating costs in terms of utility requirements, maintenance and repair labor, and operating labor. These were requested in terms of the *quantity* required, rather than the cost. This is because the costs will be analyzed in terms of low, average and high utility and labor cost areas for the final report. For this report, only the average utility costs given below were used for preparing total annual cost figures.

4. PRESENTATION OF DATA

Capital cost data is presented as a series of three graphs which relate the capital cost of the air pollution abatement device, the total equipment, and the complete "turnkey" system respectively to plant size or exhaust gas rate. Where it was possible, an analysis was made of the confidence limits of the sample — three quotations from perhaps 20 possible suppliers. Appendix IV contains a description of the mathematical procedure involved.

Operating costs are also presented in graphical form. A total annual cost has been calculated for each process by combining an annual capital charge with a direct annual operating cost. The resulting figures are presented as a graph of total annual cost versus plant size or exhaust gas rate. Section C includes a more detailed discussion of the basis for presentation of this data.

Both capital and operating cost data are presented in 1971 dollars throughout the report.

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*Published by the Robert Snow Means Company

TABLE 5

CITY COST INDICES

Average 1969 Construction Cost & Labor Indices						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 6

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

RENDERING

1. RENDERING INDUSTRY

The production of meat for human consumption produces a large amount of inedible waste. The process of converting this waste, along with other inedible animal wastes, into salable products is called rendering. Rendering has long been classified among the "offensive trades" and has merited the classification. It does however perform the desirable task of eliminating the problem of disposing of these massive quantities of animal wastes. Both feed materials and process gases have highly objectionable odors.

The inedible matter which comprises the charge to rendering operations comes from two primary sources: waste products from meat packing and processing, and the carcasses of animals which have died due to accidents, disease, or natural causes. Rendering operations run by meat packers are generally confined to processing captive wastes from their own plants. The quantities of wastes available per head from packing house operations are shown in Table 7 for several different classes of animals. Scavenger plants process wastes from packers who do not have their own rendering plants, as well as the carcasses of animals who have died for reasons other than slaughtering. Both kinds of plants produce two classes of products: fats used in the production of soaps, fatty acids, glycerol, and export; and protein concentrates used for animal feeds.

The chemistry of rendering depends heavily upon the source and kind of materials fed to the process. Qualitatively, the process employs mild heating to break down the cell structure in fatty tissues. The fat in these cells is thereby released and withdrawn as one of the products, generally called grease or tallow. The solid residue is high in protein and is used as the basis of the protein concentrate which is the other product. Large amounts of water are driven off as steam during the reaction. Volatile organics are also given off during the reaction and produce the infamous odors associated with the process.

Table 8 shows the differences in composition among possible rendering charge materials. Fat or grease contents can vary from nearly zero for blood and feathers to 70% for beef killing fat. Solids contents can vary from less than 10% for beef killing fat and hog lard to over 30% for steers.

A further indication of the chemical complexity involved is given by Table 9 which lists partial chemical analyses of the rendered protein concentrates from different charge materials. Protein contents vary from 6% in products from bone rendering to 85% in products containing ground, coagulated, dried blood. Other characteristics vary over similarly wide ranges.

TABLE 7

WEIGHT OF INEDIBLE WASTE FROM SLAUGHTERED LIVESTOCK(3)

	lb Blood/Head	lb Offal and Bone/Head
Slaughtered Livestock		
Cows	55	110-125
Canner Cows		90-100
Steers	55	90-100
Baby Beef		60-90
Calves	5	15-20
Sheep	4	8-10
Hogs (lard – edible)		30-50
Hogs (inedible)	7	10-15

TABLE 8

COMPOSITION OF TYPICAL RENDERING CHARGE MATERIALS(3, 4)

	Wt. % Grease	Wt. % Solids	Wt. % Moisture
Slaughtered Livestock Waste From:			
Cows	8-20	20-30	50-72
Canner Cows	10-15	30-35	50-60
Steers	20-30	30-35	35-50
Baby Beef	15-25	20-30	45-65
Calves	8-12	20-25	63-72
Sheep	25-35	20-25	40-55
Hogs (lard—edible)	70-80	7-10	10-23
Hogs (inedible)	15-20	18-25	55-67
Beef Killing Fat	65-70	6-10	20-29
Beef Offal	15-20	20-25	55-65
Dead Stock Wastes:			
Cattle	12	25	63
Cows	8-10	23	67-69
Sheep	22	25	53
Horses	30	25-30	40-45
Other Materials:			
Blood	—	12-13	87-88
Feathers	—	20-30	70-80
Butcher Shop Scrap	37	25	38

TABLE 9

PARTIAL CHEMICAL COMPOSITION OF RENDERED ANIMAL BY PRODUCTS(1)

	Meat and Bone Meal	Tankage	Blood Meal	Poultry Byproduct Meal	Steamed Bone Meal
Protein (N x 6.25) (%)	51.0	61.1	84.5	56.4	6.5
Fat (%)	11.8	8.1	—	16.1	3.0
Moisture (%)	4.4	6.6	6.8	5.8	3.0
Ash (%)	28.4	20.7	5.2	14.6	79.0
Calcium (%)	10.0	6.0	0.28	3.5	25.0
Phosphorus (%)	5.0	3.0	0.28	1.7	13.0
Pepsin Digestibility (%)	91.8	95.7	95.6	83.3	—
Vitamins					
Riboflavin (mg/lb)	1.5	0.88	0.5	3.5	0.5
Niacin (mg/lb)	21.0	20.2	10.2	31.7	2.0
Pantothenic acid (mg/lb)	4.3	1.3	1.2	13.8	1.0
Vitamin B_{12} (mg/lb)	33.9	26.8	4.5	168.0	—
Amino Acids (expressed as percent of sample)					
Arginine	3.01	2.99	3.64	3.08	0.50
Glutamic acid	4.95	5.28	—	5.52	—
Histidine	0.71	1.59	5.00	0.77	0.19
Lysine	2.55	3.58	6.30	3.21	0.88
Leucine	3.29	5.21	14.06	4.15	0.97
Isoleucine	1.33	1.25	0.90	1.83	0.46
Methionine	0.72	0.71	1.16	0.81	0.18
Cystine	0.35	0.29	—	0.81	—
Phenylalanine	1.59	2.38	5.93	1.77	0.56
Threonine	1.73	2.03	3.83	2.42	0.58
Tryptophan	0.55	0.82	1.06	0.68	0.05
Tyrosine	0.85	1.12	2.33	1.47	—
Valine	2.41	3.76	8.21	2.92	0.72
Glycine	7.19	6.65	—	7.45	—

Variability exists in the fat and grease products as well. Several different grades of fat can be produced depending upon the type of charge processed and the processing severity. Increased processing severity tends to produce poorer color and higher fatty acid content, both of which detract from the salability of the fat produced.

PROCESS DESCRIPTION

There are two basic process schemes by which rendering is carried out. They are known as the wet process and the dry process. The choice of processing scheme depends somewhat upon the size of the total operation and the type of waste products available as charge. However, by far the most widely used process is the dry process.

The dry process employs a steam jacketed, agitated vessel. This vessel, called a cooker or dry melter, is typically a horizontal tank of sufficient size to hold 8000 to 12000 lb of charge. Charge material, often hashed or cut into small pieces, is put into the vessel and heated indirectly through the steam jacket. The agitator helps distribute heat uniformly throughout the contents of the tank and prevents material from adhering to the hot wall. A typical layout of the equipment is shown as Figure 1. Operating conditions vary widely depending upon the composition of the charge materials and the products desired from the operation. Typical ranges are:(1, 4)*

Pressure:	0 to 50 psig
Temperature:	ambient at start of batch, increasing to 240° F at completion, or higher for pressure operation
Batch Time:	45 min to 6 hr
Agitator Speed:	25 to 65 rpm
Batch Size:	$\leq$ 70% of cooker capacity

During the cooking process, water vapor and volatile organics are given off as the cell structures in the tissue break down. Pressure in the cooker is created and controlled by the rate of release of these vapors.

Determination of the end point of the reaction is difficult and critical. Overcooking will yield poor fat color and high fatty acid content. Undercooking will produce solids which are difficult to press for fat removal after cooking. Thermal conductivity instruments are used in many operations to determine optimum processing time, but empirical estimates based upon charge composition still find application.

*Superscripts refer to literature references listed at the end of the section.

When cooking has been completed, the products are discharged from the cooker onto perforated plates where the fat is allowed to drain away. The solids, called cracklings, are collected and put into a press for further reduction of their fat content to 6 to 12%. Solvent extraction can be used in place of the press.

In some areas, continuous dry rendering processes are used. They tend to be highly mechanized using grinders, multistage cooking, and centrifugal separation. One such process(6) is shown in Figure 2. It employs a modified falling film evaporator as the cooker and conveys the ground fresh charge to the process slurried in a stream of recycled product fat. Final product separation is achieved using two stage centrifugation.

Wet rendering is a much older process than dry rendering. It is used less frequently than the dry process but still finds current use in the handling of dead stock — whole animals dead of natural causes, accident, or disease — and in the production of edible fats and oils from lard. The wet process uses a closed cooking vessel, usually mounted vertically. A typical wet rendering process layout is present in Figure 3. The vessel is charged with wastes, and live steam is introduced. Cooking proceeds under rising temperature and pressure. The process takes 6 to 8 hours and is completed under 50 to 60 psig steam pressure. During some operations, pressure is released after initial cooking and the process completed at atmospheric pressure. When the reaction has been completed, the grease is decanted. The solids, called tankage, are separated from residual water and dried.

The solids from both processes are dried, ground, and mixed with grain to produce the protein concentrate meal used for animal feeds. The fat products are dried and clarified before sale as raw materials for soaps, fatty acids, glycerol, and export.

Processes using solvents are also used. One such scheme is called the Vio-Bin process. It is based upon the fact that ethylene dichloride and water form a minimum boiling azeotrope. Solvent is put into the cooker with the animal matter and heat is applied indirectly through the walls. As water is released from the tissue, it boils off at a constant temperature below the boiling point of either water or ethylene dichloride. When almost all of the water has been removed, the temperature will increase, driving off the rest. What remains in the cooker are the solid product and a mixture of fat and solvent called miscella. Solid and liquid are separated by a filter cloth supported in a rotary drier. Solvent is driven off from the solids in the drier using indirect steam heat. The clear miscella is pumped to a jacketed fat kettle where the solvent is vaporized using steam heat and vacuum. Solvent vapors from the fat kettle and the drier are condensed, separated from the water by decantation, and reused.[7]

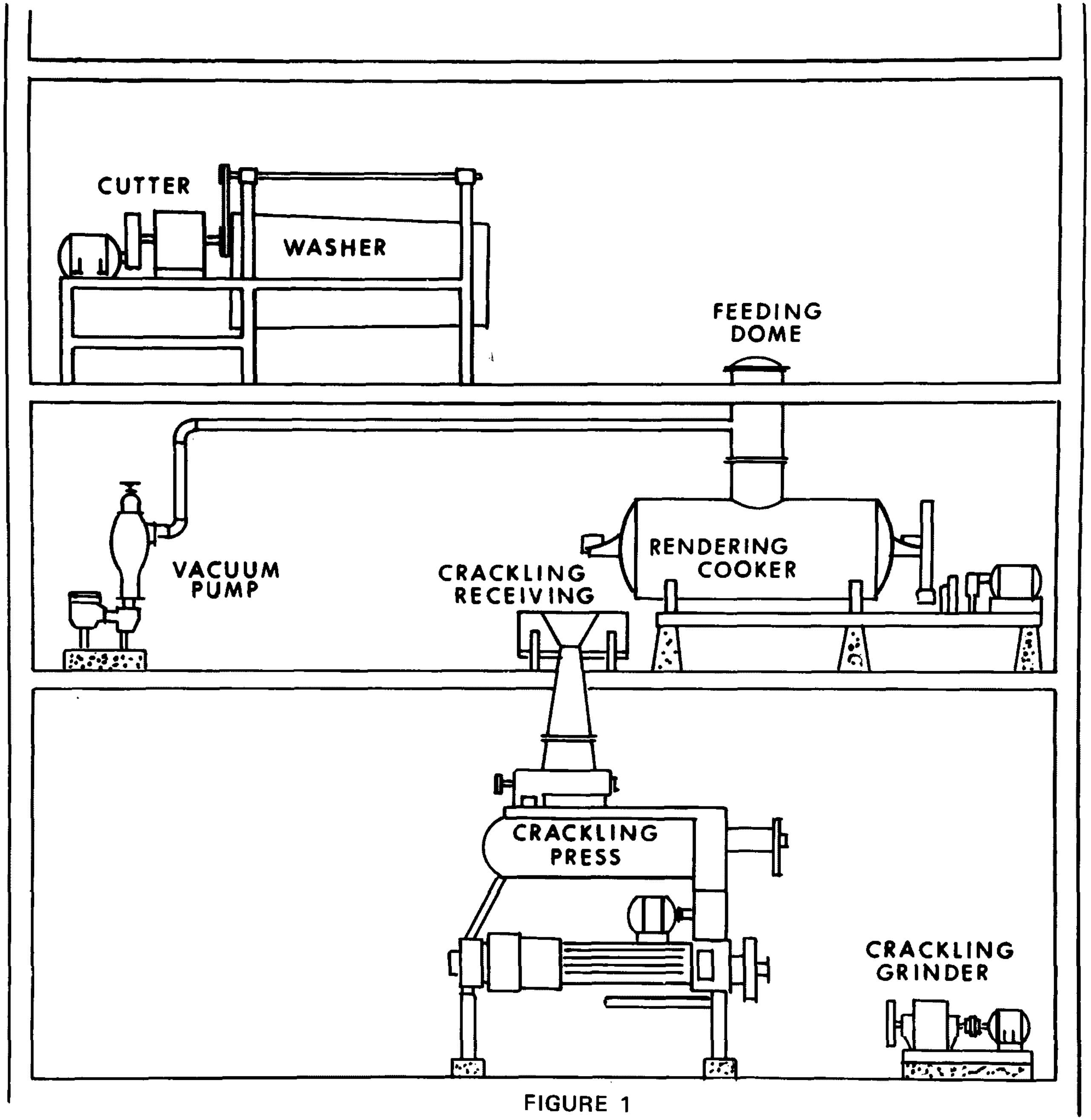


FIGURE 1

DRY RENDERING OPERATION

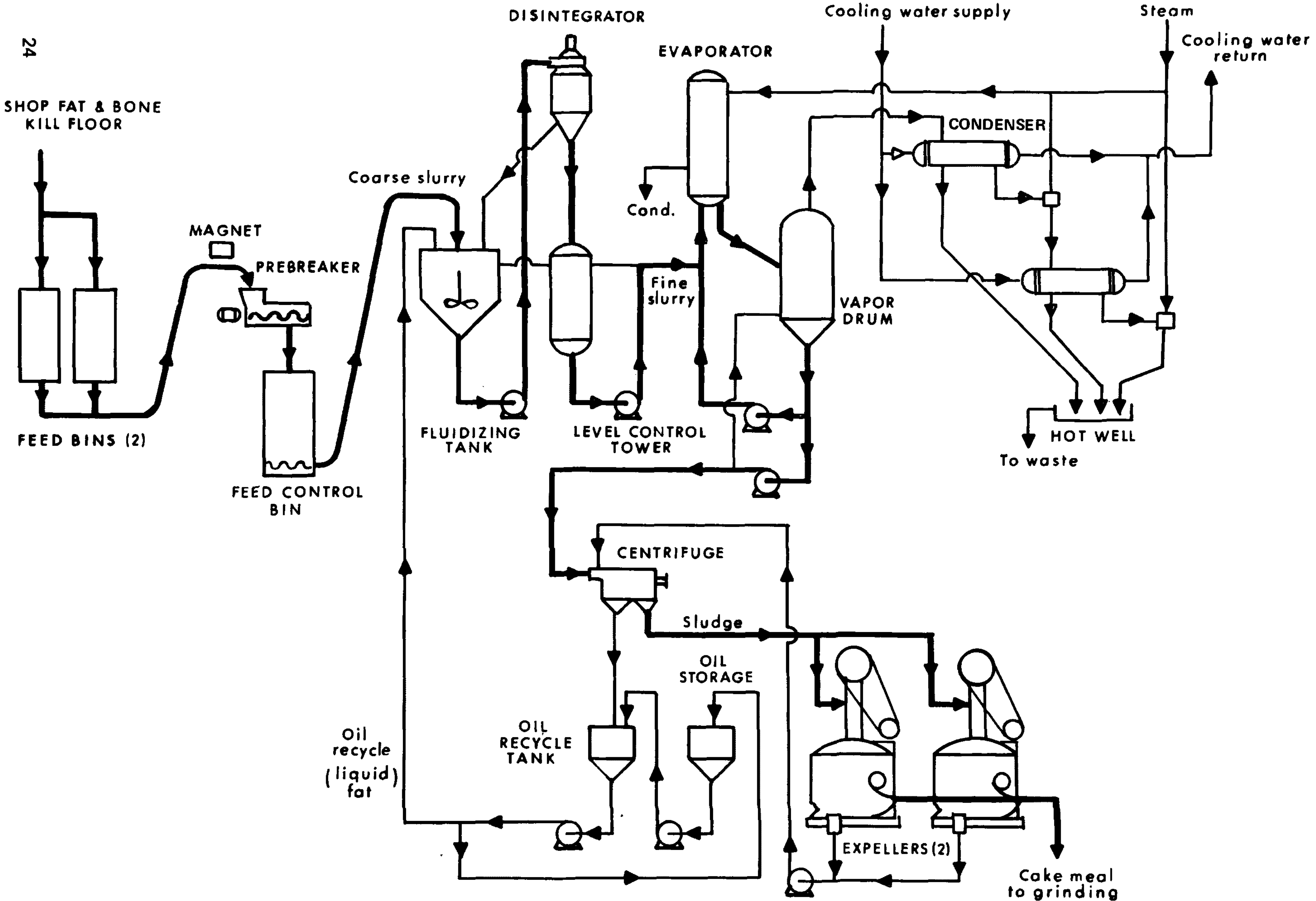


FIGURE 2

CONTINUOUS RENDERING FLOW SCHEME

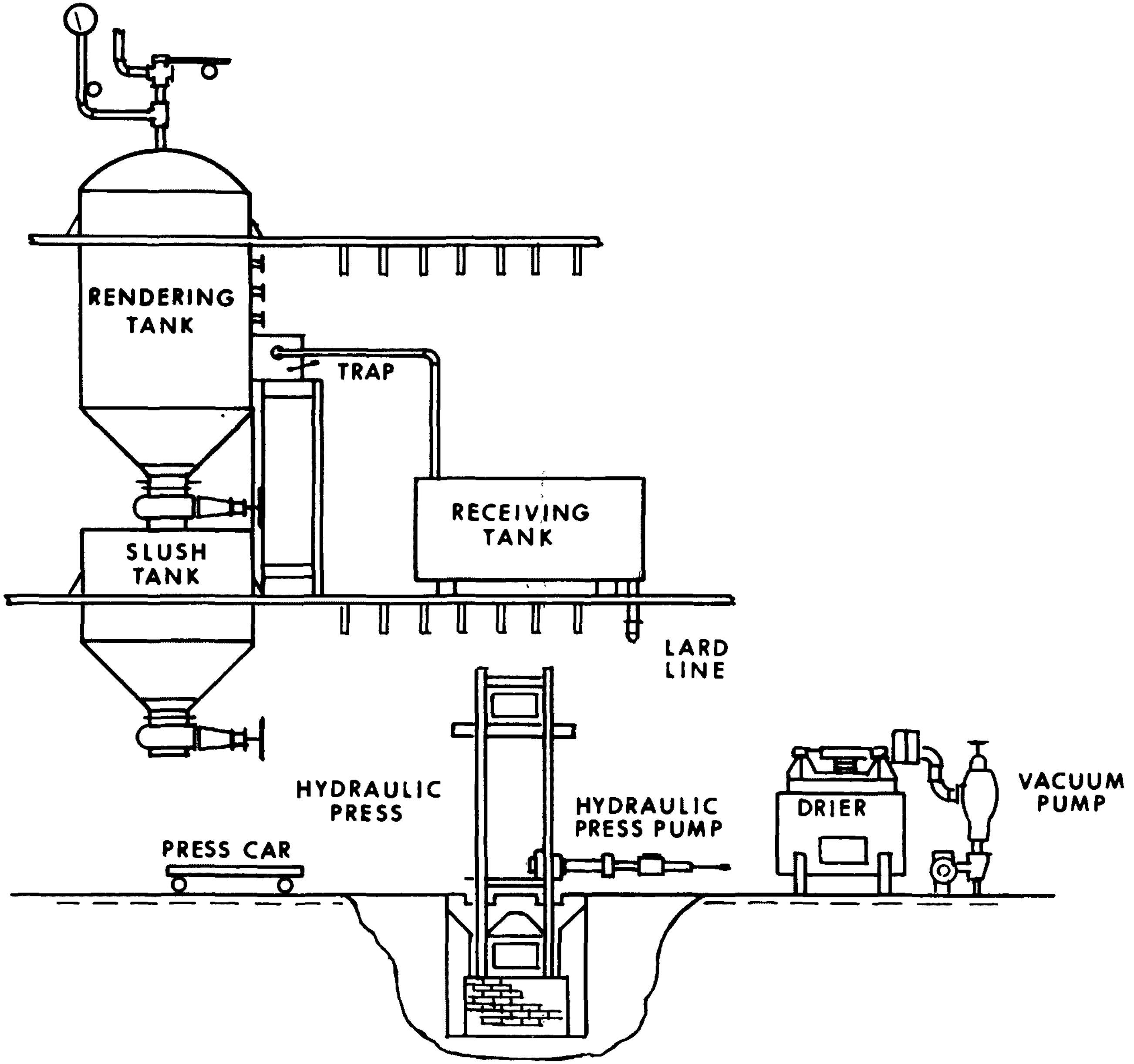


FIGURE 3

WET RENDERING OPERATION

NATURE OF THE GASEOUS DISCHARGE

A typical dry rendering reaction will reduce the moisture content of the animal matter from 60 to 70% down to 9%. For a 5000 lb batch size, this is equivalent to removing 2800 lb of moisture as a vapor. Rates of vapor evolution for this batch size have been reported(5) to vary from 40,000 ACFH during the initial minutes at temperature to 20,000 ACFH during the rest of the reaction. Both rates were measured at 212°F. Further measurement indicated that 5% of this vapor was non-condensable.(5)

Very little analytical work has been done on the vapors evolved during rendering. Roland's(9) work gives some indication of the kinds of compounds involved and why the associated odors cause so many complaints. His analysis of the condensate from dry rendering vapors is reproduced in Table 10. These data clearly show that the bad reputation of these vapors is well deserved and that rendering stale materials augments the problem.

Although the cooker is the worst odor producer in rendering operations, odors are emitted from several other sources and are caused by different classes of compounds. Several of these sources are listed in Table 11 along with a qualitative indication of the odor causing compounds.

Odors from rendering are emitted in high concentrations. Table12 summarizes odor concentrations and emission rates from some typical rendering operations. The data in the table are expressed in "odor units". One odor unit per cubic foot is that concentration of odor which is numerically equivalent to its odor threshold. A level of 5000 odor units per cubic foot would require 5000 dilutions with clean air to make it just detectable. As shown in the table, rendering can emit gases with odor concentrations as high as one million o.u./SCF at a rate of almost four billion odor units per ton of feed. The wide range of odor concentrations exists due to variability in process severity, type of charge material, and age of charge material.

POLLUTION CONTROL CONSIDERATIONS

Gases discharged from rendering operations originate from three main sources:

1. Exhausts from cookers or similar process equipment
2. Ventilation of other equipment
3. Ventilation of storage areas

TABLE 10

ANALYSIS OF CONDENSATE FROM THE DRY RENDERING OF FLESH IN FRESH AND STALE CONDITIONS(9)

	Percent of Original Flesh	
	Fresh Flesh	Stale Flesh
Water	62.75	67.04
Ammonia and monoethylamine	0.0329	0.3913
Diethylamine	Traces	0.0133
Triethylamine	Traces	0.0236
Hydrogen Sulphide	0.0027	0.0024
Carbon Dioxide	0.0133	0.0664
Oil (nonvolatile at 100° C.)	–	0.0436
Other Nonvolatile Organic Matter	0.0045	0.0226
Biochemical Oxygen Demand (ppm)	158	134
Oxygen Absorbed, (ppm) 3 min.	61.5	244

TABLE 11

SOURCES OF ODOR IN RENDERING PLANTS

Source	Compound Class Causing Odor
Dry Cooker Vapors	Amines, aldehydes
Vapor Leaks From Cookers	Aldehydes, fats, amines
Hot Fat Dumping	Fats, fatty acids
Feather Driers	Sulfides
Feather Meal Dumping	Mercaptans
Loading Docks	Fats, fatty acids

TABLE 12

ODOR CONCENTRATIONS AND EMISSION RATES FROM INEDIBLE REDUCTION PROCESSES[4]

	Odor Concentration, Odor Units/SCF				
	Range	Typical Average	Typical Moisture Content of Feeding Stocks, %	Exhaust Products, SCF/ton of feed[a]	Modal Emission rate, odor units/ ton of feed
Rendering cooker, dry-batch type[b]	5,000 to 500,000	50,000	50	20,000	$1{,}000 \times 10^6$
Blood cooker dry-batch type[b]	10,000 to 1 million	100,000	90	38,000	$3{,}800 \times 10^6$
Feather drier, steamtube[c]	600 to 25,000	2,000	50	77,000	153×10^6
Blood spray drier[c, d]	600 to 1,000	800	60	100,000	80×10^6

a) Assuming 5% moisture in solid products.

b) Non-condensible gases are neglected in determining emission rates.

c) Exhaust gases are assumed to contain 25% moisture.

d) Blood handled in spray drier before any appreciable decomposition occurs.

Exhausts from process equipment vary widely with the charge, the process step involved, and as indicated earlier, with time over any batch. The two principal pieces of equipment which emit exhaust gases are the cooker and the air drier used primarily for cooked feathers.

Exhaust rates from cookers can be estimated from the quantity of moisture to be removed from the charge. Average rates can be calculated from the cycle time and the moisture contents of feed and product. As indicated earlier the specific rate of emission at any one time varies widely during the process cycle. The maximum rate is normally twice the average.(4) For example, if 5000 lb of material is processed with a reduction in moisture content from 65% to 9% over four hours, 2800 lb of moisture will be removed at an average rate of 700 lb/hr. The maximum rate will be 1400 lb/hr. Expressed in volumetric terms the maximum rate is 31,000 SCFH, assuming 5% noncondensibles in the gas. Evaporation rates rise to a maximum early in the cook and decline thereafter following the pattern shown in Figure 4. Emission rates from continuous processes can be estimated from throughput rates and feed and product analyses. Emission rates from batch blood cookers are lower due to longer processing times. They seldom exceed 500 ACFM and are usually lower.(4)

Feather driers are run continuously to produce an exhaust gas containing 10 to 30% moisture and a cooked-feathers product containing 5% moisture.(4) If such a drier processed 1000 lb/hr of cooked feathers containing 50% moisture, it would exhaust 555 ACFM of gas at 30% moisture.

Ventilation of other equipment and storage areas is handled in three different ways in the rendering industry. These three styles of ventilation produce a wide range in the quantity of odorous air emitted from rendering plants. Older plants ventilate the storage rooms and the rooms in which the equipment operates. Ventilation consists of drawing room air out through the ceiling or walls while replacing it with fresh air which flows in through other openings. Ventilation in this way uses large quantities of air which, when exhausted, is contaminated with odors.

Newer plants use hoods over some of their equipment such as charge grinders, expellers, and fat separating plates. Hooding in this way can also cause large quantities of odorous air to be exhausted. Velocities of 100 fpm at the hood are common for this service.(4) The amount of ventilation air exhausted by either this or the previous style of ventilation can easily exceed the amount of gas exhausted from the cooker.

The most modern rendering plants have designed their ventilation systems with the criterion of minimizing the air exhaust rate from the plant. These designs involve closed hooding of process equipment and tightly closed dead stock storage areas.

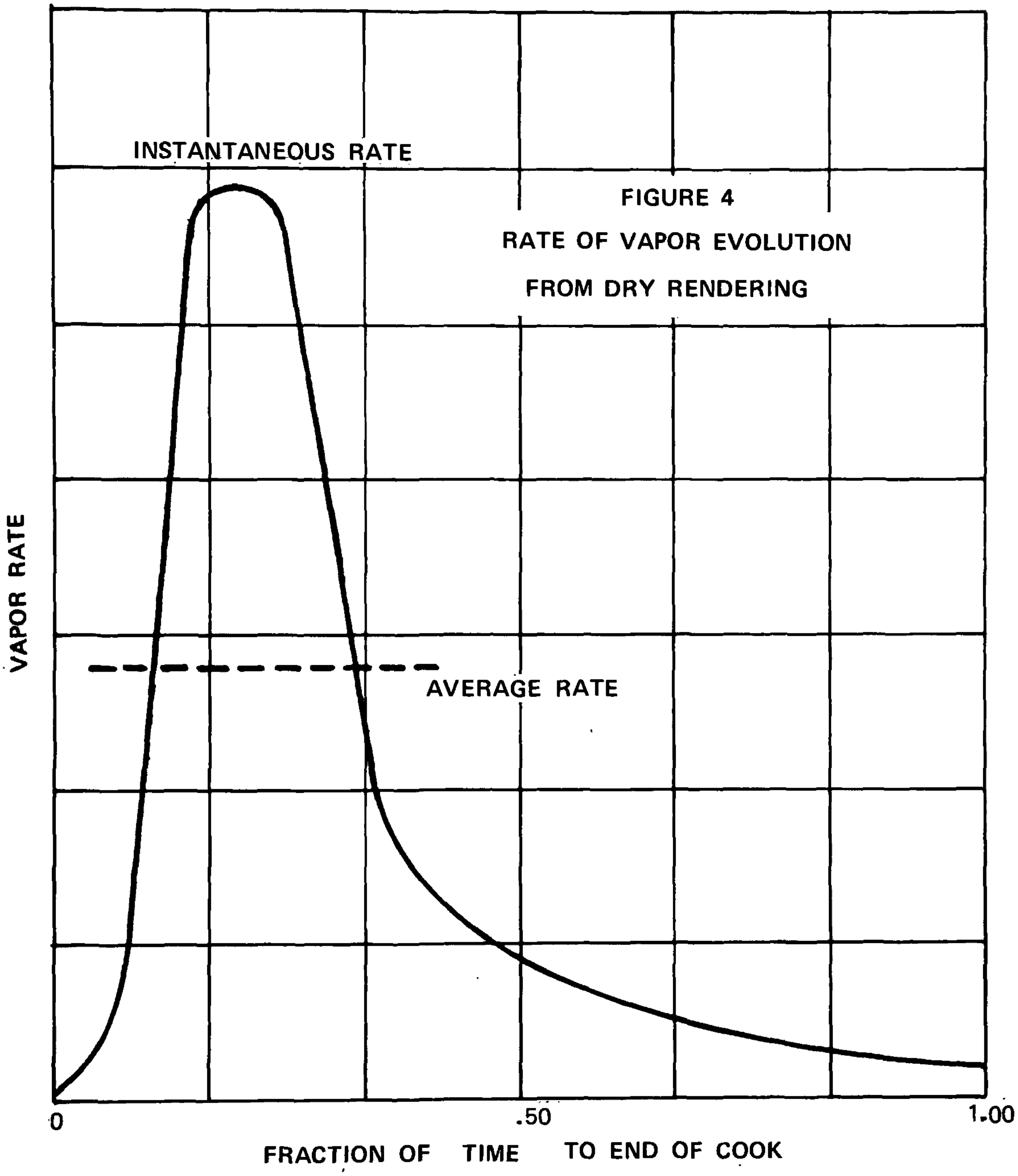


FIGURE 4

RATE OF VAPOR EVOLUTION

FROM DRY RENDERING

Because the emission problem is basically limited to odors, the pollution control systems of interest are:

1. Condensation
2. Incineration
3. Absorption
4. Adsorption

In rendering processes using solvents either for processing or product extraction, solvent loss is also an emission problem and its recovery is desirable from both environmental and economical viewpoints.

The major component of vapors from the cooker is steam. Reduction in the volume of this gas through condensation is often advisable in view of the attendant reduction in odor and the reduction in the size of subsequent equipment.

Several types of condensers have been successfully employed in rendering plants. These include contact condensers and surface condensers, both air and water cooled. Reductions in gas volume by a factor of 10 to 20 are common due to the high moisture content of the exhaust gas. Odor reductions due to condensation are high but are often insufficient to eliminate the problem by themselves. Typical reductions of odor emission rates are 50% for a surface condenser and 99% for a contact condenser. Although contact condensers are inexpensive to install, they require large quantities of once-through cooling water. Cooling water requirements range from 15 to 20 pounds per pound of steam condensed.(4) This may overload sewage systems or create water pollution problems as the used water contains dissolved odor compounds. Surface condensers can be installed at a cost of about 50% more than contact condensers, but operating charges will be 65 to 80% less due primarily to far lower water requirements.

One source(5) reports comparative costs for surface and contact condensers sized to handle a maximum flow of 40,000 ACFH and an average flow of 20,000 ACFH. The contact condenser installed cost was $2000 compared to $5050 for a water cooled surface condenser. The contact condenser used only one-third as much electricity (1½ hp vs. 4½ hp) but required 28½ times as much water (2000 GPH vs. 70 GPH). The net result was that the surface condenser operating cost was 78% less than the contact condenser.

Materials of construction for surface condensers can be a problem. Both acidic and alkaline vapors are possible. Rendering of dead stock can produce both during each cycle. Heavy gauge mild steel or stainless steel may be required, depending upon the specific wastes processed.

Incineration

The most positive control method for odors is incineration. The Los Angeles Air Pollution Control District uses this method as a standard, and in Rule 64 states that any alternative method used must be equal or better than direct flame incineration at 1200° F for a period of not less than 0.3 sec.

Incinerators are seldom used directly on gas streams from rendering due to the high moisture content of these gases. More often they are used after condensers which reduce the moisture content of the gas discharged to the incinerator so as to reduce fuel cost. The break-even point between direct incineration of the total exhaust stream and combination condensation-incineration lies between 15% and 40% moisture content of the exhaust gas, depending upon gas volume and exit temperature, fuel cost, water cost and availability, and equipment costs.(4)

Odor removal efficiencies for combined condenser-incinerator systems are shown in Table 13 compared to the performance of condensers alone. The data are based upon a typical exhaust gas from a hypothetical cooker. The gas is emitted at 500 SCFM and is 95% condensible. Odor removal efficiencies in excess of 99.9% are shown for combined systems employing either surface or contact condensers.

Incineration is an expensive abatement process due to its high operating temperatures. Operation at 1200° F is the standard and temperatures as high as 2000° F have been reported for units processing rendering gases(8). Fuel costs increase with the temperature requirements for odor control.

Catalytic incineration can reduce the operating cost of odor control relative to thermal incineration through reduced operating temperatures. Operating temperature reductions of more than 400° F have been reported using currently available catalytic equipment(8). The drawbacks to catalytic incineration are the much higher capital and maintenance costs of the equipment. This is due to the large quantity of catalyst necessary to achieve the high efficiencies required at the low combustible concentrations as well as the catalyst regeneration costs due to the decline in activity during use. Justification of a catalytic unit therefore must be based upon the difference in operating versus the capital and maintenance costs.

Absorption

Absorption has also been used to some extent to control rendering plant odors. The most common system employs a wet scrubber with air oxidizing chemical such as potassium permanganate in the scrubbing liquor. The solution is used in concentrations below 5% and is buffered to an alkaline pH. Odor compounds are oxidized by the permanganate leaving a manganese dioxide solid residue in the scrubbing system. Periodic washing is required to remove these deposits.

Experiments have been run demonstrating the odor control potential of the system for the types of odors emitted by rendering processes and several commercial installations are in operation.(11, 12)

Where low odor removal efficiency is acceptable, sodium hydroxide solution can be used in place of the permanganate solution. A pH of 10 in the circulating liquor has been found to be effective where odor removal requirements are not high. A sodium hydroxide scrubbing stage can also be used as a pretreatment step to a permanganate scrubber or a carbon bed in cases where the odor removal efficiency required is high. Other oxidation reagents such as chlorine and sodium hypochloride may also be used.

Adsorption

Adsorption systems have been used to control odors from rendering operations. There are however several limitations to their use.

1. The adsorbent material is restricted to activated carbon because of the high moisture content of the gases present.

2. The adsorption capacity of the activated carbon is low at temperatures above 120° F. Gases must therefore be cooled prior to entering the bed.

3. Regeneration cycles may be short. This is due to the high odor concentrations in rendering gases and to the tendency of light but smelly compounds such as NH_3 and H_2S to be easily desorbed as heavier compounds adsorb.

4. A means must exist for destruction of the odor compounds given off during regeneration or the carbon must be used once through.

Within these limitations, activated carbon can deodorize rendering gases. Adsorption capacities have been reported at 0.10 to 0.25 lb adsorbate per pound of carbon. The performance is as good as incineration. Several commercial installations have been reported.(5, 10) In each case the carbon bed is used in combination with a condenser to cool the gases (see Figure 5). Although numerical performance data were not reported, the gases treated were characterized as acceptable in odor concentration.

TABLE 13

ODOR REMOVAL EFFICIENCIES FOR CONDENSERS AND CONDENSER-INCINERATOR COMBINATIONS[4]

Odors from Cooker					Odors from Control System*		
Concentration, Odor Units/SCF	Emission rate, odor units/min	Condenser Type	Condensate Temp., ° F	Afterburner Temp., ° F	Concentration, Odor Units/SCF	Modal Emission rate, Odor Units/min	Odor Removal Efficiency, %
50,000	*25,000,000*	*None*	–	*1,200*	*100 to 150*	*90,000*	*99.40*
		Surface	80	None	100,000 to 10 million (Mode 500,000)	12,500,000	50
		Surface	140	1,200	50 to 100 (Mode 75)	6,000	99.98
		Contact	80	None	2,000 to 20,000 (Mode 10,000)	250,000	99
		Contact	140	1,200	20 to 50 (Mode 25)	2,000	99.99

*Based on a hypothetical cooker that emits 500 SCFM of vapor containing 5 percent noncondensable gases.

No matter what kind of primary control device is used, it should be designed with an intercepter tank between the cooker and the control equipment. It is common during rendering for the cooker vent to plug momentarily. When that plug breaks, a pressure surge carries solids and liquids out the vent. Unless provision is made to catch the material carried over, it can seriously impair performance of the control equipment.

Effective odor control in rendering requires control of many sources. Control of only the process gases, no matter how efficient, will not be effective due to odor emissions from the room ventilators and equipment hoods. Since these odors are emitted in such high concentrations, all sources of odor must be identified and treated.

SPECIFICATIONS AND COSTS

Incinerator and scrubber specifications have been written for each of three services at a batch rendering plant. The three services are:

1. Cooker vent gas combined with gas from expeller and charge grinder hoods

2. Room ventilation gases

3. The above two services combined.

Each specification was written on the basis of a gas rate rather than a plant size. This was done because of the wide range of gas flow rates which can occur in rendering plants of comparable production rates, as was explained earlier in the section titled Pollution Control Considerations. Specifications were written in such a way that the cost information generated from them covers the relevant range of gas flow rates. Each scrubber specification requests bids for both high and low efficiency at each of two gas rates. Each incinerator specification shows data for both high and low efficiency but requests only one quote for each gas rate coupled with a representation of the performance level which will be achieved. The complete specifications are shown in Tables 14 thru 19 and 26 thru 31.

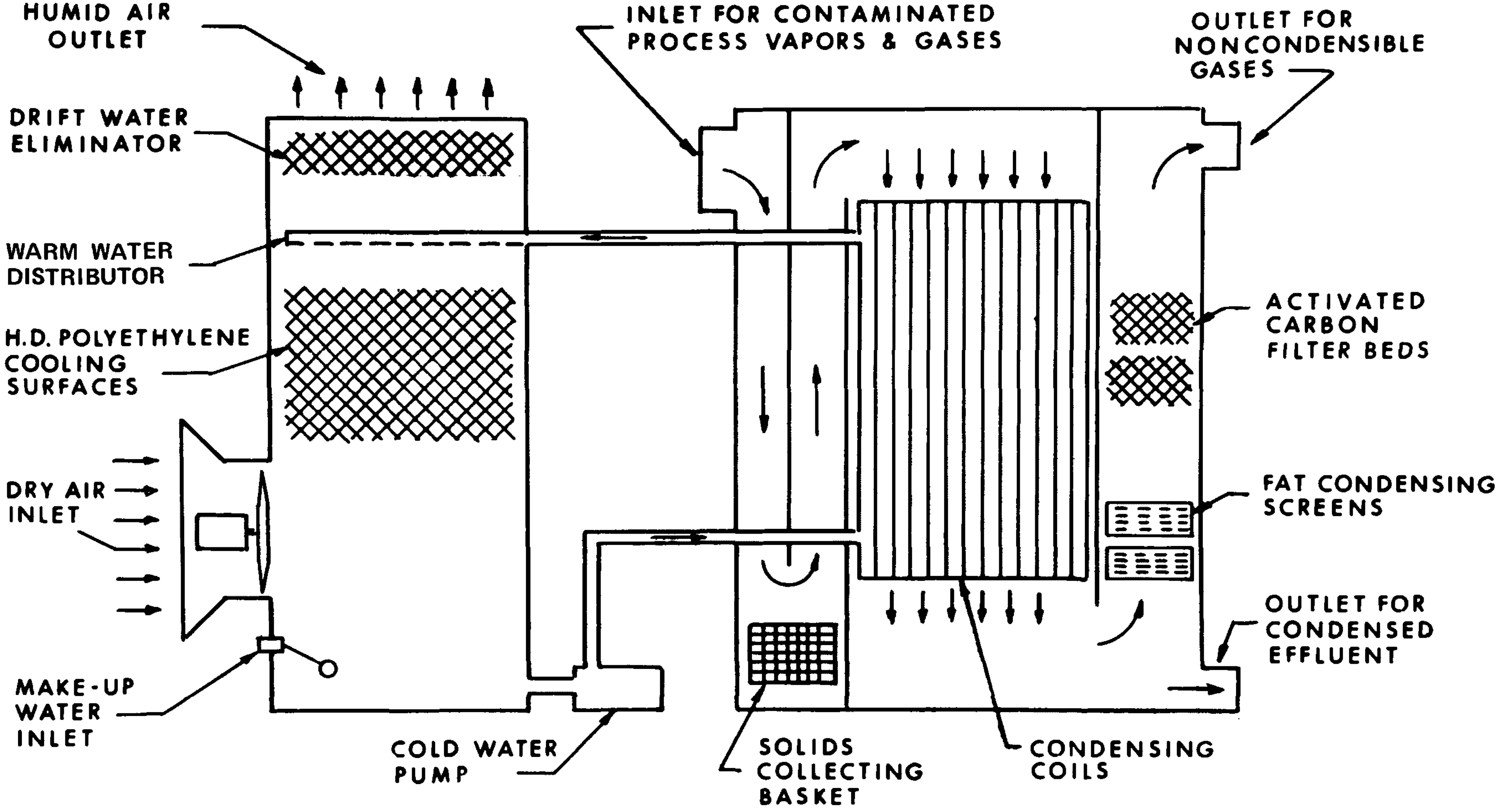


FIGURE 5

ACTIVATED CARBON DEODORIZER INTEGRATED WITH SOLIDS COLLECTOR AND CONDENSER

Capital cost data for scrubbers are presented on six graphs which show the relationship between cost and gas flow rate through the unit. Figures 6 and 7 show the cost of the scrubbers only. Figures 8 and 9 show the cost of the scrubbers plus auxiliaries such as fans, pumps, drives, solids disposal equipment, etc. Figures 10 and 11 show the cost of the turnkey scrubbing systems. The first figure in each pair presents data for the medium efficiency case while the second shows data for high efficiency performance. The data presented are the averages of either two or three bids. Statistical confidence limits were calculated for the quotes of the scrubbing device alone. The results for the medium efficiency case are presented in Figure 12. Those for high efficiency are presented in Figure 13. The calculations were made based upon the assumption that the quotations came from a population of twenty potential suppliers.

Annual operating costs for both levels of efficiency are presented in Figure 14. In all cases, the chemical usage represents more than 95% of the total annual charges. Two of the bidders quoted chemical systems other than the specified potassium permanganate solution buffered with borax. One supplier quoted a dissolved chlorine system for the room vent scrubbers. Another supplier quoted a two stage system; a sodium hydroxide stage followed by a potassium permanganate stage. At medium efficiency, the permanganate stage was not used. Chemical usage costs for each of these alternatives were much lower than those quoted for the specified system. These numbers were not included in the averages presented either on the tables or the graphs.

Capital cost data for incinerators are presented on three graphs which relate cost to gas flow rate. Figure 15 shows the cost of the incinerator only. Figure 16 shows the incinerator plus auxiliaries, such as the fan and fan drive. Figure 17 shows the cost of the complete turnkey system. Confidence limit calculations, similar to those made for scrubbers, were made for the incinerators alone and for the turnkey price of the incineration systems. Results of these calculations are presented in Figures 18 and 19.

Annual operating cost data for the incineration systems are shown in Figure 20.

TABLE 14

SCRUBBER PROCESS DESCRIPTION FOR RENDERING COOKERS AND HOODS SPECIFICATION

PROCESS DESCRIPTION

The scrubber is to deodorize exhaust gases from the cooker and the hoods over the charge grinders and expellers in a dry rendering plant. The plant is operated batchwise. The time required in the cooker for each batch is three hours. Since two or three batches will be run each day, the scrubber will be in use for 8 to 12 hours daily. Cooker exhaust gases are sent through the plant wall to a 30 ft stack located outside the building. Hood ventilation is exhausted on the roof at a height of 20 ft. A 30 ft square area is available for new equipment next to the location of the stack. A four inch concrete slab covers the area. Sufficient electric power and fresh water are available at the site. The sewer is available and will accept water in the 4 to 10 pH range, if it contains less than 1 wt. % solids content.

The scrubbing liquor is to consist of a 3 wt. % solution of potassium permanganate buffered to 9.0 pH with borax. Materials of construction should be consistent not only with the permanganate solution but also the possibility of both acidic and basic gases coming from the cooker. Bids should include the following:

1. *Low energy wet scrubber and mist eliminator.*
2. *Necessary fans and motors. Fans should operate at less than 2,000 rpm.*
3. *20 ft stack.*
4. *Recirculating tank.*
5. *Permanganate makeup and storage tank.*
6. *Inter connecting ductwork for all equipment furnished.*
7. *Appropriate control system.*
8. *Necessary provisions for periodic cleaning of manganese dioxide residue.*

All of the above, except the scrubber proper, should be treated as auxiliaries.

Each bidder will submit four separate and independent quotations; one for each of two efficiency levels at each of two plant sizes.

TABLE 15

SCRUBBER OPERATING CONDITIONS

FOR RENDERING COOKERS AND HOODS SPECIFICATION

OPERATING CONDITIONS

	SMALL		*LARGE*	
	AVE.	*MAX.*	*AVE.*	*MAX.*
Cooker				
Gas Rate, ACFM	*283*	*567*	*850*	*1,700*
Gas Temp., °F	*212*		*212*	
Odor Concentration, o.u./SCF	*150,000*		*150,000*	
Odor Emission Rate, o.u./min	32.9×10^6	65.8×10^6	98.6×10^6	197.2×10^6
Expeller and Grinder Hoods				
Gas Rate, ACFM	*2,000*		*5,000*	
Gas Temp., °F	*100*		*100*	
o.u./SCF	*90,000*		*90,000*	
o.u./min	167×10^6		418×10^6	
Combined Gases				
Gas Rate, ACFM	*2,600*		*6,750*	
Gas Temp., °F	*130*		*130*	
o.u./SCF	*102,000*		*103,000*	
o.u./min	233×10^6		615×10^6	
Low Efficiency Case				
o.u./SCF @ Ground	*8 **		*8 **	
% Removal	*45*		*46*	
High Efficiency Case				
o.u./SCF @ Ground	*< 1 **		*< 1 **	
% Removal	*93*		*93*	

30 min average as calculated by Bosenquet-Pearson and Bosenquet-Carey-Halton.

TABLE 16

SCRUBBER PROCESS DESCRIPTION
FOR RENDERING ROOM VENTS

SPECIFICATION

PROCESS DESCRIPTION

The scrubber is to deodorize room ventilation gases from a dry rendering plant. The plant is operated batchwise. The time required in the cooker for each batch is three hours. Since two or three batches will be run each day, the scrubber will be in use for 8 to 12 hours daily. Ventilation air from the feed storage area is currently exhausted through the roof at a height of 20 ft. Cooker gases are sent to a 30 ft stack located outside the building. A 30 ft square area is available for new equipment next to the location of the stack. A four inch concrete slab covers the area. Sufficient electric power and fresh water are available at the site. A sewer is available and will accept water in the 4 to 10 pH range, if it contains less than 1 wt. % solids content.

The scrubbing liquor is to consist of a 3 wt. % solution of potassium permanganate buffered to 9.0 pH with borax. Bids should include the following:

1. *Low energy wet scrubber and mist eliminator.*
2. *Necessary fans and motors. Fans should operate at less than 2,000 rpm.*
3. *30 ft stack.*
4. *Recirculating tank.*
5. *Permanganate makeup and storage tank.*
6. *Inter connecting ductwork for all equipment furnished.*
7. *Appropriate control system.*
8. *Necessary provisions for periodic cleaning of manganese dioxide residue.*

All of the above, except the scrubber proper, should be treated as auxiliaries.

Each bidder will submit four separate and independent quotations; one for each of two efficiency levels at each of two plant sizes.

TABLE 17

SCRUBBER OPERATING CONDITIONS FOR RENDERING ROOM VENTS

SPECIFICATION

OPERATING CONDITIONS

	SMALL	*LARGE*
Room Ventilation		
Effluent Gas Rate, ACFM	*3,000*	*14,000*
Effluent Gas Temp., °F	*90*	*90*
Odor Concentration, o.u./SCF	*100,000*	*100,000*
Odor Emission Rate, o.u./min	284×10^6	$1{,}320 \times 10^6$
Low Efficiency Case		
Concentration @ Ground, o.u./SCF	*8 **	*8 **
% Odor Removal	*44*	*44*
High Efficiency Case		
Concentration @ Ground, o.u./SCF	*< 1 **	*< 1 **
% Odor Removal	*93*	*93*

**30 min average as calculated by Bosenquet-Pearson and Bosenquet-Carey-Halton.*

TABLE 18

SCRUBBER PROCESS DESCRIPTION

FOR COMBINED RENDERING VENTS

SPECIFICATION

PROCESS DESCRIPTION

The scrubber is to deodorize the total gases emitted from a dry rendering plant. The plant is operated batchwise. The time required in the cooker for each batch is three hours. Since two or three batches will be run each day, the scrubber will be in use for 8 to 12 hours daily.

Ventilation air from the hoods and storage area is currently exhausted through the roof at a height of 20 ft. Cooker gases are sent to a 30 ft stack located outside the building. A 30 ft square area is available for new equipment next to the location of the stack. A four inch concrete slab covers the area. Sufficient electric power and fresh water are available at the site. The sewer is available and will accept water in the 4 to 10 pH range, if it contains less than 1 wt. % solids content.

The scrubbing liquor is to consist of a 3 wt. % solution of potassium permanganate buffered to 9.0 pH with borax. Bids should include the following:

1. *Low energy wet scrubber and mist eliminator.*
2. *Necessary fans and motors. Fans should operate at less than 2,000 rpm.*
3. *30 ft stack.*
4. *Recirculating tank.*
5. *Permanganate makeup and storage tank.*
6. *Inter connecting ductwork for all equipment furnished.*
7. *Appropriate control system.*
8. *Necessary provisions for periodic cleaning of manganese dioxide residue.*

All of the above, except the scrubber proper, should be treated as auxiliaries.

Each bidder will submit four separate and independent quotations; one for each of two efficiency levels at each of two plant sizes.

TABLE 19

SCRUBBER OPERATING CONDITIONS FOR COMBINED RENDERING VENTS

SPECIFICATION

OPERATING CONDITIONS

	SMALL	*LARGE*
Total Gas Stream		
Effluent Gas Rate, ACFM	*5,620*	*21,400*
Effluent Gas Temp., °F	*110*	*120*
Odor Concentration, o.u./SCF	*101,000*	*101,000*
Odor Emission Rate, o.u./min	517×10^6	$1{,}935 \times 10^6$
Low Efficiency Case		
Concentration @ Ground o.u./SCF	*8 **	*8 **
% Odor Removal	*45*	*45*
High Efficiency Case		
Concentration @ Ground o.u./SCF	*< 1 **	*< 1 **
% Odor Removal	*93*	*93*

**30 minute averages as calculated by Bosenquet-Pearson and Bosenquet-Carey-Halton.*

TABLE 20

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR WET SCRUBBERS FOR

RENDERING COOKERS AND HOODS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	2,600	6,750	2,600	6,750
°F	130	130	130	130
SCFM	2,340	6,060	2,340	6,060
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF				
lb/hr				
Cleaned Gas Flow				
ACFM	2,510	6,500	2,510	6,500
°F	103	103	103	103
SCFM	2,370	6,150	2,370	6,150
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr				
Cleaning Efficiency, %	45	46	93	93
(1) Gas Cleaning Device Cost	2,000	3,125	2,778	4,525
(2) Auxiliaries Cost				
(a) Fan(s)	825	925	825	1,025
(b) Pump(s)	1,600	1,700	1,750	1,950
(c) Damper(s)	250	250	250	250
(d) Conditioning, Equipment	3,630	4,180	3,630	4,180
(e) Dust Disposal Equipment	2,050	2,725	2,075	2,725
(3) Installation Cost (a) Engineering (b) Foundations & Support (c) Ductwork (d) Stack (e) Electrical (f) Piping (g) Insulation (h) Painting (i) Supervision (j) Startup (k) Performance Test (l) Other	8,305	11,155	8,757	11,855
(4) Total Cost	18,660	24,060	20,065	26,510

TABLE 21

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR WET SCRUBBERS FOR RENDERING COOKERS AND HOODS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$6/hr	2,512	2,625	2,512	2,625
Supervisor	$8/hr	27	38	27	38
Total Operating Labor		2,539	2,663	2,539	2,663
Maintenance					
Labor					
Materials					
Total Maintenance		1,650	1,750	1,700	1,800
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.011/kw-hr	300	490	362	554
Fuel		-	-	-	-
Water (Process)	$0.25/M gal	122	289	122	289
Water (Cooling)		-	-	-	-
Chemicals, Specify *$KMnO_4$	$0.38/lb	114,900	269,040	172,368	410,400
Borax	$0.0625/lb	101,250	243,000	101,250	243,000
Total Utilities		216,572	512,819	274,102	654,243
Total Direct Cost		220,761	517,232	278,341	658,706
Annualized Capital Charges		1,866	2,406	2,006	2,651
Total Annual Cost		222,627	519,638	280,347	661,357

* Not all quotes used this system of chemicals. Based on only one chemical cost quote.

TABLE 22

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR WET SCRUBBERS FOR RENDERING ROOM VENTS *

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	3,000	14,000	3,000	14,000
°F	90	90	90	90
SCFM	2,890	13,500	2,890	13,500
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF				
lb/hr				
Cleaned Gas Flow				
ACFM	2,950	13,800	2,950	13,800
°F	75	75	75	75
SCFM	2,920	13,700	2,920	13,700
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr				
Cleaning Efficiency, %	44	44	93	93
(1) Gas Cleaning Device Cost	2,487	5,453	3,005	6,707
(2) Auxiliaries Cost				
(a) Fan(s)	949	1,769	982	1,948
(b) Pump(s)	1,250	1,417	1,350	1,583
(c) Damper(s)	244	311	244	310
(d) Conditioning, Equipment	3,190	3,757	3,191	3,757
(e) Dust Disposal Equipment	633	1,400	650	1,433
(3) Installation Cost	9,801	14,555	10,068	15,359
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	18,554	28,662	19,490	31,097

*Based on two bids

TABLE 23

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR WET SCRUBBERS FOR RENDERING ROOM VENTS*

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$6/hr	1,745	1,840	1,745	1,840
Supervisor	$8/hr	23	30	23	30
Total Operating Labor		1,768	1,870	1,768	1,870
Maintenance					
Labor					
Materials					
Total Maintenance		1,100	1,200	1,117	1,268
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.011/kw-Hr	322	1,026	366	1,256
Fuel		-	-	-	-
Water (Process)	$.25/M gal	168	738	168	738
Water (Cooling)		-	-	-	-
Chemicals, Specify ** KMn0$_4$	$.38/lb	123,200	541,728	184,680	820,000
Borax	$.0625/lb	111,375	500,000	111,375	500,000
Total Utilities		235,065	1,043,492	296,589	1,321,994
Total Direct Cost		237,933	1,046,562	299,474	1,325,132
Annualized Capital Charges		1,502	2,533	1,595	2,774
Total Annual Cost		239,435	1,049,095	301,069	1,327,906

* Based on two bids.

** Not all quotes used this system of chemicals. Based on one quote.

TABLE 24

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR WET SCRUBBERS

FOR RENDERING COMBINED VENTS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	5,620	21,400	5,620	21,400
°F	110	120	110	120
SCFM	5,230	19,600	5,230	19,600
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF				
lb/hr				
Cleaned Gas Flow				
ACFM	5,400	20,500	5,400	20,500
°F	83	83	83	83
SCFM	5,280	20,000	5,280	20,000
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr				
Cleaning Efficiency, %	45	45	93	93
(1) Gas Cleaning Device Cost	2,730	6,425	3,922	9,100
(2) Auxiliaries Cost				
(a) Fan(s)	925	2,350	925	2,800
(b) Pump(s)	1,725	2,000	1,950	2,450
(c) Damper(s)	250	250	250	250
(d) Conditioning, Equipment	5,330	5,380	5,330	5,380
(e) Dust Disposal Equipment	1,130	2,400	1,175	2,600
(3) Installation Cost	10,440	19,155	11,103	20,830
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	22,530	37,960	24,655	43,410

TABLE 25

ANNUAL OPERATING COST DATA
(COSTS IN \$/YEAR)

FOR WET SCRUBBERS FOR RENDERING COMBINED VENTS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	\$6/hr	2,400	2,700	2,400	2,700
Supervisor	\$8/hr	15	45	15	45
Total Operating Labor		2,415	2,745	2,415	2,745
Maintenance					
Labor					
Materials					
Total Maintenance		1,725	1,900	1,750	2,000
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	\$.011/kw-hr	445	1,164	562	1,495
Fuel		-	-	-	-
Water (Process)	\$.25/M gal	229	824	229	824
Water (Cooling)		-	-	-	-
Chemicals, Specify *KMnO$_4$	\$.38/lb	215,870	820,800	328,320	1,231,200
Borax	\$.0625/lb	195,750	742,500	195,750	742,500
Total Utilities		412,294	1,565,288	624,861	1,976,019
Total Direct Cost		416,434	1,569,933	629,026	1,980,764
Annualized Capital Charges		2,253	3,796	2,466	4,341
Total Annual Cost		418,687	1,573,729	631,492	1,985,105

* Not all quotes used this system of chemicals. Based on one quote.

FIGURE 6

CAPITAL COST OF MEDIUM EFFICIENCY SCRUBBERS ONLY FOR RENDERING PLANTS

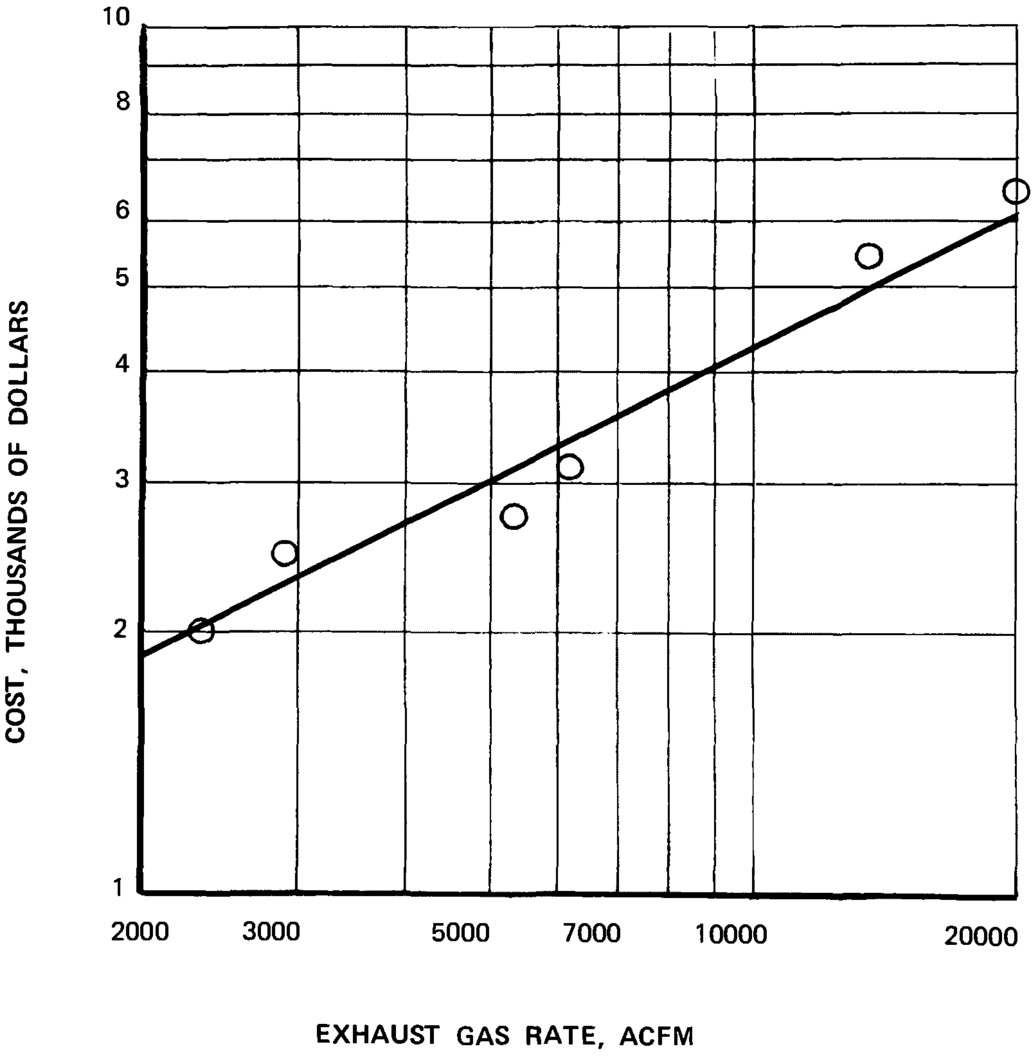


FIGURE 7

CAPITAL COST OF HIGH EFFICIENCY SCRUBBERS ONLY FOR RENDERING PLANTS

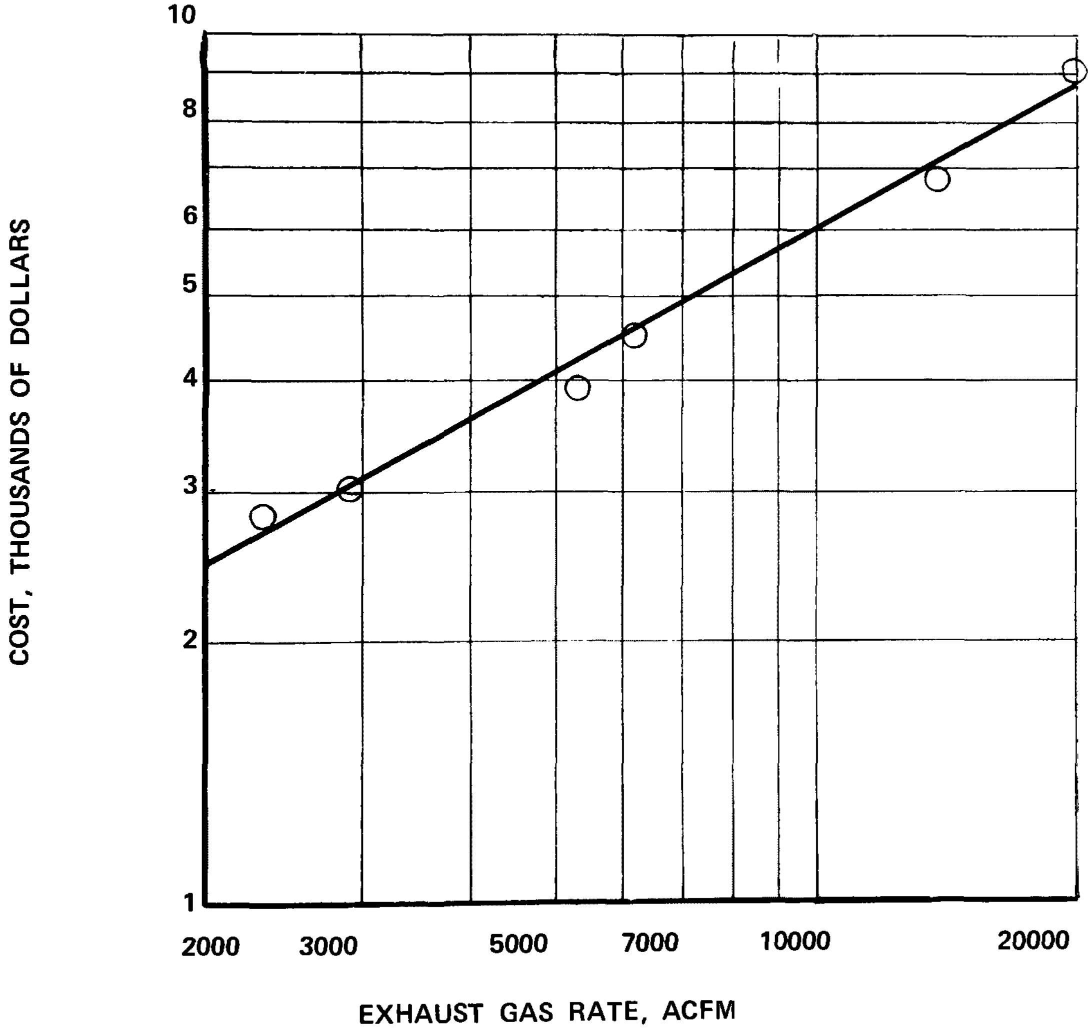


FIGURE 8

CAPITAL COST OF MEDIUM EFFICIENCY SCRUBBERS PLUS AUXILIARIES FOR RENDERING PLANTS

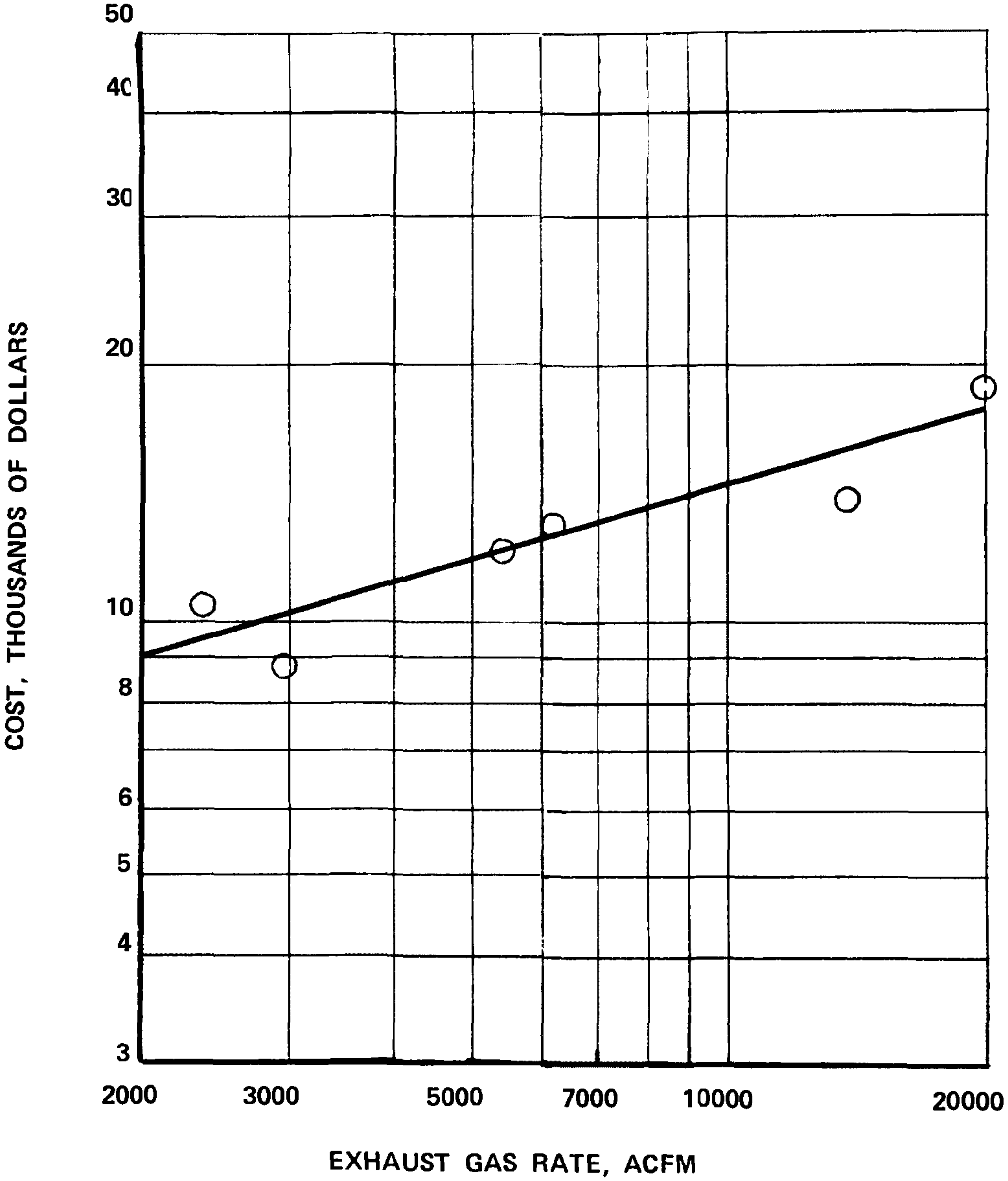


FIGURE 9

CAPITAL COST OF HIGH EFFICIENCY SCRUBBERS PLUS AUXILIARIES FOR RENDERING PLANTS

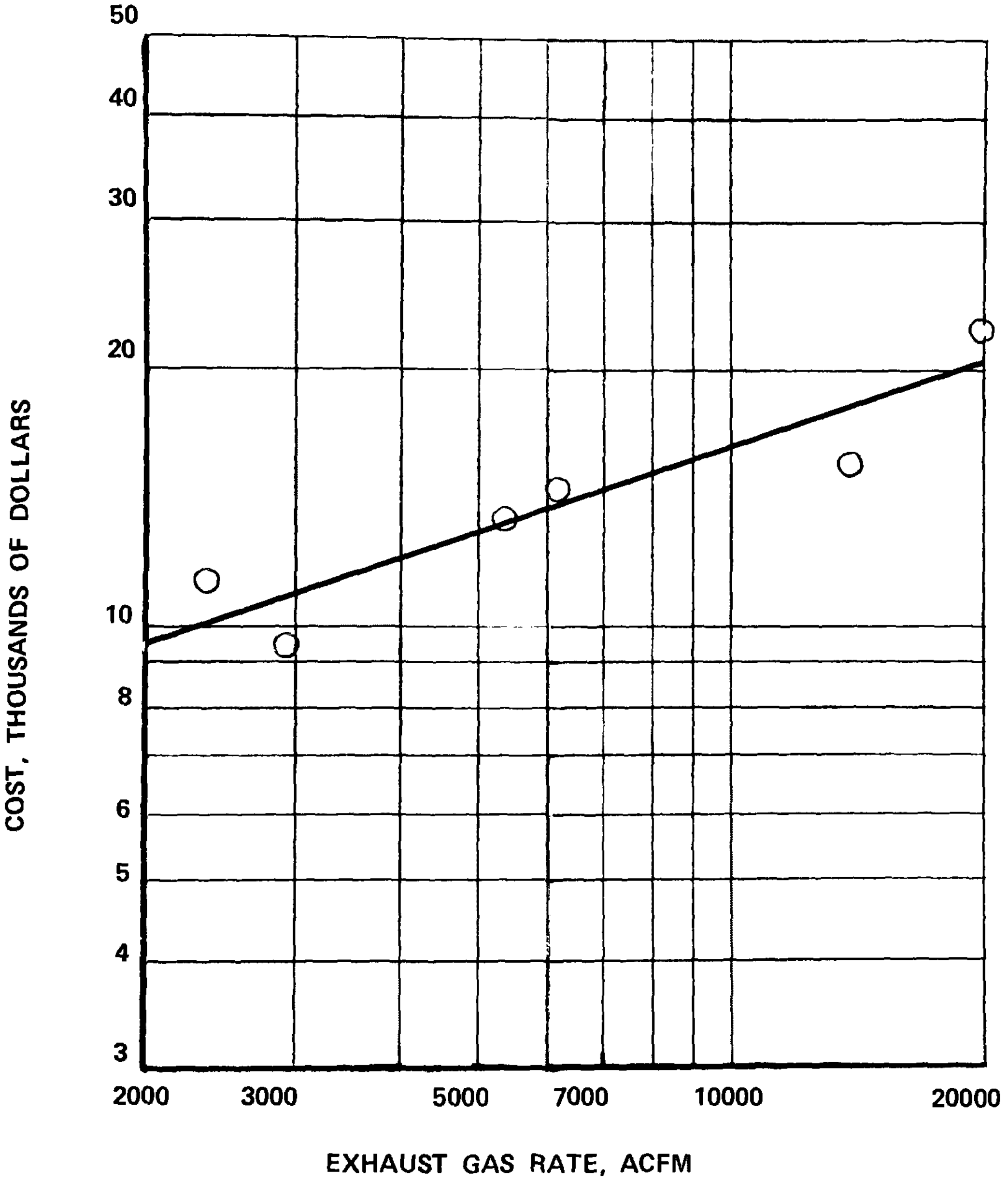


FIGURE 10

CAPITAL COST OF MEDIUM EFFICIENCY TURNKEY SCRUBBING SYSTEMS FOR RENDERING PLANTS

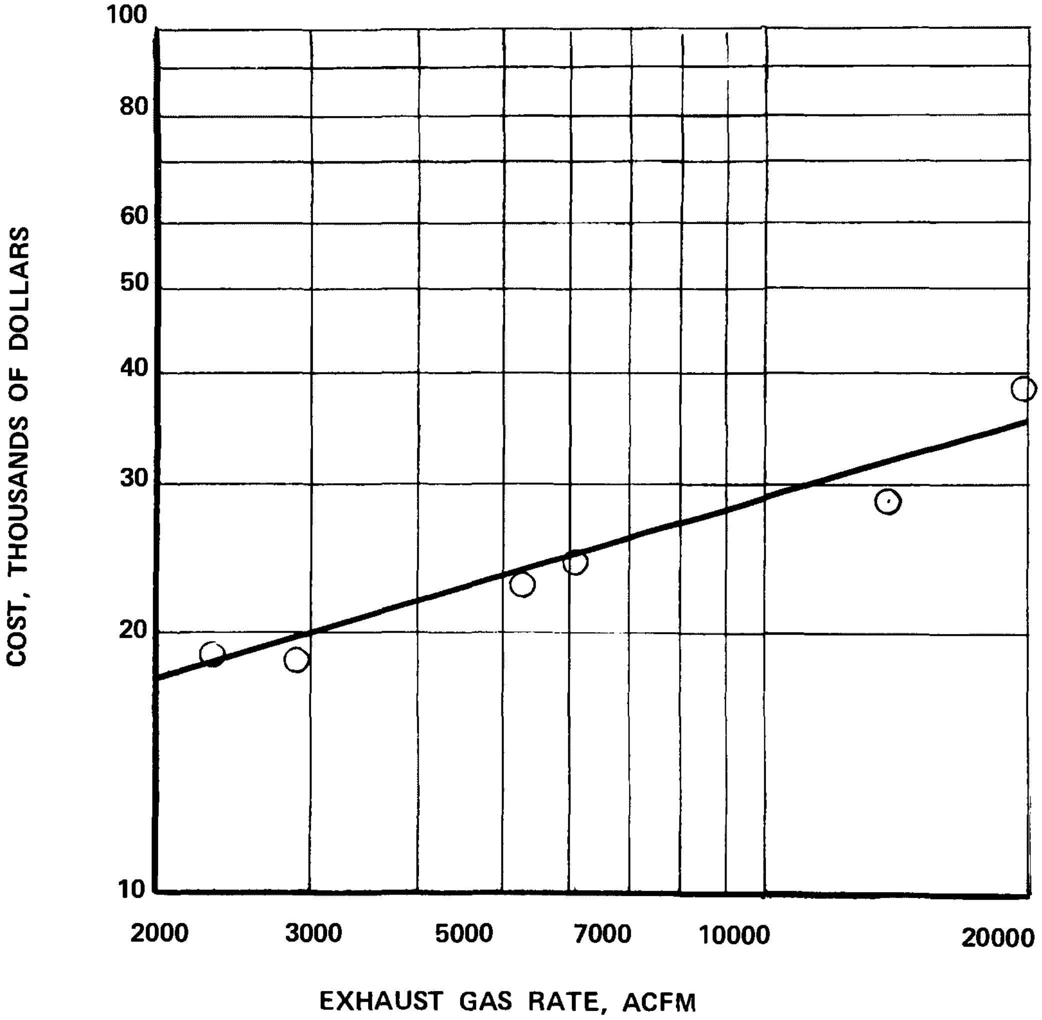


FIGURE 11

CAPITAL COST OF HIGH EFFICIENCY TURNKEY SCRUBBING SYSTEMS FOR RENDERING PLANTS

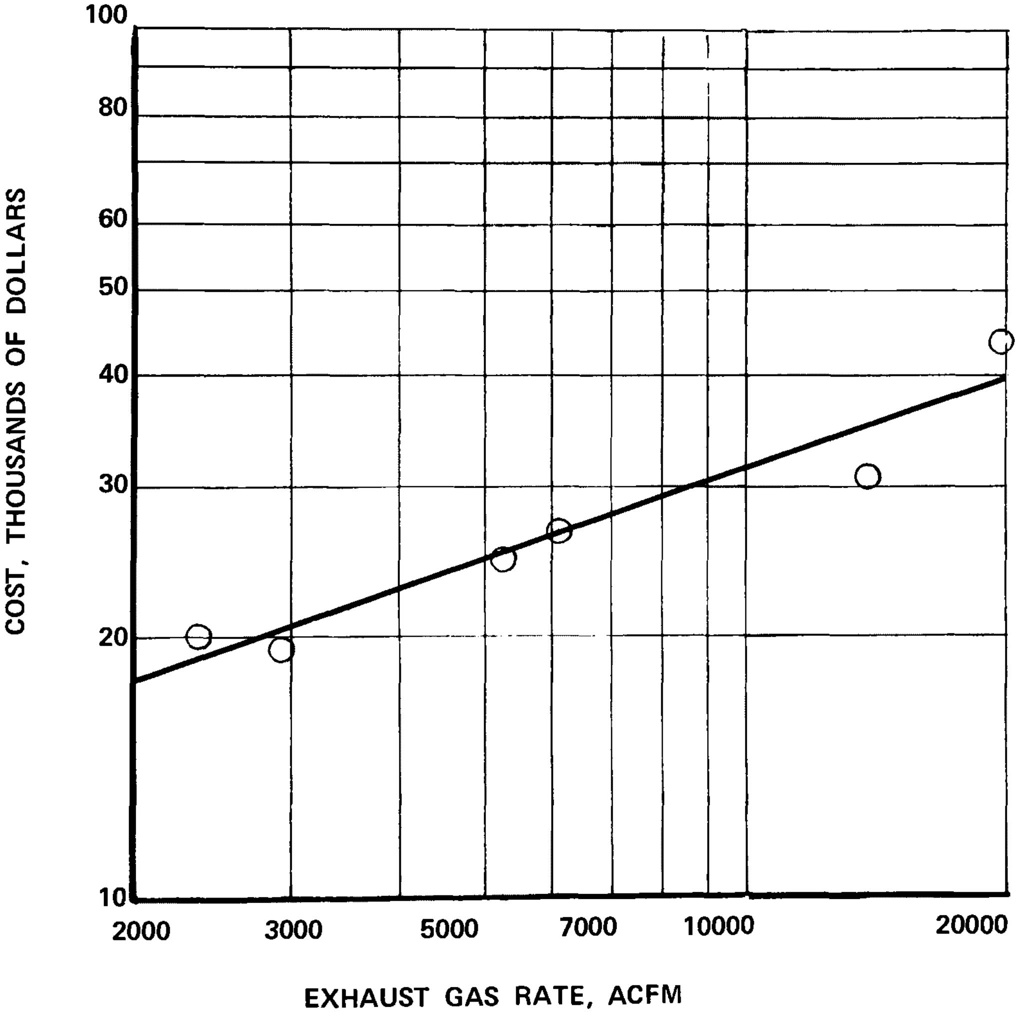


FIGURE 12

CONFIDENCE LIMITS FOR CAPITAL COST OF MEDIUM EFFICIENCY SCRUBBERS ONLY FOR RENDERING PLANTS

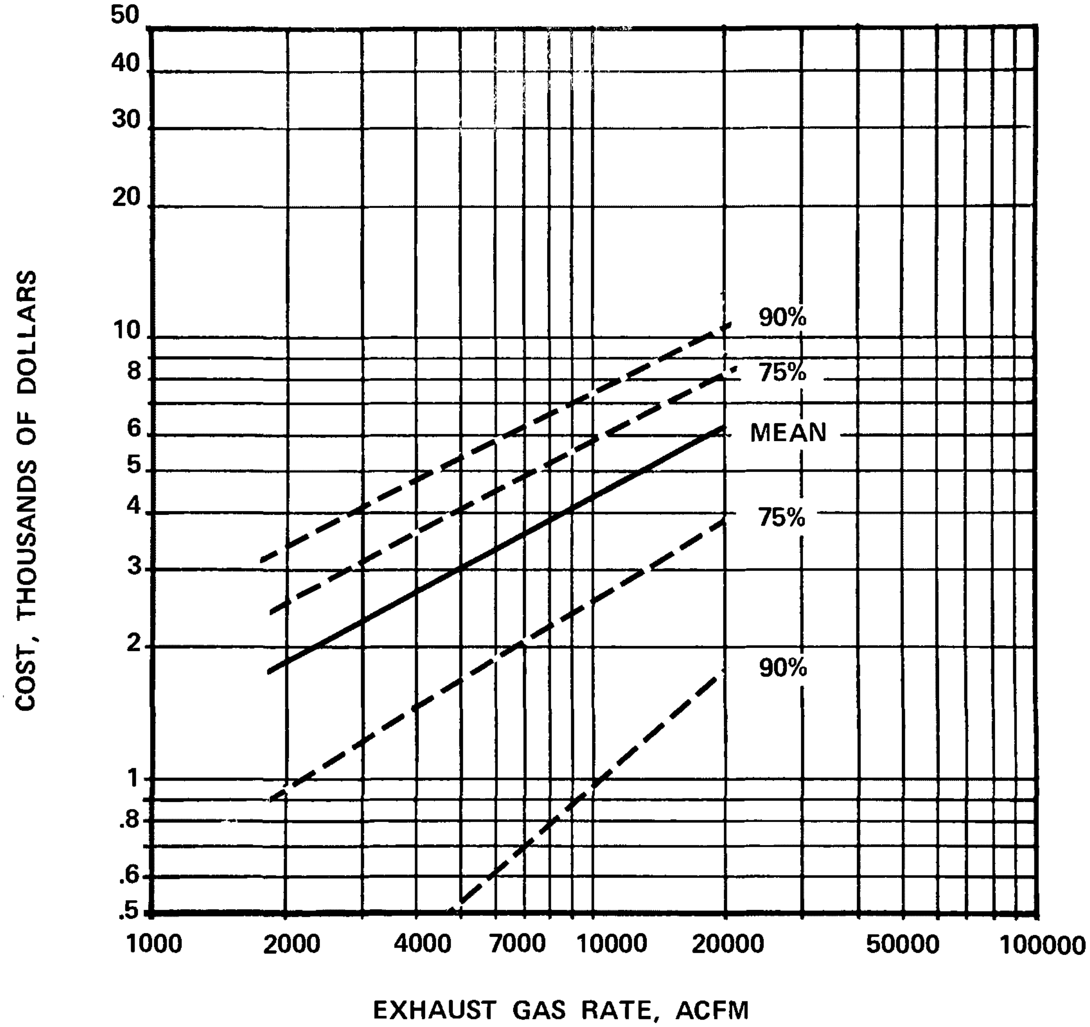


FIGURE 13

CONFIDENCE LIMITS FOR CAPITAL COST OF HIGH EFFICIENCY SCRUBBERS ONLY FOR RENDERING PLANTS

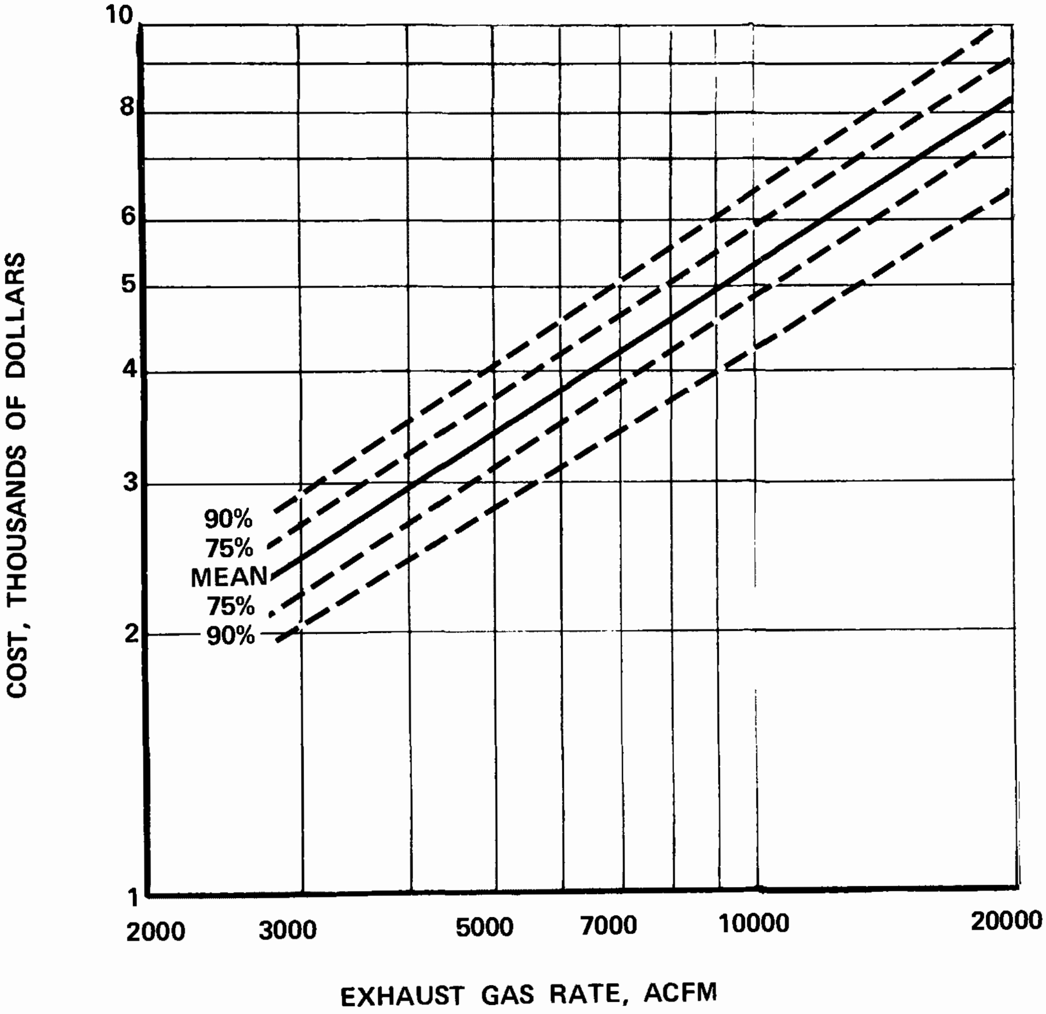


FIGURE 14

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING PLANTS

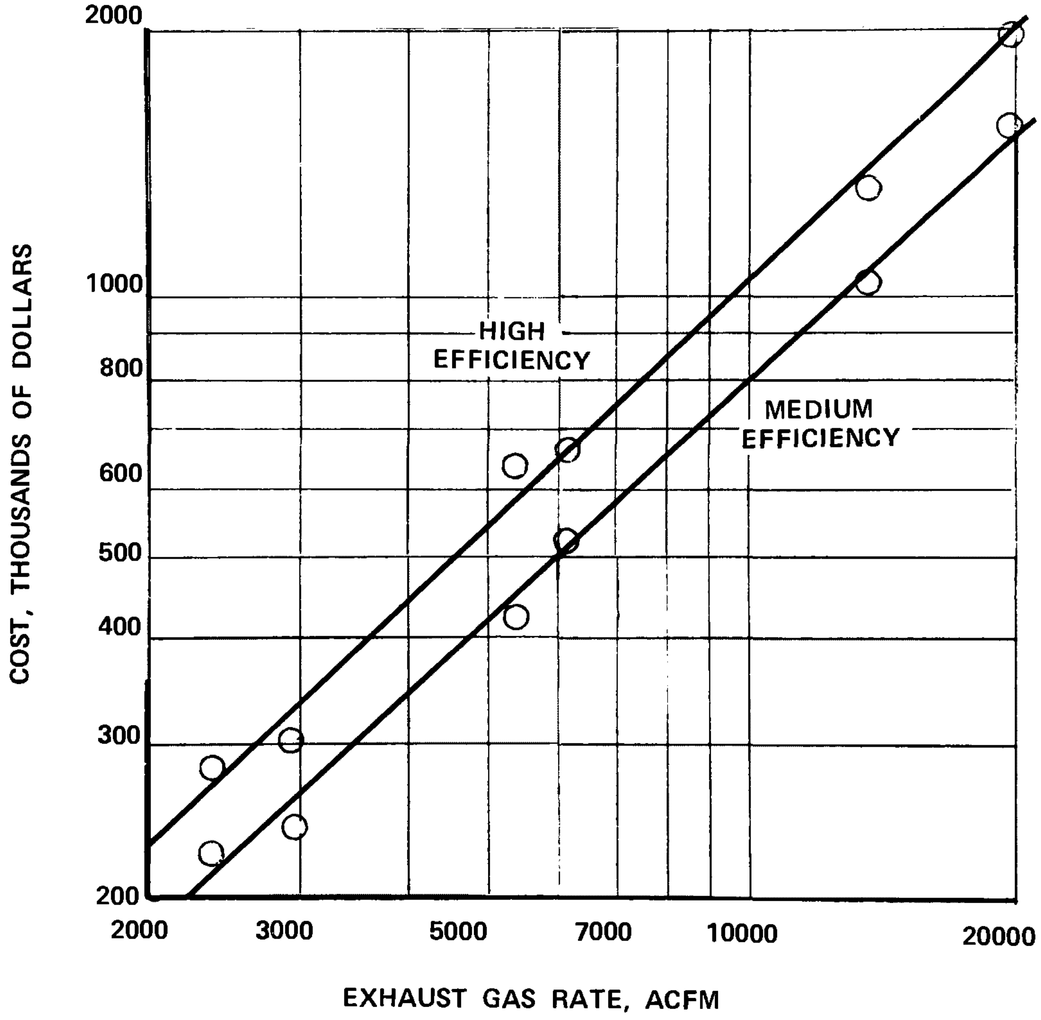


TABLE 26

INCINERATOR PROCESS DESCRIPTION

FOR RENDERING COOKERS AND HOODS

SPECIFICATION

PROCESS DESCRIPTION

The incinerator is to deodorize exhaust gases from the cooker and the hoods over the expellers and charge grinders in a dry rendering plant. The cooker is operated batchwise in this plant. Time required in the cooker for each batch is three hours. Since two or three batches will be run each day, the incinerator will be in use for 8 to 12 hours daily.

Cooker gases are exhausted through the plant wall to a condenser located on the ground outside the building. Effluent gases from the condenser are vented into a 30 ft stack. Ventilation from the hoods is exhausted on the roof at a height of 20 ft. A 30 ft square area is available for new equipment next to the location of the condenser and the stack. A four inch concrete slab covers the area. Sufficient electric power is available at the site.

The incinerator is to be natural gas fired. Gas is available at 1.0 psig having the following composition:

Component	Volume %
CO_2	0.90
N_2	0.38
O_2	0.00
CH_4	94.96
C_2H_6	3.02
C_3H_8	0.48
$i\text{-}C_4H_{10}$	0.07
$n\text{-}C_4H_{10}$	0.09
C_5+	0.10
	100.00

Specific Gravity: 0.589 *Higher Heating Value: 1034 Btu/SCF*

This specification covers the incinerator, burner, 30 ft stack, controls, and other equipment included as a part of the incinerator, such as insulation, jacketing, etc. A suitable control panel and two days startup service by a competent engineer should be included. Incinerator operation and safety controls are to be designed to meet FIA insurance requirements. The stack, controls, control panel, startup service, etc., should be considered as auxiliaries.*

Although specifications have been written for two efficiency levels at each plant size, vendors' quotations should consist of only one quotation for each plant size with a representation of the efficiency expected. Every effort should be made to achieve the performance indicated by the high efficiency specification.

**FIA indicates Factory Insurance Association.*

TABLE 27

INCINERATOR OPERATING CONDITIONS FOR RENDERING COOKERS AND HOODS

SPECIFICATION

OPERATING CONDITIONS

	SMALL		LARGE	
	AVE.	MAX.	AVE.	MAX.
Cooker				
Gas Rate, ACFM	283	567	850	1,700
Gas Temp., ^{o}F	212		212	
Odor Concentration, o.u./SCF	150,000		150,000	
Odor Emission Rate, o.u./min	32.9×10^6	65.8×10^6	98.6×10^6	197.2×10^6
Condenser Gas Discharge				
Gas Rate, ACFM	14.2	28.4	42.5	85
Gas Temp., ^{o}F	140	140	140	140
% Air	$\sim$0	$\sim$0	$\sim$0	$\sim$0
% H_2O	$\sim$20	$\sim$20	$\sim$20	$\sim$20
Odor Concentration, o.u./SCF	1.34×10^6	1.34×10^6	1.34×10^6	1.34×10^6
Odor Emission Rate, o.u./min	16.4×10^6	32.9×10^6	49.3×10^6	98.6×10^6
Expeller and Grinder Hoods				
Gas Rate, ACFM	2,000		5,000	
Gas Temp., ^{o}F	100		100	
% Air	$\sim$100	$\sim$100	$\sim$100	$\sim$100
Relative Humidity, %	$\sim$20	$\sim$20	$\sim$20	$\sim$20
Odor Concentration, o.u./SCF	90,000		90,000	
Odor Emission Rate, o.u./min.	167×10^6		417×10^6	
Combined Gas Stream				
Gas Rate, ACFM	2,030		5,090	
Gas Temp., ^{o}F	101		101	
% Air	98.5		98	
Relative Humidity, %	21		21	
Odor Concentration, o.u./SCF	97,500		102,000	
Odor Emission Rate, o.u./min	200×10^6		516×10^6	

Low Efficiency Case		
Concentration @ Ground, o.u./SCF	*8 **	*8 **
% Odor Removal	*43*	*45*
High Efficiency Case		
Concentration @ Ground o.u./SCF	*< 1 **	*< 1 **
% Odor Removal	*93*	*93*

**30 minute average as calculated by Bosenquet-Pearson and Bosenquet-Carey-Halton.*

TABLE 28

INCINERATOR PROCESS DESCRIPTION FOR RENDERING ROOM VENTS

PROCESS DESCRIPTION SPECIFICATION

The incinerator is to deodorize room ventilation gases from a dry rendering plant. The plant is operated batchwise. The time required in the cooker for each batch is three hours. Since two or three batches will be run each day, the incinerator will be in use for 8 to 12 hours daily.

Ventilation from the feed storage area is currently exhausted through the roof at a height of 20 ft. Cooker gases are sent to a condenser located on the ground outside the building. Effluent gases from the condenser are vented into a 30 ft stack. A 30 ft square area is available for new equipment next to the location of the condenser and the stack. A four inch concrete slab covers the area. Sufficient electric power is available at the site.

The incinerator is to be natural gas fired. Gas is available at 1.0 psig having the following composition:

Component	*Volume %*
CO_2	0.90
N_2	0.38
O_2	0.00
CH_4	94.96
C_2H_6	3.02
C_3H_8	0.48
$i\text{-}C_4H_{10}$	0.07
$n\text{-}C_4H_{10}$	0.09
C_5+	0.10
	100.00

Specific Gravity: 0.589 *Higher Heating Value: 1034 Btu/SCF*

This specification covers the incinerator, burner, a 30 ft stack, controls, and other equipment included as a part of the incinerator, such as insulation, jacketing, etc. A suitable control panel and two days startup service by a competent engineer should be included. Incinerator operation and safety controls are to be designed to meet FIA insurance requirements. The stack, controls, control panel, startup service, etc., should be considered as auxiliaries.

Although specifications have been written for two efficiency levels at each plant size, vendors' quotations should consist of only one quotation for each plant size with a representation of the efficiency expected. Every effort should be made to achieve the performance indicated by the high efficiency specification.

TABLE 29

INCINERATOR OPERATING CONDITIONS FOR RENDERING ROOM VENTS

SPECIFICATION

OPERATING CONDITIONS

	SMALL	LARGE
Room Ventilation		
Effluent Gas Rate, ACFM	3,000	14,000
Effluent Gas Temp., °F	90	90
% Air	~ 100	~ 100
Relative Humidity, %	25	25
Odor Concentration, o.u./SCF	100,000	100,000
Odor Emission Rate, o.u./min	284×10^6	$1{,}320 \times 10^6$
Low Efficiency Case		
Concentration @ Ground, o.u./SCF	8 *	8 *
% Odor Removal	44	44
High Efficiency Case		
Concentration @ Ground, o.u./SCF	< 1 *	< 1 *
% Odor Removal	93	93

*30 minute averages as calculated by Bosenquet-Pearson and Bosenquet-Carey-Halton.

TABLE 30

INCINERATOR PROCESS DESCRIPTION FOR COMBINED RENDERING VENTS

SPECIFICATION

PROCESS DESCRIPTION

The incinerator is to deodorize the total gases emitted from a dry rendering plant. The plant is operated batchwise. The time required in the cooker for each batch is three hours. Since two or three batches will be run each day, the incinerator will be in use for 8 to 12 hours daily.

Ventilation from the hoods and storage area is currently exhausted through the roof at a height of 20 ft. Cooker gases are sent to a condenser located on the ground outside the building. Effluent gases from the condenser are vented into a 30 ft stack. A 30 ft square area is available for new equipment next to the location of the condenser and the stack. A four inch concrete slab covers the area. Sufficient electric power is available at the site.

The incinerator is to be natural gas fired. Gas is available at 1.0 psig having the following composition:

Component	*Volume %*
CO_2	0.90
N_2	0.38
O_2	0.00
CH_4	94.96
C_2H_6	3.02
C_3H_8	0.48
$i\text{-}C_4H_{10}$	0.07
$n\text{-}C_4H_{10}$	0.09
C_5+	0.10
	100.00

Specific gravity: 0.589 *Higher heating value: 1034 Btu/SCF*

This specification covers the incinerator, burner, 30 ft stack, controls, and other equipment included as a part of the incinerator, such as insulation, jacketing, etc. A suitable control panel and two days startup service by a competent engineer should be included. Incinerator operation and safety controls are to be designed to meet FIA insurance requirements. The stack, controls, control panel, startup service, etc., should be considered as auxiliaries.

Although specifications have been written for two efficiency levels at each plant size, vendors' quotations should consist of only one quotation for each plant size with a representation of the efficiency expected. Every effort should be made to achieve the performance indicated by the high efficiency specification.

TABLE 31

INCINERATOR OPERATING CONDITIONS FOR COMBINED RENDERING VENTS

SPECIFICATION

OPERATING CONDITIONS

	SMALL	*LARGE*
Total Gas Stream		
Effluent Gas Rate, ACFM	*5,030*	*19,090*
Effluent Gas Temp., °F	*95*	*95*
% Air	*~99*	*~99*
Relative Humidity, %	*23*	*23*
Odor Concentration, o.u./SCF	*103,000*	*103,000*
Odor Emission Rate, o.u./min	*484 x 10^6*	*1,836 x 10^6*
Low Efficiency Case		
Concentration @ Ground, o.u./SCF	*8 **	*8 **
% Odor Removal	*46*	*46*
High Efficiency Case		
Concentration @ Ground, o.u./SCF	*< 1 **	*< 1 **
% Odor Removal	*> 93*	*>93*

**30 minute averages as calculated by Bosenquet-Pearson and Bosenquet-Carey-Halton.*

TABLE 32

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR INCINERATORS FOR RENDERING COOKERS AND HOODS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			2,030	5,090
°F			101	101
SCFM			1,918	4,809
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF				
lb/hr				
Cleaned Gas Flow				
ACFM				
°F				
SCFM			1,970	4,920
Moisture Content, Vol. %			6	6
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr				
Cleaning Efficiency, %			93	93
(1) Gas Cleaning Device Cost			8,750	11,000
(2) Auxiliaries Cost				
(a) Fan(s)			787	1,098
(b) Pump(s)			-	-
(c) Damper(s)			71	81
(d) Conditioning, Equipment			-	-
(e) Dust Disposal Equipment			-	-
(3) Installation Cost				
(a) Engineering			2,750	3,188
(b) Foundations & Support			893	1,015
(c) Ductwork			2,090	2,485
(d) Stack			494	633
(e) Electrical			600	712
(f) Piping			170	220
(g) Insulation			-	-
(h) Painting			-	-
(i) Supervision			930	930
(j) Startup			475	475
(k) Performance Test			1,225	1,225
(l) Other			-	-
(4) Total Cost			19,235	23,062

TABLE 33

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR INCINERATORS FOR RENDERING COOKERS AND HOODS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$6/hr			780	780
Supervisor	$8/hr			48	48
Total Operating Labor				828	828
Maintenance					
Labor	$6/hr			384	390
Materials				166	220
Total Maintenance				550	610
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$0.011/kw-hr			0.1	0.1
Fuel	$0.80/MMBTU			6,032	14,789
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				6,032	14,789
Total Direct Cost				7,568	16,385
Annualized Capital Charges				1,924	2,306
Total Annual Cost				9,492	18,691

TABLE 34

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR INCINERATORS FOR RENDERING ROOM VENTS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			3,000	14,000
°F			90	90
SCFM			2,891	13,491
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF				
lb/hr				
Cleaned Gas Flow				
ACFM				
°F				
SCFM			2,960	13,820
Moisture Content, Vol. %			6	6
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr				
Cleaning Efficiency, %			93	93
(1) Gas Cleaning Device Cost			10,000	18,000
(2) Auxiliaries Cost				
(a) Fan(s)			890	2,206
(b) Pump(s)			-	-
(c) Damper(s)			-	-
(d) Conditioning, Equipment			-	-
(e) Dust Disposal Equipment			-	-
(3) Installation Cost				
(a) Engineering			2,813	4,250
(b) Foundations & Support			933	1,340
(c) Ductwork			2,230	3,798
(d) Stack			540	1,025
(e) Electrical			631	1,155
(f) Piping			185	358
(g) Insulation			-	-
(h) Painting			-	-
(i) Supervision			930	930
(j) Startup			475	475
(k) Performance Test			1,225	1,225
(l) Other			-	-
(4) Total Cost			20,852	34,762

TABLE 35

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR INCINERATORS FOR RENDERING ROOM VENTS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$6/hr			780	780
Supervisor	$8/hr			48	48
Total Operating Labor				828	828
Maintenance					
Labor	$6/hr			390	480
Materials				220	270
Total Maintenance				610	750
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$0.011/kw-hr			0.4	1.91
Fuel	$0.80/MMBTU			8,736	40,872
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				8,736	40,874
Total Direct Cost				10,332	42,610
Annualized Capital Charges				2,085	3,476
Total Annual Cost				12,417	46,086

TABLE 36

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR INCINERATORS FOR RENDERING COMBINED VENTS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			5,030	19,090
°F			95	95
SCFM			4,803	18,240
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF				
lb/hr				
Cleaned Gas Flow				
ACFM				
°F				
SCFM			4,915	18,670
Moisture Content, Vol. %			6	6
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr				
Cleaning Efficiency, %			94	94
(1) Gas Cleaning Device Cost			11,000	19,500
(2) Auxiliaries Cost				
(a) Fan(s)			1,098	2,693
(b) Pump(s)			-	-
(c) Damper(s)			202	248
(d) Conditioning, Equipment			-	-
(e) Dust Disposal Equipment			-	-
(3) Installation Cost				
(a) Engineering			3,188	4,750
(b) Foundations & Support			1,015	1,488
(c) Ductwork			2,850	4,600
(d) Stack			633	1,210
(e) Electrical			713	1,280
(f) Piping			220	438
(g) Insulation			-	-
(h) Painting			-	-
(i) Supervision			930	930
(j) Startup			475	475
(k) Performance Test			1,225	1,225
(l) Other			-	-
(4) Total Cost			23,549	38,837

TABLE 37

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR INCINERATORS FOR RENDERING COMBINED VENTS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$6/hr			780	780
Supervisor	$8/hr			48	48
Total Operating Labor				828	828
Maintenance	$6/hr				
Labor				384	465
Materials				186	235
Total Maintenance				570	700
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.011/kw-hr			0.1	0.3
Fuel	$.80/MMBTU			14,539	55,162
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				14,539	55,162
Total Direct Cost				16,095	56,848
Annualized Capital Charges				2,355	3,884
Total Annual Cost				18,450	60,732

FIGURE 15

CAPITAL COST OF INCINERATORS ONLY FOR RENDERING PLANTS

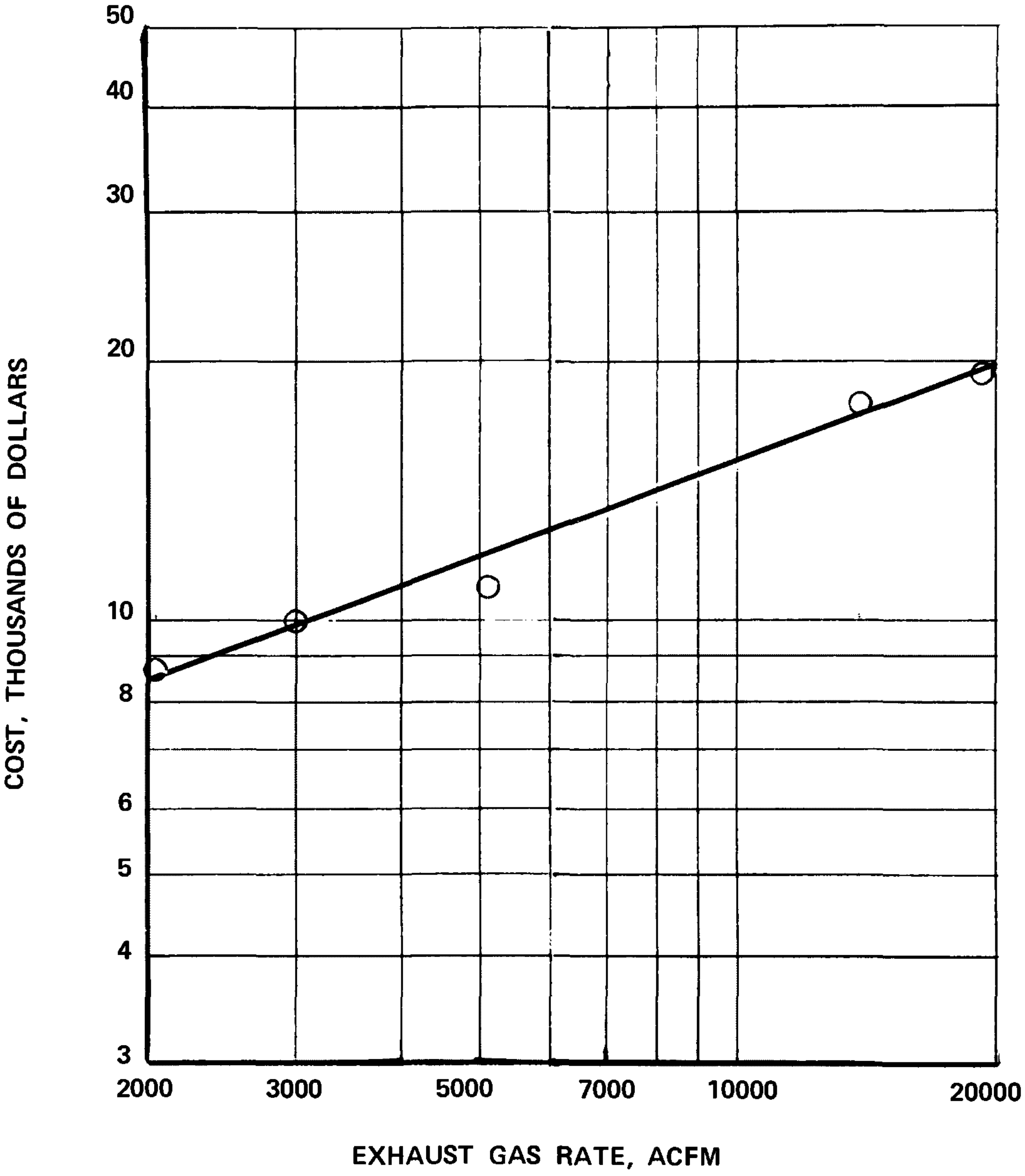


FIGURE 16

CAPITAL COST OF INCINERATORS
PLUS AUXILIARIES FOR RENDERING PLANTS

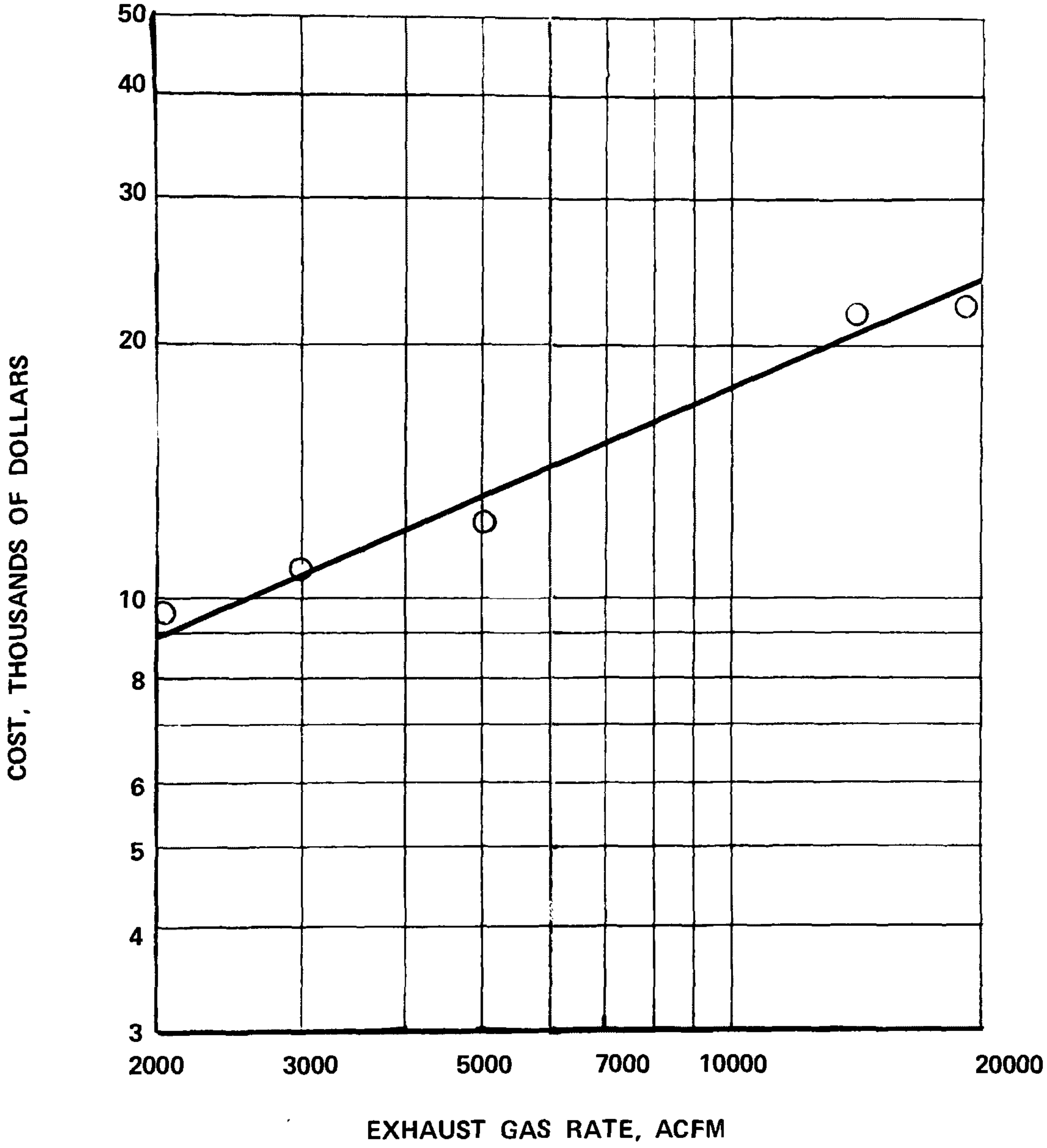


FIGURE 17

CAPITAL COST OF TURNKEY INCINERATOR SYSTEMS FOR RENDERING PLANTS

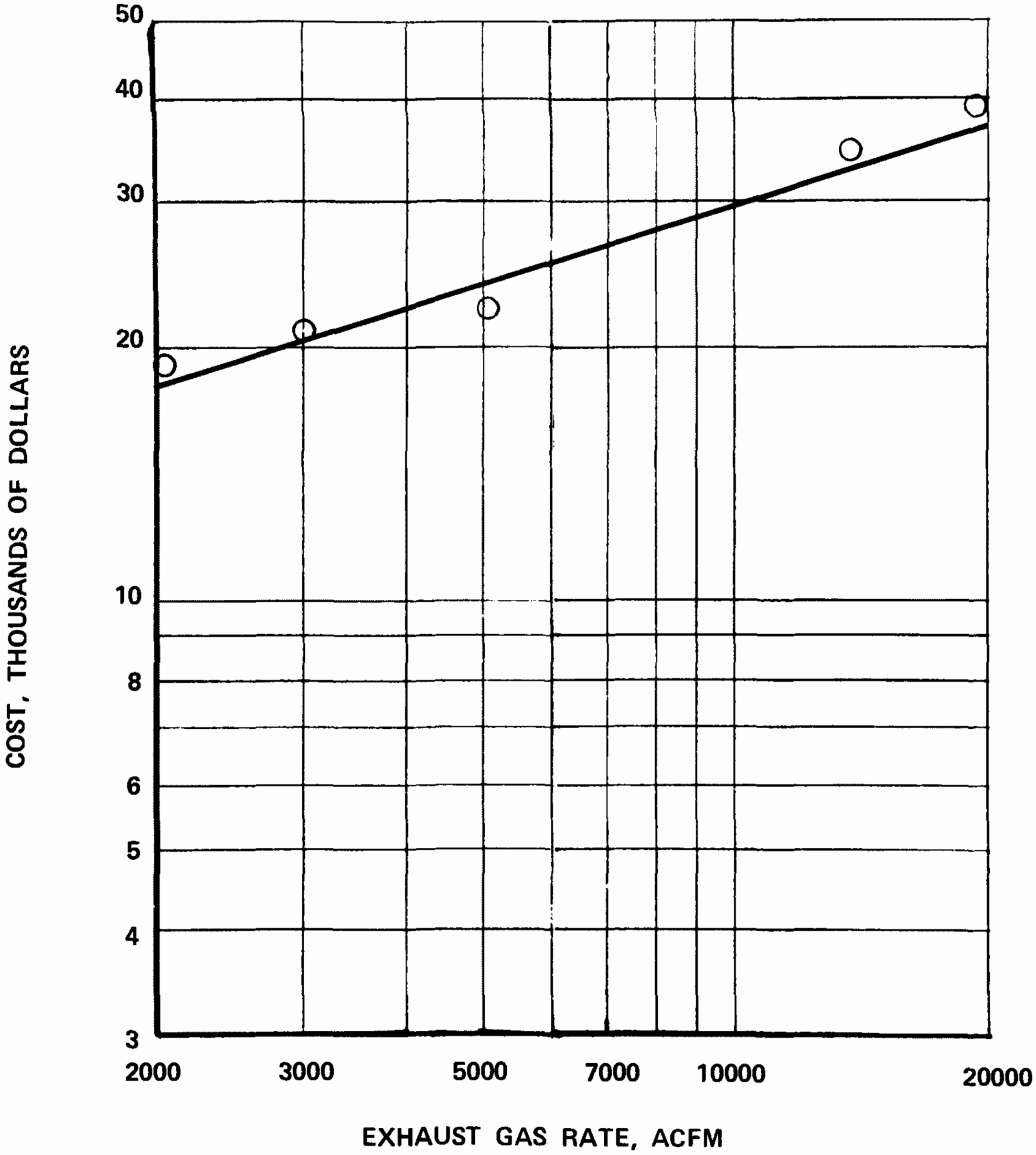
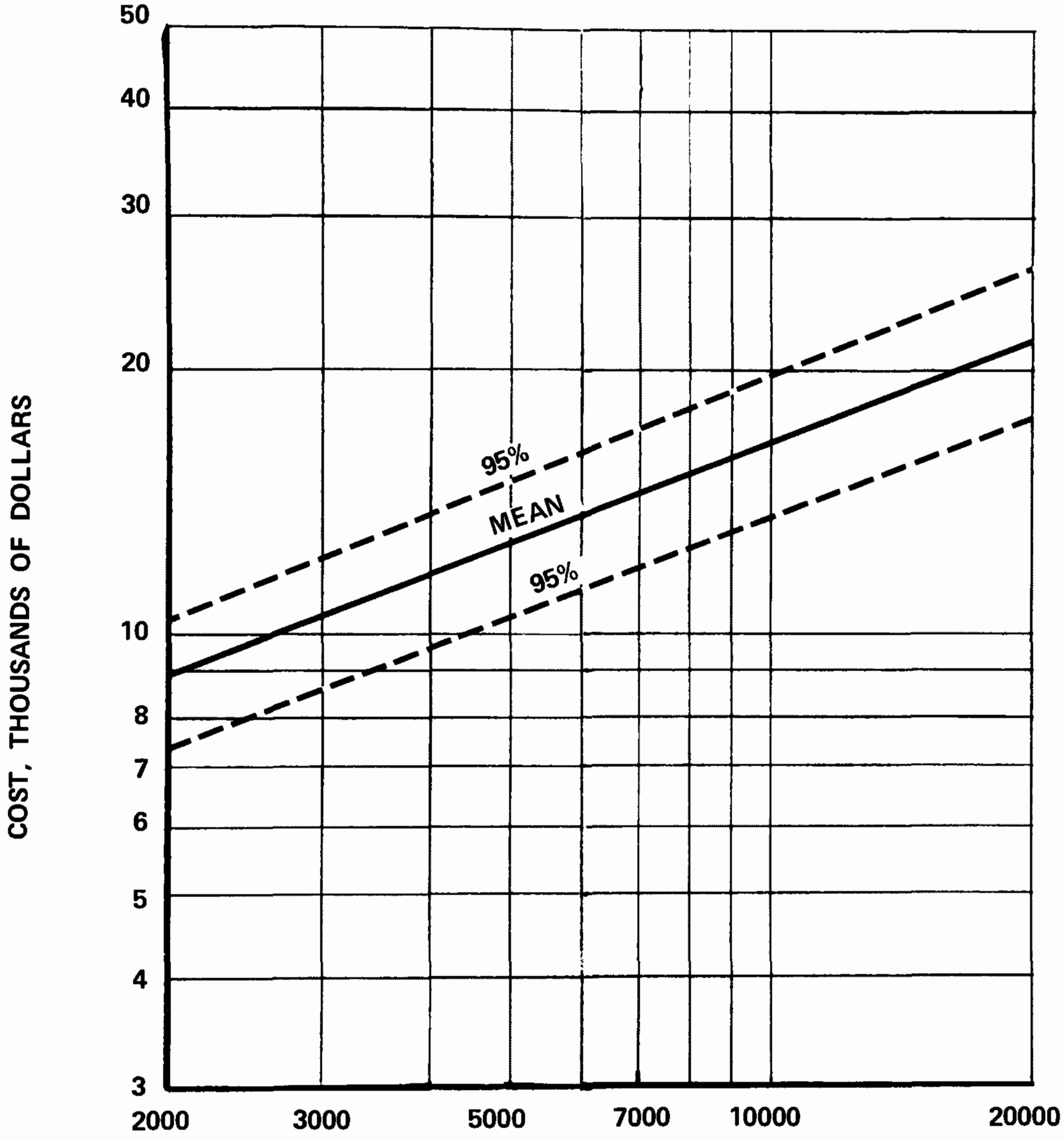


FIGURE 18

CONFIDENCE LIMITS FOR INCINERATORS PLUS AUXILIARIES FOR RENDERING PLANTS



EXHAUST GAS RATE, ACFM

FIGURE 19

CONFIDENCE LIMITS FOR TURNKEY INCINERATOR SYSTEMS FOR RENDERING PLANTS

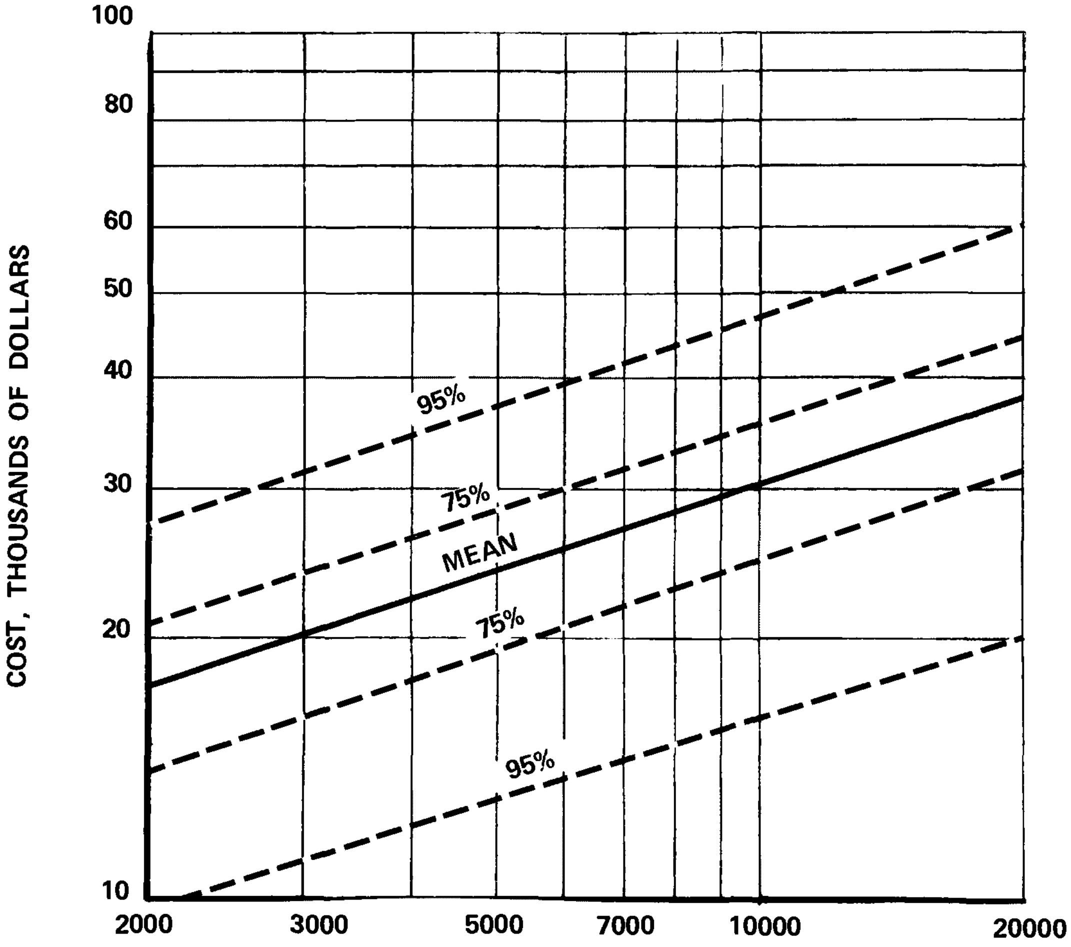
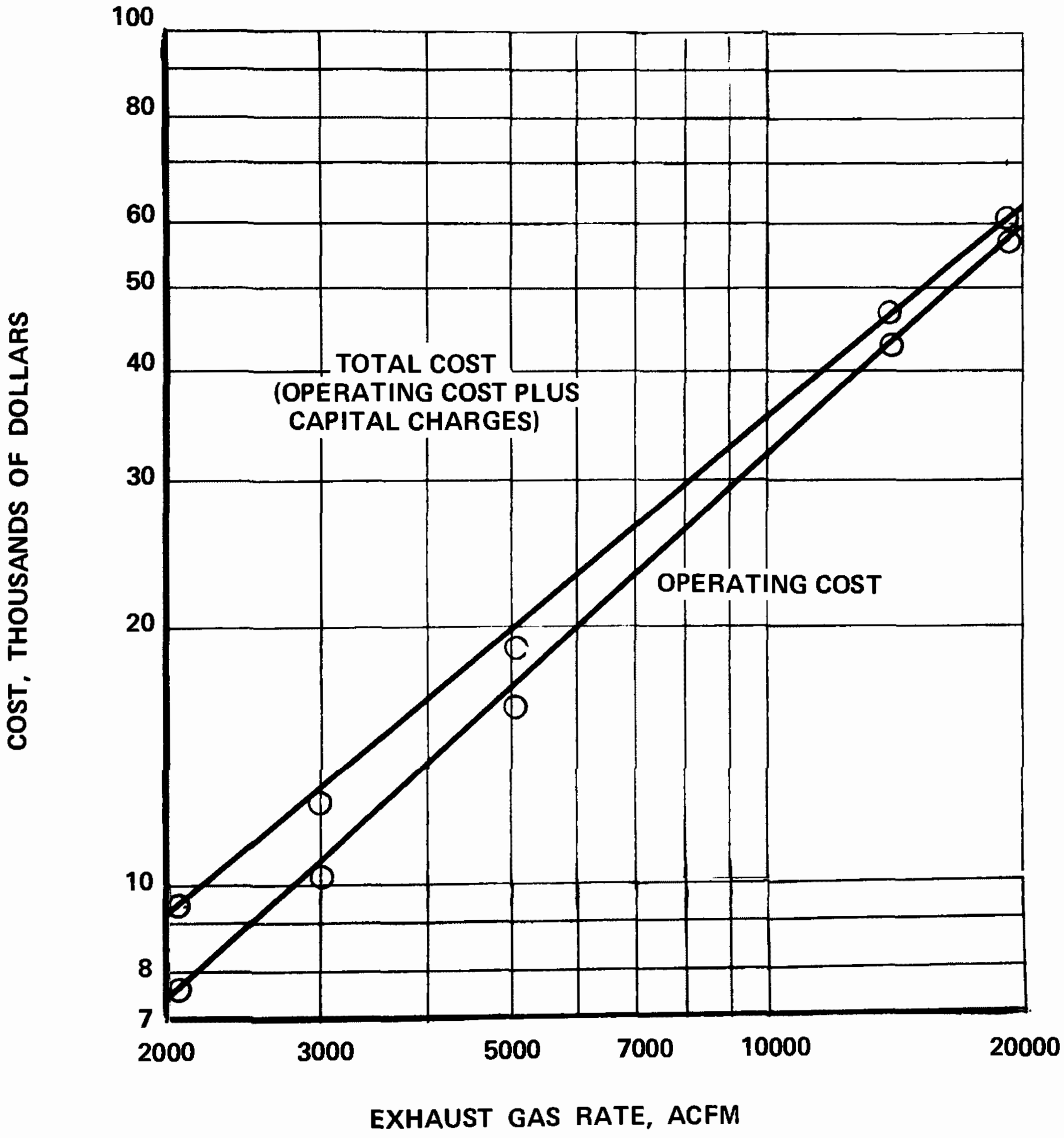


FIGURE 20

ANNUAL COSTS FOR INCINERATORS FOR RENDERING PLANTS



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CATALYTIC CRACKING

2. THE PETROLEUM REFINING INDUSTRY FLUIDIZED BED CATALYTIC CRACKING UNITS (with CO Boilers)

Petroleum Refineries process crude oil to produce a variety of products, most of which are used for fuel. These products include:

Product	Use
propane (LPG)	fuel
butane (LPG)	fuel
gasoline	automotive fuel
kerosene	jet fuel
#2 distillate	burner and diesel fuel
#6 residual oil	burner fuel
asphalt	road paving

These products are differentiated from each other more by their boiling temperature range (which is related to the molecular weight and hydrocarbon type) than any other single factor. Those fuels boiling at temperatures in the gasoline range (200-400° F) and below command premium prices. Kerosene (350-550° F) and distillate fuels (450-600° F) are desirable for jet and diesel fuels as well as for heating purposes. However, those materials boiling above 600° F are generally undesirable products, and one objective of refinery operation is to minimize them. Catalytic Cracking is the principal process used to convert high boiling point hydrocarbons into more valuable lower boiling point materials.

A typical crude petroleum may contain as much as 70% high boiling point materials. After the gasoline, kerosene and distillate oils have been fractionated out of crude petroleum, the remaining materials are fractionated in vacuum distillation columns to remove asphalt (the very heaviest portion of the crude oil). The heavy distillate material is called *gas oil.* Cracking of this material to reduce the molecular weight and boiling point may be accomplished thermally (by the application of heat without a catalyst), in fixed catalyst beds, in moving beds or in fluidized beds. Because cracking is accompanied by the formation of very heavy byproduct hydrocarbons called *coke*, the fluidized or moving bed processes, in which the catalyst can be regenerated by a continuous removal of the coke, are widely used in the petroleum refining industry to produce gasoline and distillate components from gas oils and deasphalted stocks. As of January 1, 1971, the installed capacity for catalytic cracking units amounted to 4,512,545 barrels per stream day* of fresh feed for all units in 253 U.S. refineries.(1)

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*Barrels per stream day is the usual unit of flow in petroleum refining. This unit, abbreviated BPSD, is the number of 42-gallon barrels processed per day of operation. Occasionally the average number of barrels processed per day over a typical year is used. This designation is barrels per calendar day, or BPCD. The BPCD figure takes into account a period of down-time for service which ordinarily amounts to two weeks per year. Thus the BPCD capacity of a FCC unit is about 50/52 or 96% of the BPSD capacity.

This represents 37.5% of the total amount of crude oil processing capacity in the U.S. as of January 1, 1971.(1)

Three general types of moving bed catalytic units are used in the United States. These types and their installed capacities as of January 1, 1970 are as shown in Table 38.

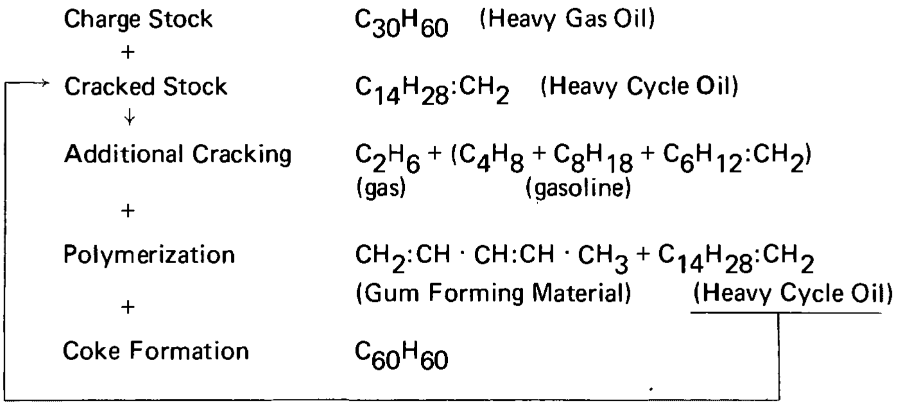
TABLE 38

INSTALLED CAPACITIES OF THE THREE TYPES OF CATALYTIC CRACKING UNITS

	Combined Feed Capacity (BPSD) (2)	Percent Of Total
Fluid Catalytic Cracking (FCC)	5,007,470	85.4
Thermofor Catalytic Cracking (TCC)	669,870	11.4
Houdriflow Catalytic Cracking (HCC)	186,500	3.2
	5,863,840	100.0

TABLE 39

SCHEMATIC REPRESENTATION OF CRACKING REACTIONS(3)



In this table, the *combined feed capacity* is used. This includes some partially cracked *heavy cycle oil* which is recycled back into the process. The "size" or capacity of catalytic cracking units is generally given in terms of the combined feed rate.

Each of the above types of catalytic cracking units employs the same general process principals and feed stocks to produce similar products. Powdered catalysts which can be maintained in a fluidized state by the flow of gases upward through the catalyst beds are used in FCC units while large beads of catalyst are used in the TCC process for moving bed operation.

As noted in the above tabulation, the FCC type dominates and no TCC or HCC units have been sold for about 10 years in this country. Therefore, the remainder of this discussion will center on the FCC process only.

PROCESS DESCRIPTION

FCC units of all types are essentially comprised of a reactor, a regenerator and product separation equipment, as shown in Figure No. 21. The relative position of reactor and regenerator installation may vary among various process installations. The reactor is either located above or adjacent to the regenerator. The relative positions are important only in that the catalyst is circulated by "hydrostatic" pressure head developed by the fluidized beds of catalyst.

Fresh feed stock and recycle stock are charged separately or as combined feed to the reactor section. The feed is commingled in a riser with hot regenerated catalyst removed from the base of the regenerator. In the riser, the cracking reaction is initiated and a catalyst-hydrocarbon vapor mixture is then introduced into the reactor section of the unit where a fluidized bed of catalyst may be maintained. The combination of catalyst, temperature and time cause the hydrocarbon to undergo a cracking reaction which produce products of lower boiling point than the charge stock. In most new units the design causes all of the reaction to occur in the riser. The riser then either discharges into the reactor vessel or directly into the cyclones contained in this vessel. No bed is maintained in the reactor. In addition to the new units, many older units have to be converted to this type of design. However, not all of the reactions lead to desirable products. A fraction of the combined feed is converted into byproducts even heavier than the feed stock, which will not vaporize and leave the surface of the catalyst. This carbonaceous residue on the catalyst – called coke – is composed mainly of carbon, hydrogen, sulfur and oxygen.

A simplified picture of the overall reactions taking place in cracking reactors(3) is shown in Table 39.

TABLE 40

TYPICAL OPERATING CONDITIONS FOR A MEDIUM-SIZE FCC UNIT

Feed Rate, BPSD	
Fresh Feed	40,000
Recycle Feed	10,000
Total Feed	50,000
Operation Ranges	
Catalyst/Oil Weight Ratio	17
Catalyst Circulation Rate, Tons/hr.	4,500
Reactor	
Temperature, °F	913
Pressure, psig	22.0
Regenerator	
Temperature, °F	1,240
Pressure, psig	27.5
Carbon Burning Rate, lb/hr	33,000

TABLE 41

TYPICAL PROPERTIES OF FRESH AND EQUILIBRIUM FCC CATALYSTS

	Fresh Catalyst	Equilibrium Catalyst
Composition, wt. %		
Si	35.0	34.3
Al	13.2	12.9
O	51.8	50.8
C (from coke)	–	1.9
H (from coke)	–	0.1
Total	100.0	100.0
Particle Size Distribution(5) (microns)		
<20	2	0
<40 but > 20	18	12
<80 but > 40	50	76
> 80	30	12
	100	100
Geometric Mean Diameter, microns	60	60
Particle Density, g/cc	1.3	1.5
Apparent Bulk Density, lb/ft^3	40	44

A portion of the fluidized catalyst separates by gravity from the cracked components of hydrocarbon vapor in the reactor. The cracked components are passed through one, two, or three stage cyclone separators to remove entrained catalyst and then charged to product fractionation equipment. The separated fluid catalyst containing deposit of tar and polymers, or coke, flows by gravity through a steam stripper. In the stripper the catalyst is contacted with steam to remove volatile materials from the catalyst prior to its introduction in the regenerator. The volatile matter and much of the steam goes back into the reactor. The catalyst bed in the regenerator is contacted with air to burn coke deposits from the catalyst. This produces CO, CO_2 and H_2O as the reaction products, and supplies hot regenerated catalyst to be comingled with the feed hydrocarbon.

Products of combustion, or regenerator flue gas, are passed through either two or three cyclone stages to effect catalyst separation before processing for heat recovery. Modern FCC unit regenerators run from 1150 to 1350° F exit gas temperature. Typical FCC operation conditions for a medium sized unit might be as shown in Table 40.

The products of combustion are at a sufficiently high temperature that heat recovery in some form is usually economical. The heat recovery is usually accomplished using a gas heat exchanger and/or a carbon monoxide (CO) boiler to produce steam; however, a few FCC units use power recovery turbines as well as steam generation. A gas heat exchanger alone is used on some FCC units and consists simply of a shell and tube heat exchanger to produce steam by absorption of some of the sensible heat of the flue gas prior to discharge to the atmosphere. A CO boiler is essentially a furnace which utilizes the sensible heat of the flue gas and the heat of combustion of carbon monoxide to produce steam. While high carbon monoxide concentrations are present in regenerator flue gas, supplementary fuel is usually needed to support combustion.(4) Many CO Boilers have been added because of regulations limiting CO emissions rather than because of the economics of heat recovery. The FCC unit illustrated in Figure No. 21 uses both a flue gas heat exchanger and a CO Boiler.

Catalyst used in FCC units may be of several types. These catalysts are fine powders of synthetic or natural materials of silica-alumina composition. In recent years, the use of "molecular sieve type" catalyst has grown substantially due to the improved activity (the ability to bring about the desired cracking reaction) and stability (the retention of activity for a long time) of these materials. The sieve catalysts are synthetic aluminosilicate materials processed to give special crystalline structures. Some of the properties of typical fresh (unused) and equilibrium (used) FCC Catalysts are listed in Table 41.

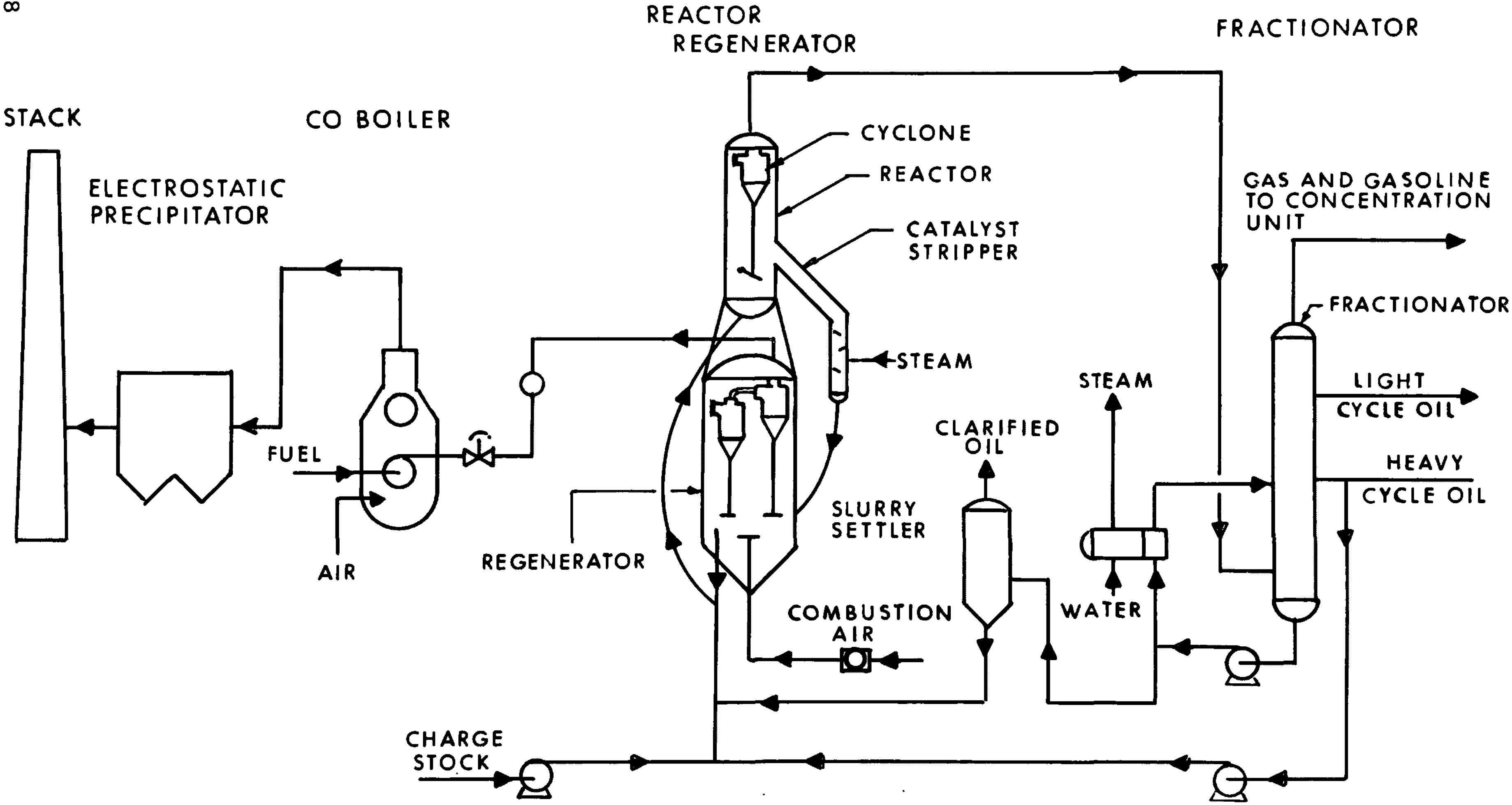


FIGURE 21

FLOW DIAGRAM OF FCC UNIT

FEED MATERIALS AND PRODUCTS

Feed materials for FCC units are comprised of a variety of high molecular weight hydrocarbon fractions. The most common charge material is vacuum distilled gas oil. However, deasphalted* oils and some cracked materials produced by thermal cracking or related processes such as visbreaking or coking are also processed.

Products from FCC units consist of light hydrocarbon gases, gasoline, distillate and heating oils. The hydrocarbon products all leave the reactor as vapors which pass through the cyclones to separate catalyst and return it to the reactor. The mixed products are cooled and part of the product condensed. The liquid condensate is pumped and the uncondensed gases are compressed to about 250 psig and a complex absorption-fractionation system is used to separate the total product into the following fractions:

- Noncondensable gases
    - Hydrogen
    - Methane
    - Ethane
    - Ethylene
    - Inert Gases
- LPG
    - Propane
    - Propylene
- Butanes (optional)
- Gasoline
- Light Cycle Oil (#2 fuel oil)
- Heavy Cycle Oil (Returned to the reactor or blended into #6 fuel oil)

Each of these products is subjected to additional treatment or processing before release as salable product. Table 42 lists the product distribution(6) for typical FCC operations.

From the standpoint of air pollution control, the non-hydrocarbon feed materials – catalyst and air – are of significance.

Catalyst is added to the process for two reasons. Losses reduce the inventory in the unit and would cause reduced conversion if the lost material were not replaced. The principal functions of the internal cyclones is to prevent the loss of excessive catalyst with the gas, so that fresh catalyst additions can be minimized.

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*This is a term for heavy oils from which the asphalt has been removed by solvent extraction rather than by vacuum distillation.

TABLE 42

OPERATING RESULTS
FLUID CATALYTIC CRACKING PROCESS (6)

Catalyst	High Al_2O_3	Zeolite	Zeolite
Conversion	70	70	80
Yields (Volume Percent):			
Debutanized Gasoline	44.43	56.76	60.11
Light Cycle Oil	18.54	21.00	12.24
Heavy Cycle Oil	11.45	9.0	7.76
Butylenes	8.90	6.42	8.32
Butanes	8.13	7.37	9.49
Propylene	6.96	5.84	8.00
Propane	3.41	2.65	3.43
Fuel Gas, FOE*	5.69	3.10	4.48

*Fuel oil equivalent basis

TABLE 43

CALCULATED COMPOSITION OF GAS FROM FCC REGENERATOR AND CO BOILER

	From FCC Regen.		Aux. Fuel	Comb. Air	Total to CO Boiler	Total from CO Boiler	
	Vol. %	SCFM	SCFM	SCFM	SCFM	SCFM	Vol. %
CH_4	–	–	1,600	–	1,600	–	–
CO	9.5	8,550	–	–	8,550	–	–
CO_2	10.0	8,940	–	–	8,940	18,940	16.0
N_2	69.7	61,300	–	25,400	86,700	86,700	73.4
O_2	1.0	880	–	7,460	8,340	880	0.7
Water Vapor	9.6	8,610	–	–	8,610	11,720	9.9
	100.0	88,280	1,600	32,860	122,740	118,240	100.0

The cyclones must retain not only the powdered catalyst of the particle size range added to the unit, but they must also limit the loss of fine material produced by attrition or breakage of the catalyst particles. Modern cyclones serve this process requirement satisfactorily, and often operate at efficiencies over 99.99% in multistage systems.

In addition to physical loss of catalyst from the FCC system there is a loss of activity which takes place gradually. This must also be corrected by the addition of new, fresh catalyst to the unit. The requirement for new catalyst addition to maintain activity runs from about 0.1 to 0.3 lb of new catalyst per barrel of combined feed.

In order to add this much catalyst to the system, an equivalent volume must be removed from the system. The mechanisms available for removal are:

1. loss through the regenerator cyclones
2. loss through the slurry settler or the reactor cyclones
3. manual withdrawal

In most cases cyclone losses are substantially less than the required catalyst addition rate and it is necessary to manually withdraw some catalyst. The withdrawals and additions of catalyst may be continuous, or intermittent.

NATURE OF THE GASEOUS DISCHARGE

The effluent from the FCC regenerator consists of the products of combustion of coke burned off the catalyst with the regenerator air. The important variables in establishing the gas flow rate and composition are:

1. the rate of coke burning
2. the completeness of combustion of carbon to CO_2.

The coke burning rate is influenced by a number of variables, some of which are properties of the charge stock, and others which are under the control of the operators. The coke make tends to run between 5 and 10 percent by weight of the fresh feed. Operation with very heavy charge stocks, or poorly deasphalted materials tends to increase the coke make. Operation at very high catalyst/oil ratios also tends to raise the coke make.

However, it is not possible to allow the coke burning rate to vary independently of other considerations. The size of the regenerator air blower may limit the throughput of feed. For example, if the regenerator air blower is limited to 50,000 SCFM, the coke burning rate will be limited to around 23,000 lb/hr. Operating conditions which tend to produce coke faster than this rate cannot be sustained. The unit is said to be limited by coke burning capacity if the charge rate is limited in this way.

Similarly, the necessity for the entire unit to run in heat balance places restrictions on the rate at which coke can be burned off of the catalyst. It is necessary that the heat produced by burning coke in the regenerator just equal the heat leaving with the flue gas, plus that absorbed by the processes taking place in the reactor.

Changes in the feed stock, the type of catalyst being used and the desired product mix all tend to produce changes in the coke make and the heat balance. For this reason it is desirable to size the gas treating equipment for the maximum coke burning rate which can be handled; that is, for the maximum rate at which flue gas can be generated with the regenerator air blower at its maximum capacity.

In order to establish the gas flow to a collector following a regenerator, but upstream of any CO Boiler, it is necessary to know:

1. the maximum air blower capacity
2. the ratio of hydrogen to carbon in the coke
3. the ratio of CO to CO_2 in the flue gas.

The blower capacity is specified as a part of the FCC unit design, and may be used for selection of abatement equipment. The actual maximum air rate established by operation of the FCC unit is more reliable and should be used if it is available.

The ratio of hydrogen to carbon in the coke influences the weight of coke which can be burned per standard cubic foot of air supplied by the blower. Usually this ratio runs around 7 to 9 wt. % hydrogen in the total coke, or nearly a 1:1 atomic ratio of hydrogen to carbon.

The ratio of CO/CO_2 is important for those cases where the gas cleaning equipment receives gas directly from the regenerator, whether or not a CO Boiler is used. The ratio ordinarily runs close to 1:1, or one mol of CO per mol of CO_2. However, regenerator design and operating conditions can influence the ratio significantly. Increases in residence time in the regenerator tend to increase the ratio, as the carbon tends to burn to CO_2 which in turn reacts with carbon according to

$$CO_2 + C \rightarrow 2CO.$$

The conditions specified by the FCC unit designer may be used, but actual operating experience is preferable for existing units.

Where the CO Boiler is located ahead of the gas cleaning equipment, as shown in Figure 21, the design ratio of CO/CO_2 is significant only to the extent that it can be used to calculate how much additional air will be required for combustion of the CO. In order to properly burn the CO, auxiliary fuel must be added to achieve the proper combustion temperature. Therefore, when designing gas cleaning equipment to follow a CO Boiler, the design exhaust gas conditions from the CO Boiler should be used, and these modified by actual operating experience whenever it is possible.

The composition of major gas components for flue gases from a FCC regenerator and from the corresponding CO boiler are calculated on the basis of a 1:1 ratio of hydrogen to carbon in the coke, and a 0.95:1 ratio of CO/CO_2 in the effluent from the regenerator. The results are shown in Table 43 for a FCC unit with a coke burning capacity of 33,000 lb/hr. Sufficient auxiliary fuel is added to bring the total heat content of the feed gases to 60 BTU/SCF of total gas fired to the boiler. Values lower than about 50 are not ordinarily capable of sustaining combustion. Typically, larger amounts of auxiliary fuel and excess air are used to insure reliable operation.

NATURE OF GASEOUS CONTAMINANTS

Regeneration of catalyst in FCC units is carried out by burning coke off of the catalyst with air, and results in the formation and discharge of air contaminants. These contaminants arise due to thermal and catalytic oxidation reactions with the coke constituents, which include carbon, hydrogen, sulfur and nitrogen containing compounds. Particulate contamination also is caused by fine or low micron size materials present in the initial catalyst charge and generated by attrition of the catalyst during processing. Typical amounts of contaminants produced by regeneration shown in Table 44(4) have been estimated based on a number of FCC units.

TABLE 44

TYPICAL CONTAMINANT RATES FROM FCC UNIT REGENERATORS

Contaminant	lb/hr
Carbon monoxide	36,940
Sulfur dioxide	828
Hydrocarbons	351
NO_x as nitrogen dioxide	122
Particulate matter	99.6
Ammonia	87.2
Sulfur trioxide	49.7
Aldehydes as formaldehyde	32.8
Cyanides as hydrogen cyanide	0.50
	38,510.8

TABLE 45

EMISSIONS FROM FCC REGENERATOR

	lb/hr	Mol/hr	Vol. %	PPM
CO_2	61,100	1,388	10.0	–
N_2	27,132,000	9,333	69.7	–
O_2	4,410	137.7	1.0	–
Water Vapor	23,710	1,317	9.6	–
(Contaminants)	(38,510)	(1,348)		
CO	36,940	1,319	9.5	–
SO_2	828	11.4	0.093	930
HC (as C_3)	351	8.0	0.057	570
NO_x (as NO_2)	122	2.70	0.019	190
Particulate	99.6	–	–	(0.13 gr/SCF)
NH_3	87.2	5.13	0.035	350
SO_3	49.7	0.62	0.005	50
Aldehydes (as formaldehyde)	32.8	1.08	0.007	70
Cyanides (as HCN)	0.5	0.018	0.0002	2
	27,252,730	13,523	100.0	–
Combustion Air, SCFM				
Flue gas, SCFM		88,280		
Flue gas, ACFM @ 1200° F		276,300		

These can be placed in better perspective for consideration as air pollutants by casting them in terms of their concentration in the regenerator flue gas. This is done on the basis of a hypothetical regenerator with 9% CO by volume in Table 45.

The carbon monoxide (CO) waste heat boiler converts essentially all of the carbon monoxide to carbon dioxide. In addition, other combustibles such as hydrocarbons, ammonia, aldehydes and cyanides are also oxidized in the CO Boiler, and leave as H_2O, CO_2 and N_2.

After conversion of carbon monoxide in the CO Boiler, the principal contaminant remaining is particulate matter. This particulate matter is comprised of catalyst particles which were passed through the cyclone separator. The amount of particulate can vary widely with the type of catalyst used, the operation conditions and the number, as well as the condition of cyclone stages used. Particulate emission rates for a number of FCC unit stacks were reported by Sussman(7) as follows:

Total particulate, lb/hr*
57.50
61.00
181.00
58.70
28.30
6.42

The chemical composition of the solids discharged from the FCC regenerators differ little from the composition of equilibrium catalyst, as shown in Table 41. The properties of the particulate contaminants of the greatest importance with respect to air pollution abatement are given in Table 46.

*Note: Plant capacities were not available.

POLLUTION CONTROL CONSIDERATIONS

FCC units with CO Boilers ordinarily require additional particulate collection equipment in order to achieve acceptable pollutant emission. While adding an external cyclone stage will reduce particulate emissions, and may produce relatively clear stacks on small units, optimum results require more efficient collection devices. Electrostatic precipitators have been widely used on FCC units to provide high particulate removal efficiencies. Wet scrubbers of the high energy Venturi type also offer the capability for acceptable particulate reduction; however, these have not been used to date for FCC service. Fabric collectors are considered unsuitable because of the temperature variability.

Electrostatic Precipitators

Electrostatic precipitators can be used efficiently for particulate collection on FCC units. Power requirements are low and in the range of 35 KVA for small units to 140 KVA for the larger units(4). Precipitators are installed either ahead of or after the CO Boiler on FCC units. With installation ahead of the CO Boiler, a flue gas heat exchanger is required to reduce the gas temperature entering the precipitator.

The wide range of possible pressures, temperatures and moisture concentrations which can be selected makes the application of electrostatic precipitators to FCC units particularly challenging. The size of the unit is minimized by installation on the upstream side of the CO Boiler. This is due to the fact that the auxiliary fuel and combustion air do not pass through the precipitator. However, mechanical design considerations require the installation of a gas cooler or steam generator to reduce the temperature before it is introduced into the casing.

Design for operation at the regenerator pressure further reduces the volume of gas to be treated, but the cost reduction is more than offset by the high cost of the casing.

The temperature chosen for the outlet of the gas cooler is of prime importance. Temperatures in the 600 to 700° F range provide a good compromise between optimizing mechanical design, which becomes more difficult at higher temperatures, and acceptable resistivity of the collected catalyst, which generally improves with increasing temperature.

Generally, the resistivity of the particulate matter collected is too high for

TABLE 46

TYPICAL PROPERTIES OF FCC CATALYST FINES

PARTICLE SIZE DISTRIBUTION RANGE

Size, Microns	Fine	Coarse
< 10	77	50
> 10 but < 20	21	24
> 20 but < 40	2	23
> 40 but < 80	Trace	3*
	100	100

Electrical Resistivity, ohm-cm(9) at 350° F, 25% H_2O	5×10^{11}
same with ammonia added	1.4×10^{10}
Density, g/cc of particles	1.6
Density (apparent bulk density) lb/ft^3	25-30

*When more than 3 wt. % is greater than 40 microns, there is usually something wrong with the cyclone system.

optimum performance of the precipitator without one or more circumstances operating to reduce the resistivity. Some of the factors effective in bringing about decreased resistivity, or of "conditioning" the particulate matter are

1. High carbon or coke content
2. High gas temperature
3. Presence of adsorbable electrolyte materials, such as
    a. Ammonia
    b. Ammonium Sulfate
    c. Diethanolamine

In the case of electrolyte conditioning agents, water vapor in the effluent also contributes somewhat to improved performance. High temperatures tend to reduce the effectiveness of electrolytes and water vapor, however.

Where the precipitator is installed after the CO Boiler, a significantly higher gas volume must be handled, but the precipitator casing may be designed for near-atmospheric pressure, and many of the mechanical problems associated with pressure design can be eliminated.

Temperature is an important variable in the case of installation after the CO Boiler. High temperatures cannot be used because of the loss in boiler efficiency. The same basic factors affecting resistivity operate at this location, but with some significant differences.

1. The particulate matter is burned cleaner; there is less coke remaining on it.
2. The natural "conditioning agents" present in FCC gas such as NH_3 and SO_3 tend to decompose in the furnace.
3. The lower pressure reduces absorption of water vapor and electrolytes.

These factors all tend to make the resistivity higher and the dust more difficult to collect at atmospheric pressure following the CO Boiler. In many installations, ammonia injection is used ahead of the precipitator to decrease electrical resistivity of the collected solids in order to obtain high particulate removal efficiency.

Wet Scrubbers

High energy wet scrubbers offer an alternative abatement approach. Energy in the flue gas stream is available to supply the power requirements for efficient scrubbing. Both water consumption and steam plume formation will depend to a large extent on inlet gas temperatures at the scrubbers. For this reason it is desirable to locate these in a manner to process flue gas with the lowest possible temperature.

Two approaches suggest themselves here. One involves the use of a Venturi scrubber ahead of the CO Boiler preceded by a high efficiency steam generator to reduce the regenerator flue gas temperature to a low level, say 350° F. The Venturi scrubber would then operate as a partial throttling device, and pressure differences of 100 or more inches water column could be utilized without any cost for gas moving equipment or power. Operation at this velocity would, however, make the scrubber subject to high erosion rates. This is particularly significant since continuous operation for periods as long as three years is normal practice. The CO Boiler would require more auxiliary fuel to sustain combustion and would operate at a somewhat lower efficiency level. However, the two largest drawbacks associated with scrubbers (the high power cost and the steam plume formation) would be eliminated. Very high efficiencies can be projected for scrubbers at this energy level.

The other approach involves application of the scrubber to the CO Boiler discharge. Here it is unlikely that the boiler will be capable of withstanding the pressure required to push the gas through the scrubber (40 inches w.c. minimum, or about 1.3 psi). Therefore a fan capable of moving the gas through the scrubber and a heat exchanger or reheat burner will be required.

In addition, several problems are associated with the handling and disposal of the catalyst/water slurry produced by the scrubber. The catalyst cannot be returned to the regenerator. To do so would set up a high recirculation rate between the regenerator and the pollution control equipment and defeats the purpose of the pollution control equipment. In most cases, the disposal of the water will be difficult, and water recycle will be required in the majority of cases.

Due to the large size of FCC units and the large volumes of regenerator flue gas produced, space considerations are a prime factor. The piping and ductwork required to install a precipitator represents a major portion of installation cost, and convenience of location can, therefore, affect these costs significantly. Wet scrubber installations will be similarly affected. They will, however, require less space adjacent to the FCC than precipitators since thickeners and/or settling ponds may be located at some distance from the FCC.

Application of either electrical precipitators or high energy wet scrubbers should both be evaluated economically for the specific installation involved. Precipitators can be of carbon steel construction while corrosion and erosion resistant construction is required for wet scrubbers. The precipitator provides a dry collection of particulate and presents a dry particulate disposal consideration. Wet scrubbing will recover a water slurry stream containing catalyst particulate which will also require disposal consideration and possibly additional processing. However, wet scrubbers can be used for gaseous pollution control as well as particulate control, and this may be an important consideration where SO_2 emissions must be abated.

There is some potential for use of the particulate collection device to collect catalyst for return to the process. However, this is likely to be a marginal operation. First the catalyst would have to be classified and that portion smaller than 20 microns discarded. This step is necessary to prevent recirculating small particles between pollution control device and regenerator. For example, a 60 lb/hr catalyst loss, if fully returnable to the process, would have an operating credit of

$$\frac{60 \text{ lb/hr} \times 24 \text{ hr/day} \times \$400/\text{ton}}{2000 \text{ lb/ton}} = \$288/\text{day}$$

This is likely to be unrealizable because:

1. Most of the collected material is too fine for return to the regenerator, and

2. The amount which must be discarded to accommodate the desired activity level is likely to be 60#hr or more.

However, the potential for some economic payback may be significant for special cases.

SPECIFICATIONS AND COST

Equipment specifications have been written only for the case of control by an electrostatic precipitator. Those specifications appear in Tables 47 and 48. Cost data generated from those specifications appear in Tables 49 and 50. Capital costs are presented in Figure 22. The primary collector averages about one-third of the total system price. Turnkey installation prices are shown in Figure 24 along with the 75% and 90% statistical confidence limits. Confidence limits for the precipitator alone are shown in Figure 25.

One quotation was also received for tertiary cyclones operating in the same service. Cost data from this quote are presented in Tables 51 and 52. The capital costs are shown in Figure 26. These costs show much greater sensitivity to plant size than do the comparable costs for precipitators. They also indicate that the installation cost is a lower fraction of the total system price.

Operating costs for precipitators are presented in Figure 23. Operating costs for cyclone are shown in Figure 27. As in the case of capital costs, operating cost of cyclones is much more sensitive to size than precipitators. Cyclone costs fall between the costs of precipitators operating at low and high efficiency.

Table 47

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR FLUIDIZED BED CATALYTIC CRACKING UNIT SPECIFICATION

A single electrostatic precipitator is to treat the regenerator flue gas from a conventional FCC unit with a CO Boiler. The FCC unit processes a combination of atmospheric and vacuum gas oils from a typical midcontinent crude oil.

Both the FCC and CO Boiler are new, and are expected to operate within the design limitations given in the attached specifications. The regenerator air blower is to be assumed to limit the carbon burning rate to the level indicated. Regenerator superficial velocity is 2.5 FPS maximum. Catalyst is to be "high alumina" silica-alumina initially, but molecular sieve type catalysts will be used in the future.

The flue gas from the regenerator passes through a pressure reducing manifold and slide valve to reduce the gas pressure from approximately 25 psig to approximately 6" w.c. pressure before introduction into the CO Boiler. Air and natural gas auxiliary fuel are also supplied to the burners.

The precipitator is to continuously reduce the particulate content of the flue gas leaving the CO Boiler to the levels specified. A minimum of two fields in the direction of gas flow must be provided to reduce the effect of an electrical failure.

The precipitator must be equipped with hoppers capable of retaining the dust collected over 24 hours of normal operation. During normal operation the hoppers will be emptied by a screw conveyor discharging into a dust bin, with a 15 ft elevation above grade to allow for truck loading. The storage bin will be located adjacent to the precipitator and will be sized for seven days storage capacity. Automatic voltage control shall be provided to maximize operating efficiency. Rappers shall be adjustable both as to intensity and rapping period. The precipitator shall be equipped with a safety interlock system which prevents access to the precipitator internals unless the electrical circuitry is disconnected and grounded. A safety interlock shall be provided to automatically de-energize the precipitator in the event of flame failure in the CO Boiler.

A model study for precipitator gas distribution will be required. The precipitator, dust handling equipment and auxiliaries are to be included in the vendors proposal. The stack will be supplied by the CO Boiler contractor.

Table 48

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR FLUIDIZED BED CATALYTIC CRACKING UNIT SPECIFICATION

Two sizes of electrostatic precipitators are to be quoted for each of two efficiency levels. Vendors quotation should consist of four separate and independent quotations.

	Small (low loading)	*Large (high loading)*
Unit Size, BPSD		
Fresh feed	*9,400*	*40,000*
Recycle feed	*1,000*	*10,000*
Combined feed	*10,400*	*50,000*
Catalyst circulation rate, ton/hr.	*1,040*	*5,000*
Coke burnoff rate, lb/hr	*8,000*	*38,000*
Process weight, lb/hr	*2,200,000* ***	*10,000,000* ***
CO Boiler outlet gas		
Flow, ACFM	*70,000*	*335,000*
Temp., °F	*470*	*470*
% Moisture	*9.9*	*9.9*
Precipitator inlet loading, lb/hr	*27*	*278*
Precipitator inlet loading, gr/ACF	*0.045*	*0.10*
Case 1 – Moderate Efficiency		
Outlet loading, lb/hr	*40*	*40*
Outlet loading, gr/ACF	*0.10*	*0.014*
Efficiency, wt. %	*No Collection Required*	*86***
Case 2 – High Efficiency*		
Outlet loading, lb/hr	*9*	*43*
Outlet loading, gr/ACF	*0.015*	*0.015*
Efficiency, wt. %	*70***	*85***

**NOTE: Removal of particulate matter at 470°F does not assure a color free effluent.*

***This specification may be satisfied by a third stage mechanical cyclone.*

****Process weight is the weight of catalyst circulated to the regenerator.*

TABLE 49

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR ELECTROSTATIC PRECIPITATORS FOR
FCC UNITS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	70,000	335,000	70,000	335,000
°F	470	470	470	470
SCFM				
Moisture Content, Vol. %	9.9	9.9	9.9	9.9
Effluent Dust Loading				
gr/ACF	0.045	0.10	0.045	0.10
lb/hr	27	278	27	278
Cleaned Gas Flow				
ACFM	70,000	335,000	70,000	335,000
°F	470	470	470	470
SCFM				
Moisture Content, Vol. %	9.9	9.9	9.9	9.9
Cleaned Gas Dust Loading				
gr/ACF	0.045	0.014	0.015	0.015
lb/hr	27	40	9	42
Cleaning Efficiency, %	none	86	67	85
(1) Gas Cleaning Device Cost		249,333	78,233	249,333
(2) Auxiliaries Cost		44,667	25,934	44,667
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost		487,167	159,400	487,167
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost		781,167	263,567	781,167

TABLE 50
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS
FOR FCC UNITS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,000				
Operating Labor (if any)					
Operator	$6/hr	-	300	300	300
Supervisor	$8/hr	-	-	-	-
Total Operating Labor		-	300	300	300
Maintenance					
Labor	$6/hr	-	1,968	672	1,968
Materials		-	500	150	500
Total Maintenance		-	2,468	822	2,468
Replacement Parts		-	7,400	2,275	7,400
Total Replacement Parts		-	7,400	2,275	7,400
Utilities					
Electric Power	$.011/kw-hr	-	25,052	15,675	25,052
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify (Ammonia)	$.03/lb	-	8,940	2,160	8,940
Total Utilities		-	33,992	17,835	33,992
Total Direct Cost		-	44,160	21,232	44,160
Annualized Capital Charges		-	78,117	26,357	78,117
Total Annual Cost			122,277	47,589	122,277

FIGURE 22

CAPITAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR FCC UNITS

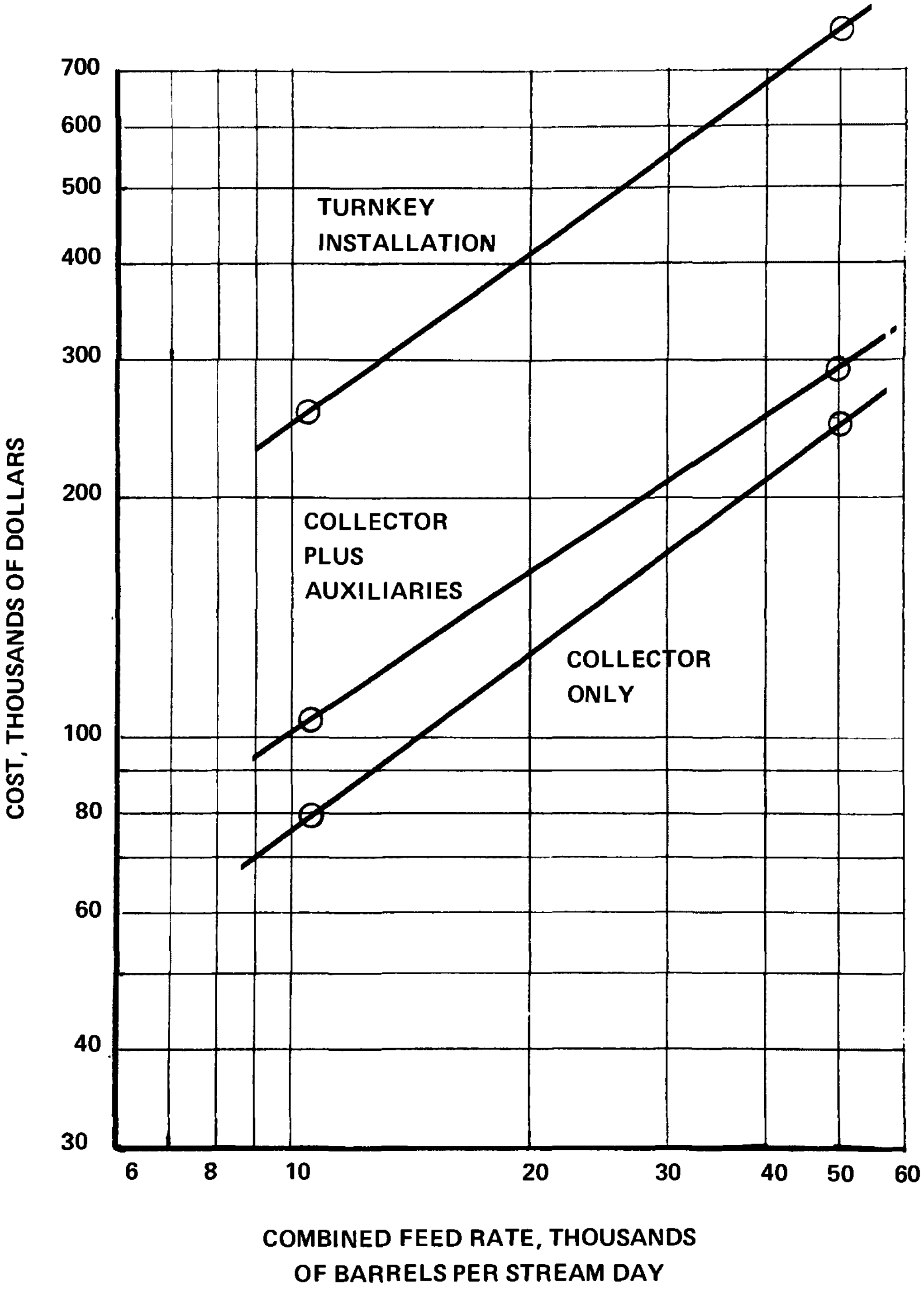


FIGURE 23

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR FCC UNITS

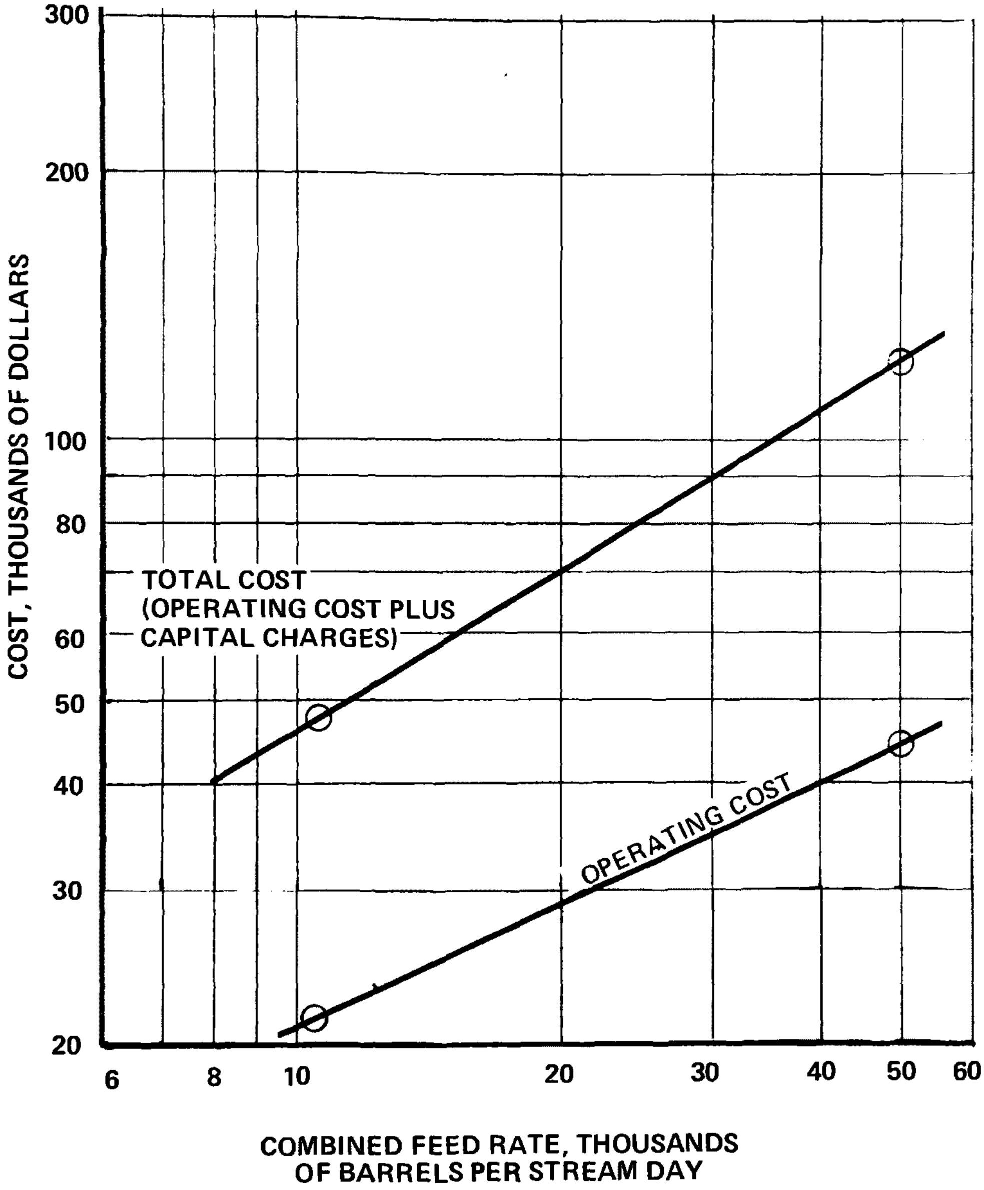


FIGURE 24

CONFIDENCE LIMITS FOR CAPITAL COST OF INSTALLED ELECTROSTATIC PRECIPITATORS FOR FCC UNITS

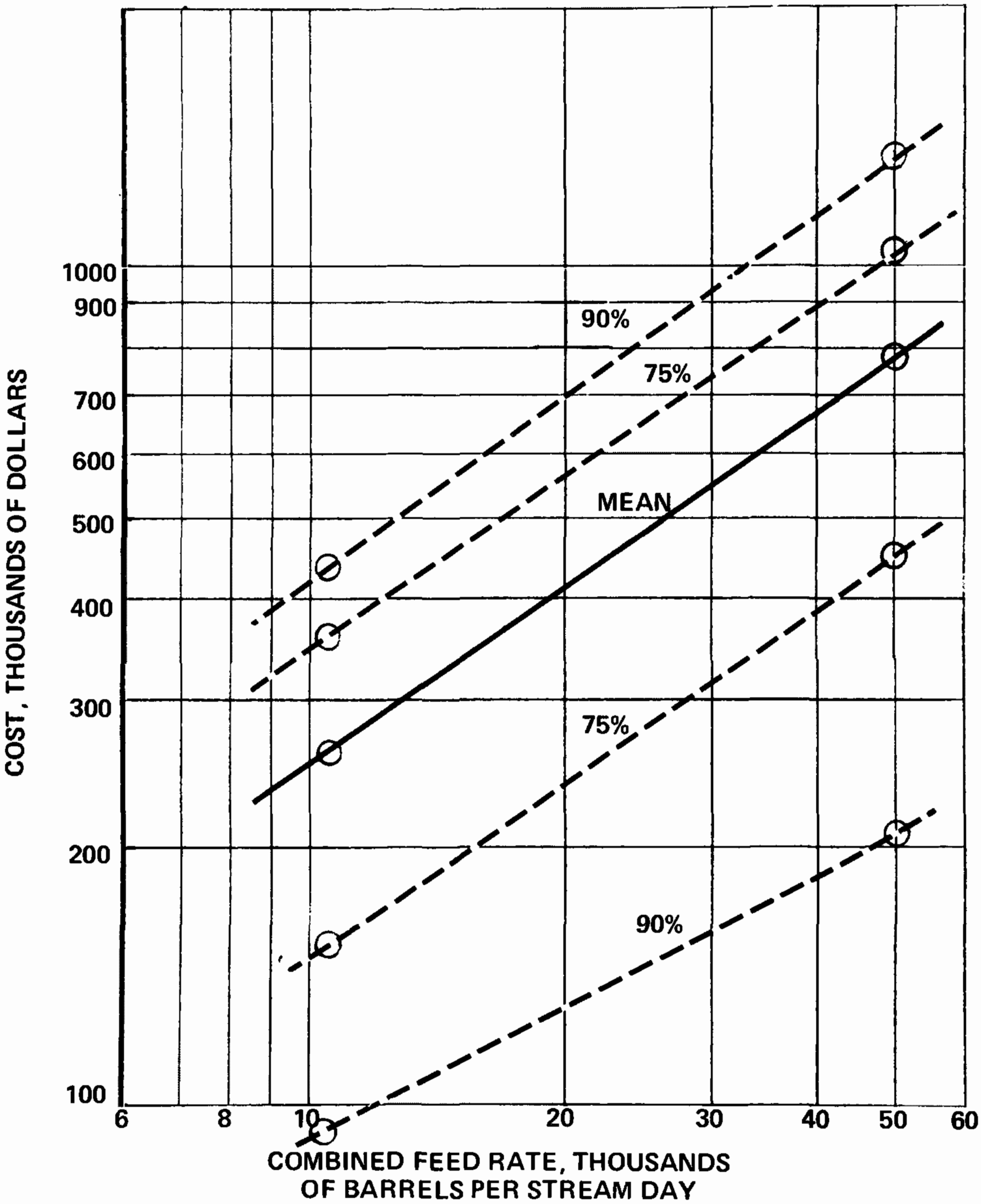


FIGURE 25

CONFIDENCE LIMITS FOR CAPITAL COST OF PRECIPITATORS ONLY FOR FCC UNITS

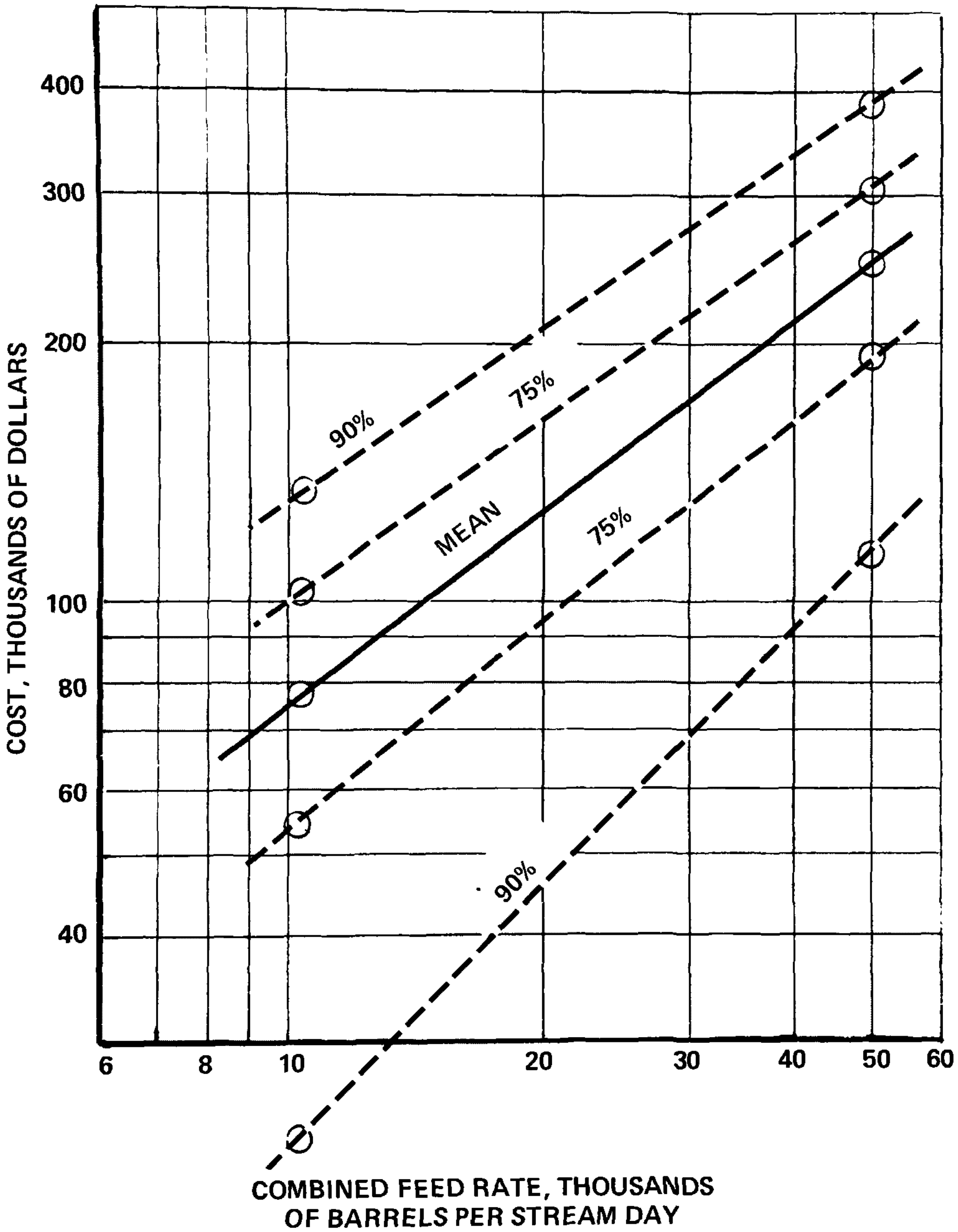


TABLE 51

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR TERTIARY CYCLONES
FOR FCC UNITS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM				
°F	1,200	1,200	1,200	1,200
SCFM	28,000	133,300	28,000	133,300
Moisture Content, Vol. %	15.0	15.0	15.0	15.0
Effluent Dust Loading				
gr/ACF	0.09	0.2	0.093	0.2
lb/hr	27	278	27	278
Cleaned Gas Flow				
ACFM	34,500	164,000	34,500	164,000
°F	1,175	1,175	1,175	1,175
SCFM	28,000	133,300	28,000	133,300
Moisture Content, Vol. %	15.0	15.0	15.0	15.0
Cleaned Gas Dust Loading				
gr/ACF		0.0143(1)	0.0095(1)	0.0143(1)
lb/hr		41.1	5.7	41.1(2)
Cleaning Efficiency, %		85.2	78.9	85.2(2)
(1) Gas Cleaning Device Cost	-	563,300(3)	85,200(3)	563,300(3)
(2) Auxiliaries Cost				
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment	-			
(e) Dust Disposal Equipment		25,000	12,000	25,000
(3) Installation Cost				
(a) Engineering		22,500	5,100	22,500
(b) Foundations & Support		55,000	12,500	55,000
(c) Ductwork		18,000	4,100	18,000
(d) Stack		-	-	-
(e) Electrical		-	-	-
(f) Piping		-	-	-
(g) Insulation		4,000	1,000	4,000
(h) Painting		-	-	-
(i) Supervision		4,100	900	4,100
(j) Startup		-	-	-
(k) Performance Test		1,500	1,500	1,500
(l) Other		-	-	-
(4) Total Cost	-	693,400	122,300	693,400

(1) Based on flow leaving CO Boiler and Cyclone pressure drop of 1.3 psi

(2) Could be designed for 40 lb/hr at slightly higher pressure drop

(3) This device normally installed ahead of CO Boiler, 40% of the weight of the gas leaving the CO Boiler was assumed at the cyclone

TABLE 52
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR TERTIARY CYCLONES
FOR FCC UNITS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,000				
Operating Labor (if any)					
Operator			-	-	-
Supervisor					
Total Operating Labor					
Maintenance					
Labor			1,000	1,000	1,000
Materials					
Total Maintenance					
Replacement Parts			-	-	-
Total Replacement Parts					
Utilities					
Electric Power					
Fuel					
Water (Process)			-	-	-
Water (Cooling)					
Chemicals, Specify					
Total Utilities					
Total Direct Cost			1,000	1,000	1,000
Annualized Capital Charges			69,340	12,230	69,340
Total Annual Cost			70,340	13,230	70,340

FIGURE 26
CAPITAL COSTS FOR TERTIARY CYCLONES
FOR FCC UNITS

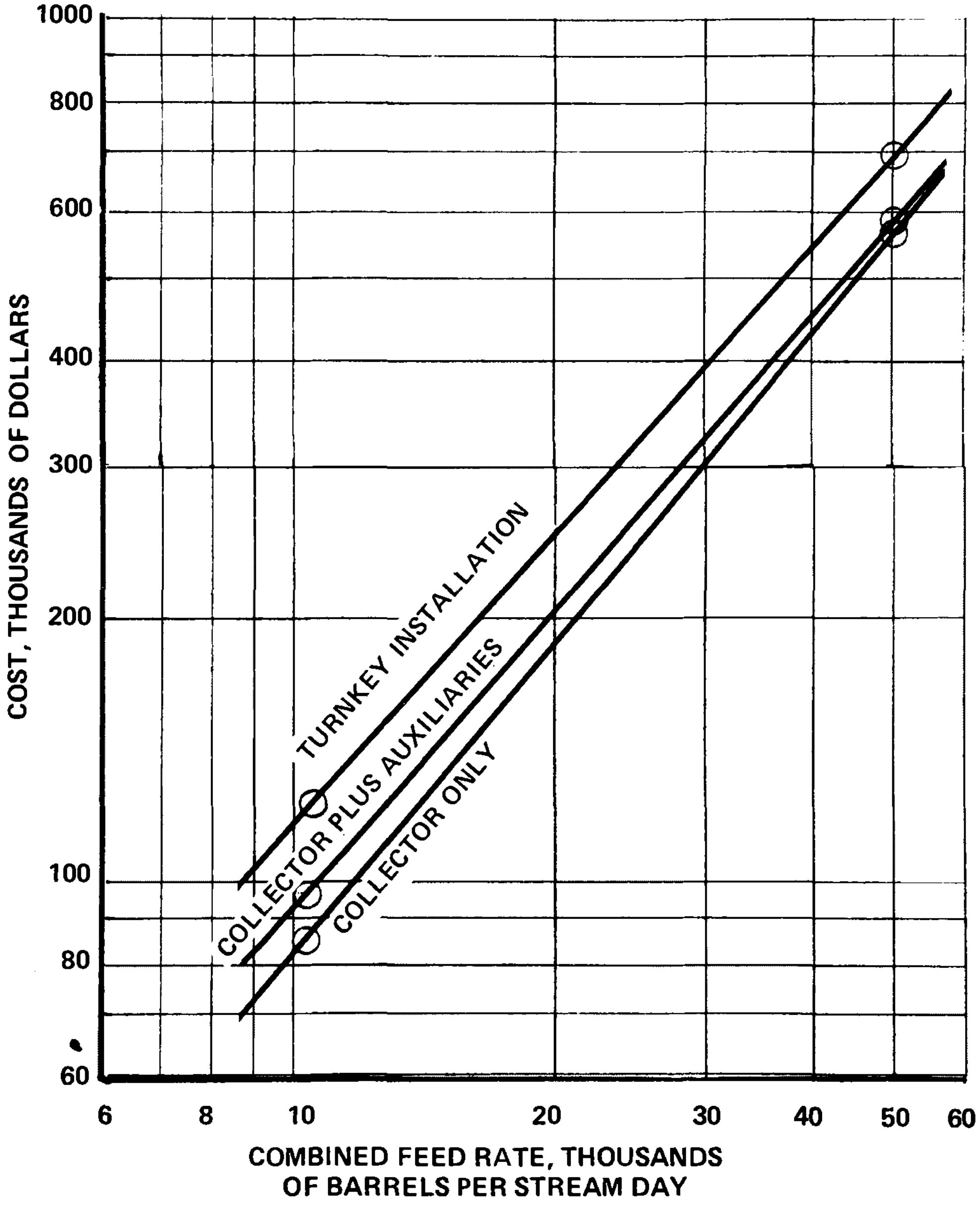
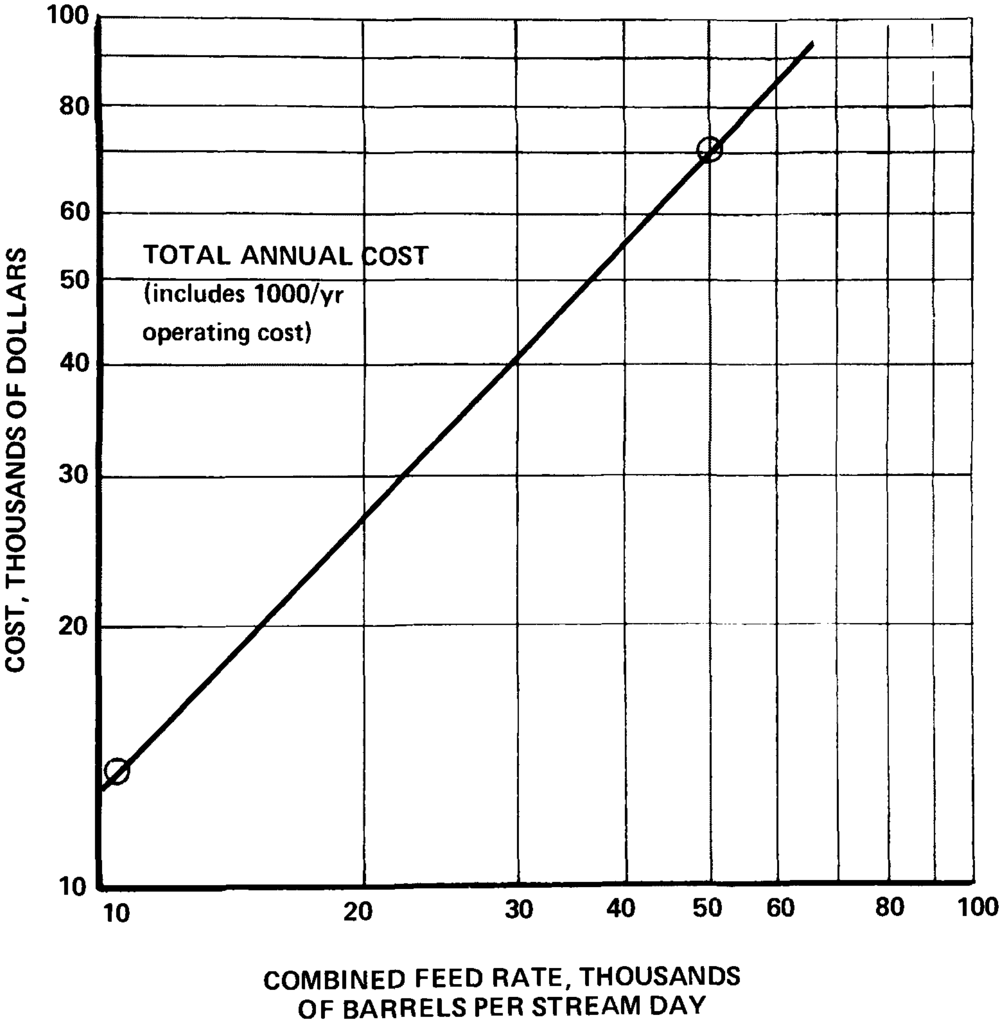


FIGURE 27
ANNUAL COSTS FOR TERTIARY CYCLONES FOR FCC UNITS



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ASPHALT BATCHING

3. ASPHALT BATCHING INDUSTRY

Hot-mix asphalt plants produce the familiar asphalt paving material which consists of an aggregate of mineral load-bearing material that has been uniformly mixed with hot asphalt cement in a batch production process. As each batch is completely mixed, it is loaded into waiting trucks for immediate transportation to the paving site, where it is deposited and then compacted by heavy rolling equipment. There is an emerging technology known as "Hot Storage" used by a few asphalt plants. In this technique a smaller dryer and a smaller mixer can be used to make paving material on a 24 hour a day basis and store it in the finished form. Delivery to the contractors doing the paving usually takes place only during a 6 to 8 hour day. The hot-mix asphalt industry in the United States produces about 251 million tons of paving material a year(7), but production is scattered among a number of small plants, producing about 100 to 200 ton/hr during the working hours of the local paving season. These plants are located near the sites of potential use, due to the great importance of transportation costs in overall profitability.

PROCESS DESCRIPTION

A typical configuration for such a hot-mix asphalt batch plant is given in Figure 28. The production flow in the plant starts with the cold aggregate which is stored in bins until required. At that time it is transported by elevator to a rotary drier which heats the aggregate and drives off surface moisture. In place of bins, many plants use open pile storage with front end loader retrieval and feed to the drier. The hot aggregate, as it leaves the drier, is conveyed by elevator to a size classifier that commonly takes the form of a series of vibrating screens. Here, the hot aggregate is sorted into various size categories and is stored separately, by category, in bins just above the mixer. When a batch is to be mixed, proper portions of each size of aggregate are loaded into the mixer by means of a weigh hopper. In the mixer, the hot asphalt cement, as drawn from a heated tank, and possibly a very fine mineral filler, are added to the hot aggregate, and the batch is agitated until it is mixed thoroughly. When mixing is complete, the batch is loaded into trucks and transported to the paving site.

The equipment in a hot-mix asphalt batch plant varies from design to design; for example, conveyors may replace or supplement the aggregate elevators, or storage bins may be arranged differently. However, the most critical piece of equipment from the standpoint of emission abatement, the rotary drier, is usually of a fairly standard direct, countercurrent design, although other designs exist. Such a drier is basically a rotating cylinder which is inclined to the horizontal with a stationary oil or gas-fired burner on or near the axis at the depressed end, and the aggregate entrance at the elevated end. The aggregate is directly exposed to the burner flame, and the direction of the aggregate flow is opposed to that of the burner combustion gases (see Figure 29). Often the drier will contain internal flights to agitate the aggregate and further expose it to the heating and drying action of the combustion gas stream. In typical operations, the burner heats the aggregate to 250 to 450° F, and the gas stream has a velocity of 450 to 800 ft/min with a volume rate of 20,000 to 70,000 ACFM. The air flow through the drier is usually maintained by an exhaust fan and stack system, and the temperature and air flow are regulated as necessary to remove the maximum amount of aggregate surface moisture and heat the material.

Thus, the exact operating parameters of the rotary drier depend upon the desired production rate and the surface moisture of the aggregate. It has been determined, in general, that an increase in drier gas velocity permits an almost directly proportional increase in maximum production (see Figure 30*). However, the dust carryout increases in proportion to the square of the velocity (see Figure 31*). Thus, production and air flow levels must be balanced against increased dust loss in drier operation(1).

The other equipment in a hot-mix plant is fairly conventional in design and operation, and is, in any event, usually non-critical. However, such factors as the amount of aggregate transportation system enclosure and the quality of ventilation and burning in the asphalt and fuel oil heater burners should be examined in any analysis of emission potential.

FEED MATERIALS AND PRODUCTS

The raw materials for a hot-mix asphalt batch plant are essentially the aggregate, the asphalt cement, and the fuel, either oil or gas. Fuel oil or gas are, of course, excluded in any process weight consideration. Paving mixes are produced for different uses with correspondingly different characteristics, as determined primarily by the size distribution of the aggregate used. Although there are detailed mix classifications used within the industry which are based on more elaborate distribution specifications, the primary mix characteristics are determined by the fraction of the total aggregate in each of the following three categories:

Coarse aggregate	(retained on No. 8 mesh sieve)
Fine aggregate	(passing No. 8 mesh sieve)
Mineral dust	(passing No. 200 mesh sieve)

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*Courtesy of Barber—Greene

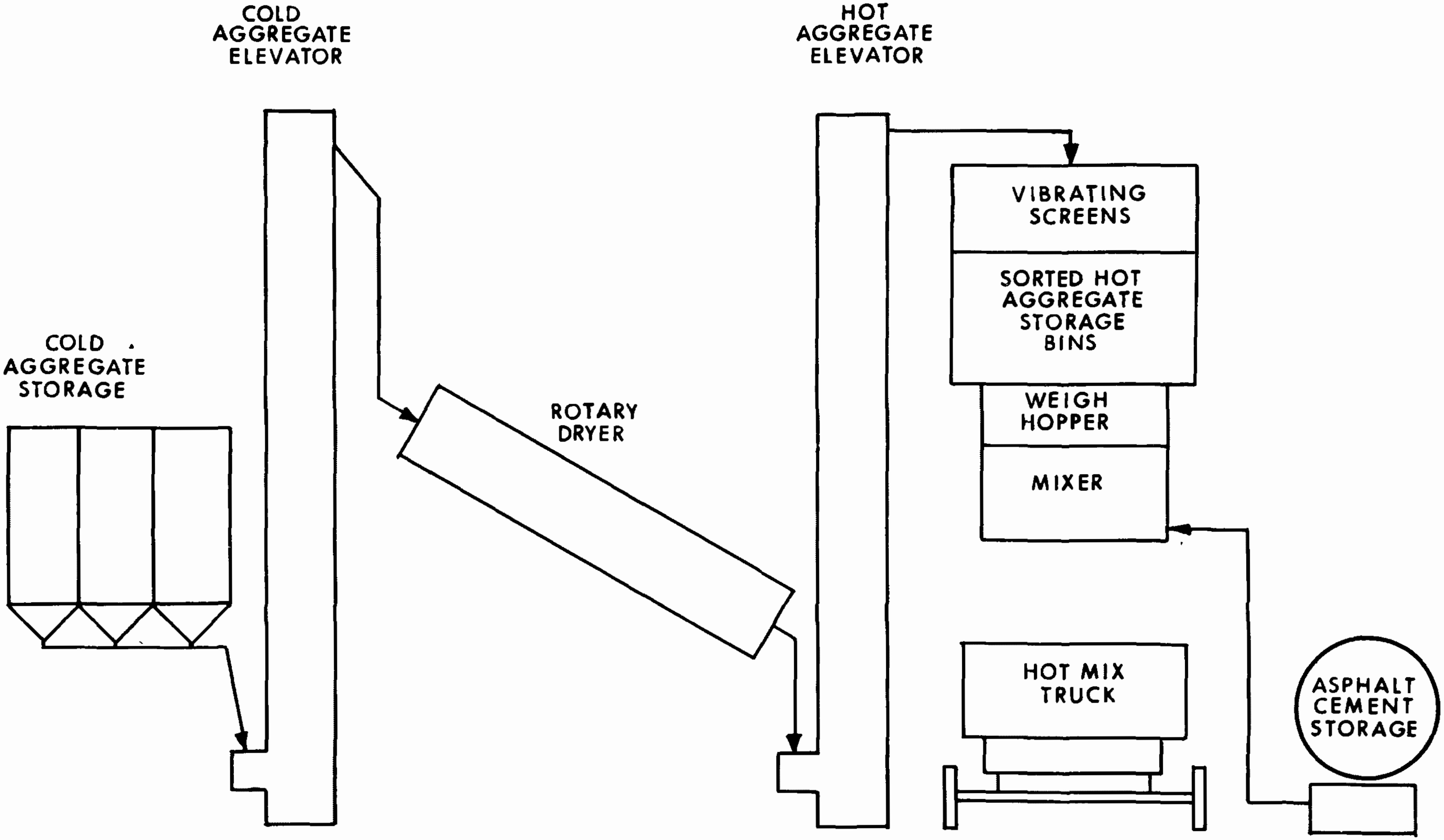


FIGURE 28

FLOW DIAGRAM FOR HOT-MIX ASPHALT BATCH PLANT

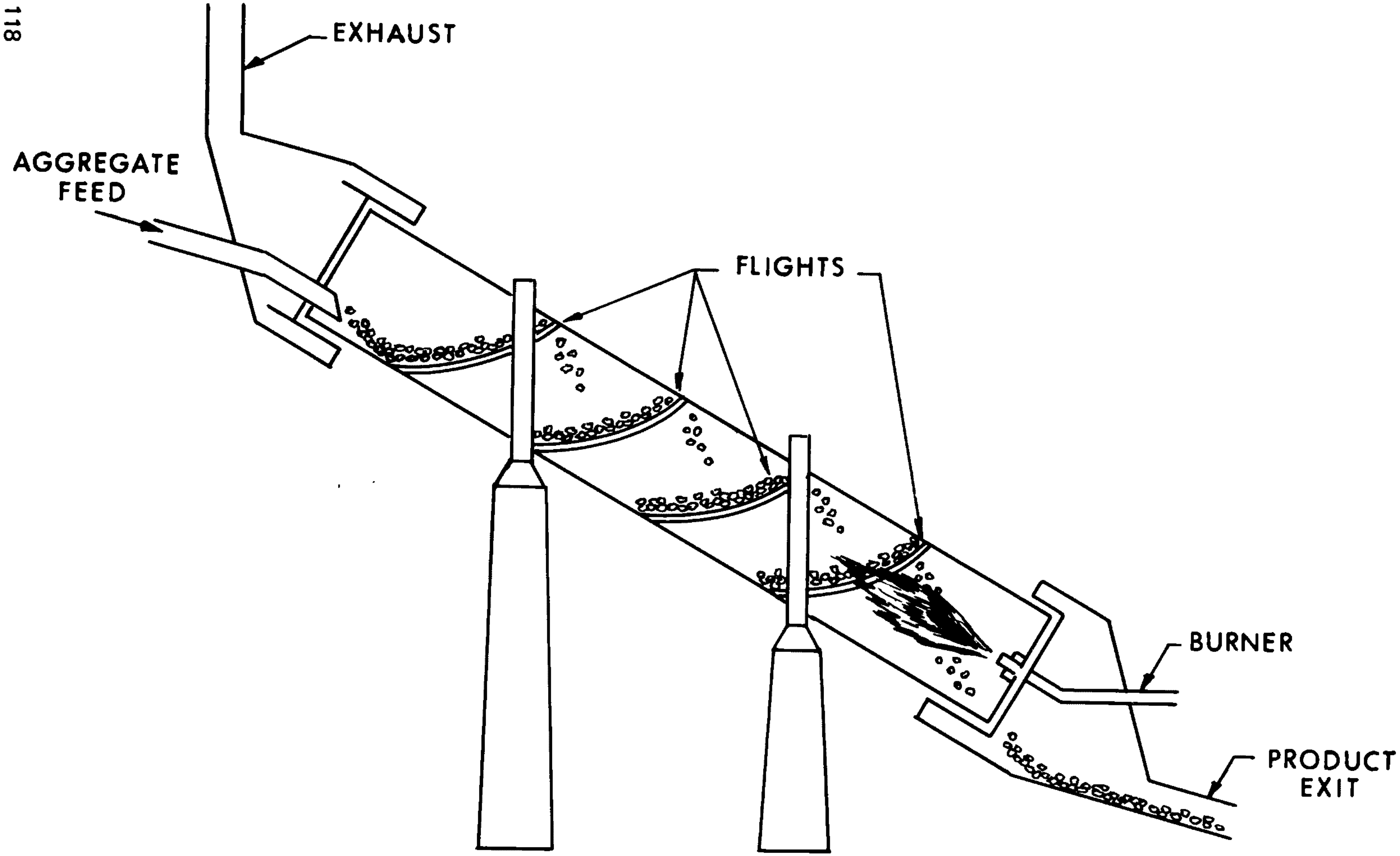


FIGURE 29

ROTARY DRIER CONFIGURATION

FIGURE 30

DRYER PRODUCTION CAPACITY
VS
DRUM GAS VELOCITY

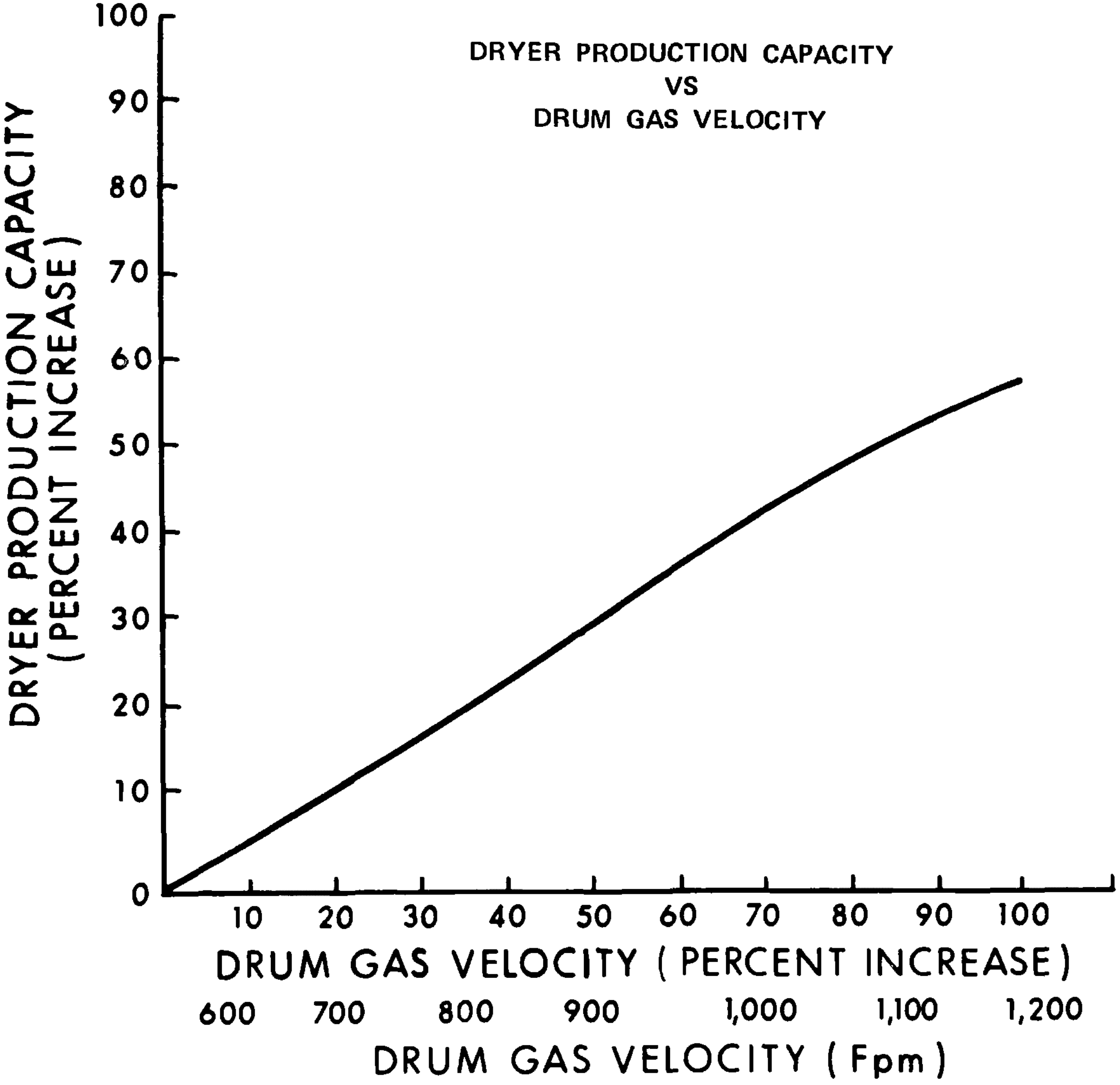
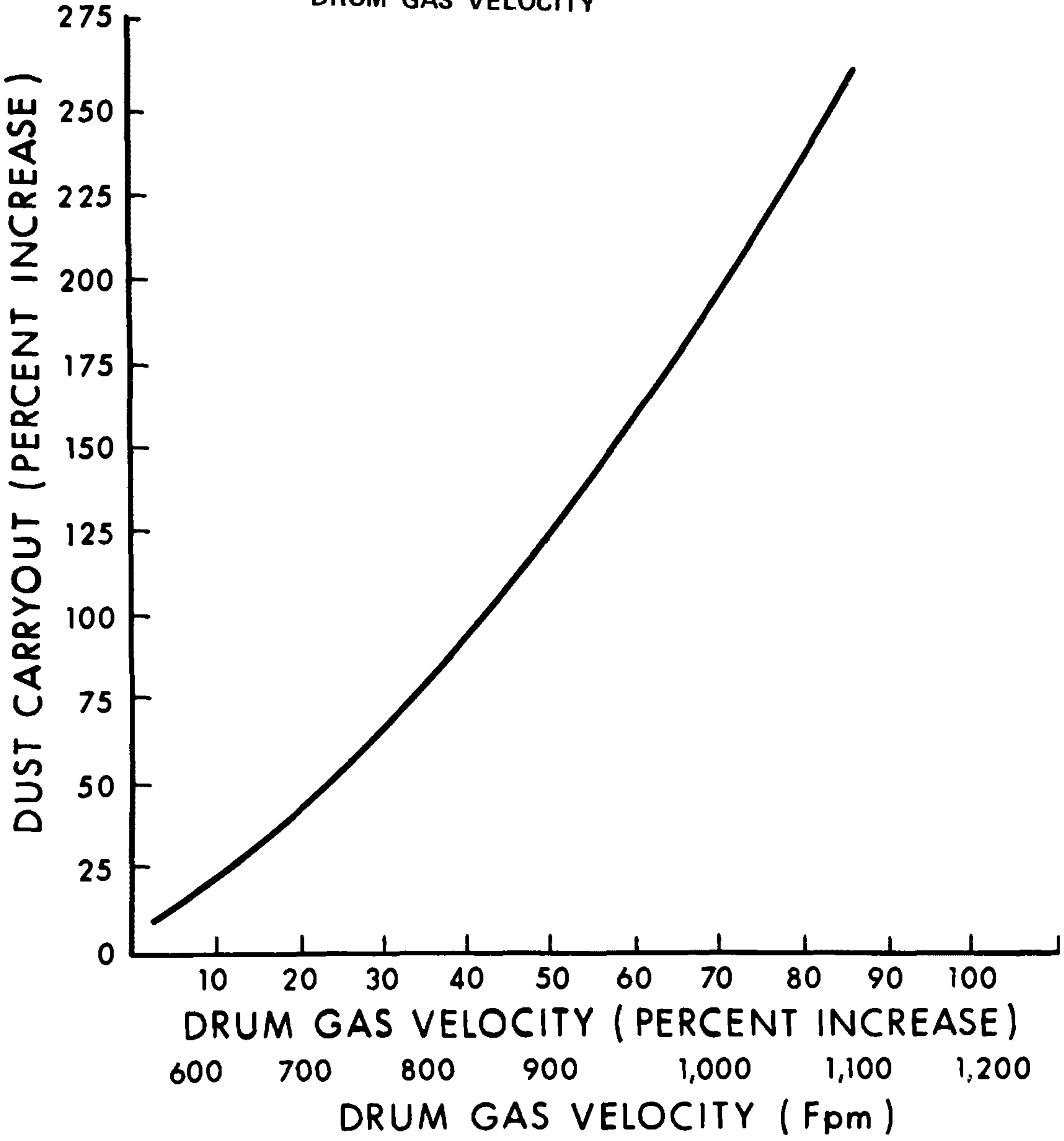


FIGURE 31

DUST CARRYOUT
VS
DRUM GAS VELOCITY



Coarse aggregate is used in all diameters up to 2-1/2 inches. This usually consists of crushed stone, slag, or gravel, or naturally fractured aggregate, or combinations thereof. Fine aggregate is usually natural sand with such added materials as crushed stone, slag, or gravel. Mineral dust is a special filler that is used in certain applications. It is usually finely ground particles of crushed rock, limestone, hydrated lime, Portland cement or other similar mineral matter.(1)

The asphalt cement is mixed at about 3 to 12% by weight with the aggregate in the final paving mix, depending upon the specific mix design and the end use. The asphalt is manufactured from crude petroleum, and is semi-solid at ambient temperature. On heating it becomes liquid in the range 275 to 375° F, at which it is stored and mixed. Thus, each batch plant must provide heat sources for the asphalt storage facilities. The asphalt cement is graded by an industrial classification or *penetration*. The proper penetration for a particular use is usually specified under local or state highway specifications.

The fuel used in the rotary drier and in the asphalt heaters is fuel oil or natural gas. Natural gas is a required fuel in some locations, but fuel oil is often used because of the lower cost. The grade of fuel oil is usually No. 6, and provisions for heating the oil to provide for efficient burning may be necessary if ambient temperatures are low.

NATURE OF THE AIR CONTAMINANTS

The air pollutant emissions from a hot-mix asphalt plant are both gaseous and particulate. Of these, the gaseous pollutants are the least troublesome and can occur in the following ways:

1. Combustion gases

    a. Combustion of high sulfur fuel oil in the drier and heater will produce SO_2 emissions.

    b. Poor combustion maintenance in the drier or heaters will lead to CO emissions.

2. Mixer — the entrance and mixing of the asphalt cement in the mixer will cause hydrocarbon emission.

3. Hot-mix trucks — significant odor primarily attributed to some oxidation of the liquid asphalt after encountering the hot aggregate.

The particulate pollution consists of:

1. Unburned fuel oil droplets – these result from poor combustion maintenance in the drier or heaters.

2. Soot – particles of unburned carbon that are emitted due to insufficient oxygen at the drier or heater burners.

3. Fly ash – noncombustible impurities which are emitted from the combustion of fuel oil.

4. Stone dust – this is the primary air pollutant from hot-mix asphalt manufacture. It results from the air flow in the drier carrying off fine particles of aggregate and from fine aggregate being thrown off during the transportation, screening and mixing processes.

A number of these emissions are not amenable to abatement through gas cleaning equipment or may more easily be corrected through a proper choice of fuels and proper combustion management. The odor problem from the loading of hot-mix trucks is an example of such a problem. Gas cleaning equipment is clearly not applicable here, but some success has been reported in curtailing the odor emissions through the coating of truck bodies with lime-water slurries instead of fuel oil or kerosene(3). In the latter category, SO_2 and fly ash emissions may be controlled by using fuel oil that has a lower sulfur and ash content, or switching to natural gas; while soot, unburned fuel oil droplets, and CO emissions may be reduced by the practice of good combustion management at all burners, which is desirable anyway.

If the above elementary emission abatement procedures are followed, the only emissions that will warrant consideration are the hydrocarbons released in the mixer and the production of stone dust in the aggregate handling. The hydrocarbon emission problem is a difficult one that can really only be handled by thermal incineration. However, this technique is not frequently used; the primary method of control is to maintain a tight enclosure of the mixer. This will certainly eliminate some problems, but, unless this enclosure is ventilated, it is quite likely that ground level leakage will occur. If the mixer enclosure is ventilated, the advisability of coupling this with the stone dust ventilating system will depend upon the ultimate design of the stone dust control system, as is discussed with the consideration of types of pollution control equipment. If separate ventilation of the mixer is attempted, minor amounts of stone dust should be anticipated in the exhaust. At the present time, such separate ventilation is uncommon and in most plants the mixer is merely closed and vented to the stone dust system.

The emission of stone dust from hot-mix plants is their primary air pollution problem. Dust is produced in the plant in two major areas; the first and most important is the rotary drier. In the drier, dust is produced by the gas flow picking up fine particles of aggregate and fracture dust from the aggregate and carrying it out in the exhaust gases. The second area of dust emission includes a variety of sources at which aggregate is handled; these may be termed collectively the "secondary sources", and the dust emitted from them "fugitive dust". These include the aggregate elevators, storage bins, screen classifier, and mixer. In a typical plant, the hourly weight production of stone dust from the drier is about 3 to 5 times that of the secondary sources and the total dust loss from the plant is about 40 pounds per ton of paving mix produced(1, 7). For a reasonably sized plant producing 150 tons of paving mix an hour, the dust emission is on the order of 6000 lb/hr. Therefore, the design of air pollution control equipment for the hot-mix asphalt batch plant is essentially for the regulation of these significant amounts of dust emission.

AIR POLLUTION CONTROL CONSIDERATIONS

The first step in controlling dust emission at any hot-mix plant is to completely enclose and ventilate all areas where dust is produced. At the drier, suitable equipment consists, at the exhaust end, of complete hooding to carry off the exhaust gases and entrained dust. At the burner end, the ventilation requirements are less critical. In most cases, a hood will not be required due to the large inflow of secondary combustion air. Where a hood is required, a suitable arrangement is a ring type hood between the stationary and rotating portion of the drier with a spacing that produces at least the standard 200 feet per minute in the opening between the drier and the hood (see Figure 32).

The sources of fugitive dust emission, including the storage bins, elevators, vibrating screens, and mixer, should be completely enclosed, and these enclosures should be ventilated as well. The volume rate sufficient for ventilation of these secondary sources is typically 3000 to 4000 ACFM.

Primary Collector

The air used for ventilation of the sources of dust emission must be treated to remove the entrained dust in order to avoid serious air pollution problems. However, these systems should be designed with the consideration that much of the entrained dust is valuable as a mineral dust filler in the mix and should be recovered if possible.

Therefore, it is usual for all dust sources to be ventilated in the same system and the air carried to a primary collector such as a cyclone or knockout chamber which will remove a sizable percentage (usually 50 to 90% by weight) of the entrained dust, mostly of the larger sizes[8] (see Table 53), and return it to the system at the hot aggregate storage bins or some other point, in the form of mineral dust. This primary mechanical collector can be considered as a part of the process, since it is merely a device for returning escaped materials to the system, and since its use is usually advantageous for economic reasons alone. (See Figure 33 for augmented plant design.)

The dust which is not retrieved by the primary collector is predominantly of small diameter and has a large percentage of clay and organic particles that were brought in originally with the aggregate. This dust may or may not be usable as a mineral filler depending upon the nature of the aggregate used, the specification of the product being produced, and the method of dust collection employed. The device used to capture this dust is termed the secondary collector.

The types of gas cleaning equipment suitable for application as the secondary collector in an asphalt batch plant are the wet scrubber, fabric filter, and electrostatic precipitator. Historically, the wet scrubber has been used most frequently, but in recent years the fabric filter has seen increasing use. Each type can, within its own technical limits, handle the dust and gas stream emitted from the primary, and the final choice between the three types will hinge on relative costs, plant room for ancillary equipment, plant room for collection equipment, the exact nature of local regulations, and the need for maximizing the retention of <200 mesh material for filler.

Wet Scrubbers

The types of wet scrubbers first applied to batch plant service were primarily low energy centrifugal or baffled spray chamber types. These, especially the latter, do not provide the desired collection efficiencies and, recourse has been made to moderate to high energy configurations, such as the dynamic, Venturi, or orifice types. The technical advantages of a wet scrubber include the lack of any need for exhaust precooling and the capability of ventilating the mixer into the fugitive dust system and thus allowing dispersion of the hydrocarbon emissions from the exhaust stack. Moreover, the amount of space required by the scrubber proper within the working area of the plant is small.

The disadvantages of the wet scrubber lie primarily in its need for large quantities of recycle water. This requires a pumping and piping system designed to prevent the dust-slurry from settling until it reaches a settling pond or tank

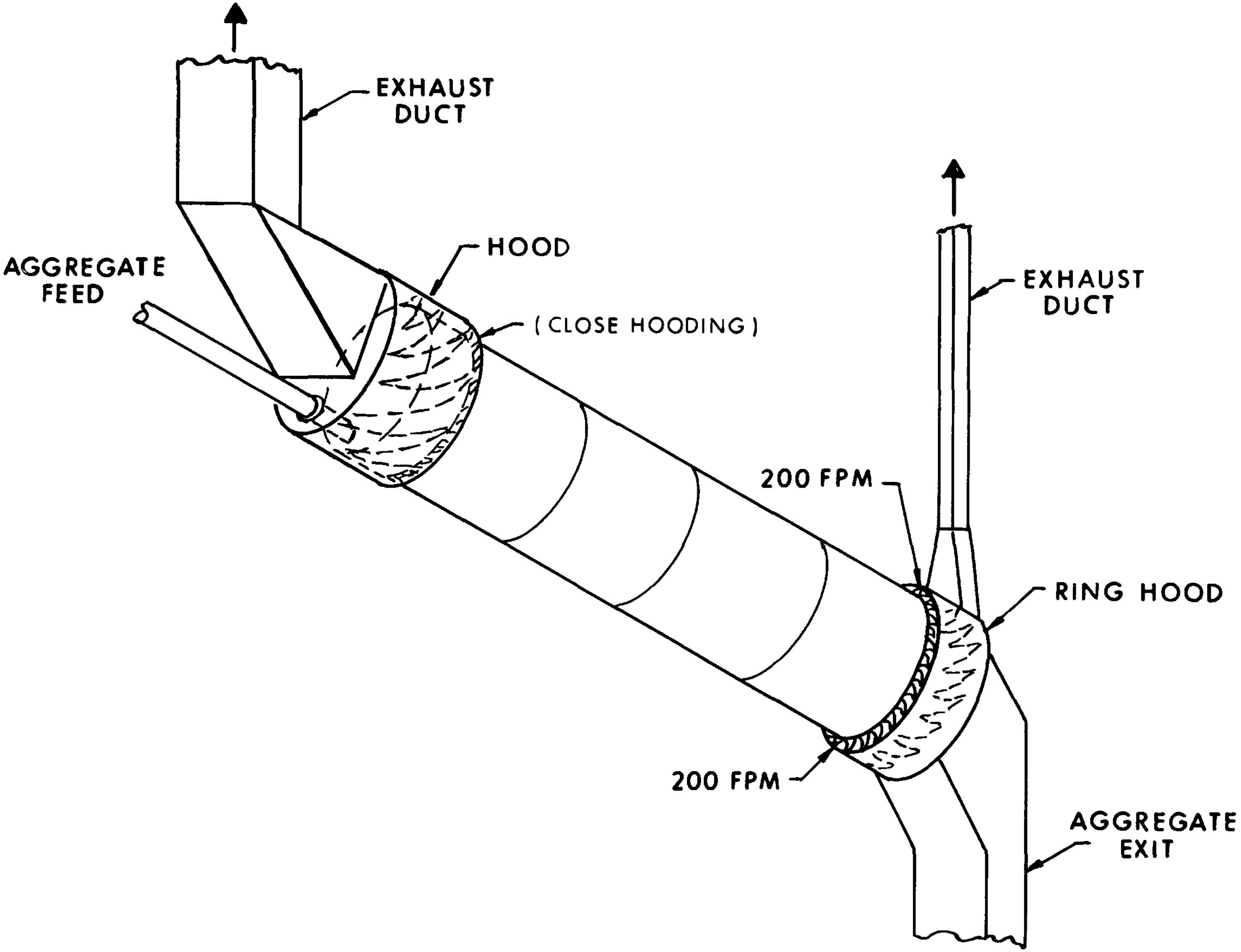


FIGURE 32

RING TYPE HOOD ON A DRIER

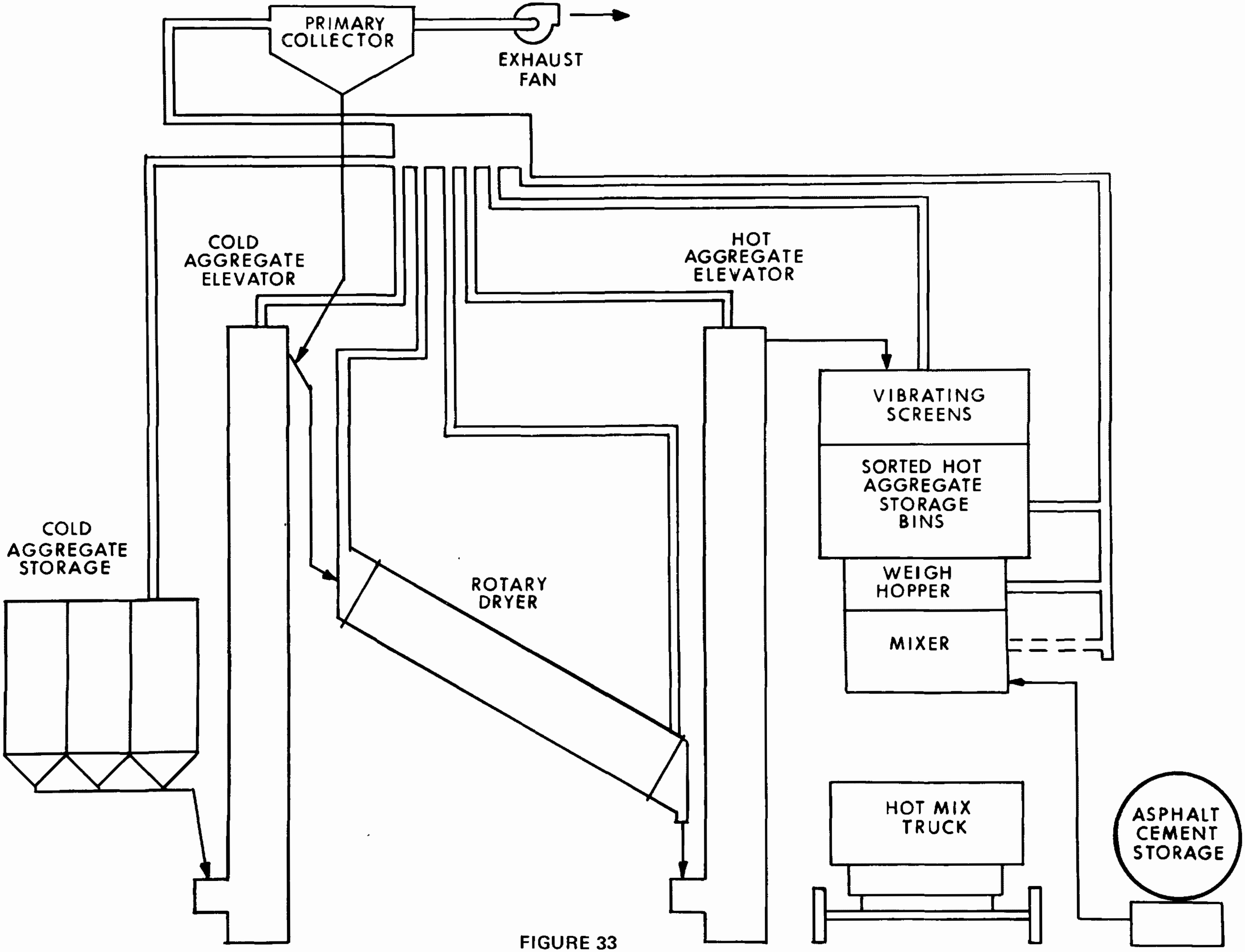


FIGURE 33

FLOW DIAGRAM SHOWING PRIMARY COLLECTION

TABLE 53

PARTICLE SIZE DISTRIBUTION

BEFORE AND AFTER PRIMARY COLLECTION

FROM DRYER AND VENT		FROM PRIMARY COLLECTOR	
Size µ	% Less Than	Size µ	% Less Than
5	19.5	5	78.00
10	30.5	10	96.40
15	38.2	15	97.50
20	45.1	20	97.80
25	50.1	25	97.90
30	55.5	30	98.03
35	60.0	35	98.20
40	64.0	40	98.28
45	67.5	45	98.40

located near the plant. The recycle water generally becomes alkaline or acidic and odoriferous, and may be corrosive if high sulfur fuel oil is burned. This requires added protection through construction or chemical additives in the piping system and care in disposal of the sludge so as not to cause water pollution.

Fabric Collectors

The alternative to the wet scrubber is the fabric filter. In a hot-mix plant, the fabric filter configuration is frequently that of a pulse jet automatic baghouse without compartments, although conventional shaker-type bag houses may also be used. The advantages of a baghouse are that it is a small compact installation (although it may require more of the working area immediately within the plant than a wet scrubber) and that the only water in the baghouse exhaust comes from the aggregate, and does not produce a steam plume except at low ambient temperature. Moreover, the material recovered from a baghouse is dry and may be disposed of by land fill methods or used as < 200 mesh mineral filler.

The disadvantages of a baghouse, however, are certainly worth noting. The inlet temperature of a baghouse must be high enough to prevent condensation anywhere in the gas stream and low enough to meet the temperature limits of the filtering medium. Some batching plants operate at a very steady temperature condition with relatively dry aggregate so that temperatures in the 250° F range can be maintained on a steady basis and insulation is not required. Other plants operate at temperatures down to 150° F in the dust collector because they are making a product known as "Cold Mix." In these cases, very often not only insulation but secondary heat is required to keep the bags above the dew point at all times. At the other end of the scale, there are many plants that operate either steadily or occasionally up to temperatures in the 350 to 400° F range. These plants may require special bleed-in air systems to prevent over temperature in the bag collectors. Many of the baghouses currently in operation use media with a temperature limitation of 425° F. A smaller number use a lower temperature media with a limitation of 275° F. Finally, when a baghouse is used, the mixer may not be ventilated through the fugitive dust system, as the hydrocarbon emissions may blind the fabric filter.

SPECIFICATIONS AND COSTS

With this consideration of the job to be performed and the applicable type of equipment, suitable specifications may be written for pollution abatement measures at hot-mix asphalt batch plants. Two such specifications are given in Tables 54, 55, 58 and 59; one set for a wet scrubber system and one set for a fabric collector. In the case of the scrubber, specifications are given for two levels of efficiency. The fabric collector, however, is written so as to solicit a single quotation for the high efficiency level. Cost data generated from the filter specification are presented in Tables 56 and 57 while data from the scrubber specification are presented in Tables 60 and 61.

During the course of this study, it was found that one IGCI member company had supplied a number of electrostatic precipitators for asphalt batch plants. As a result, a specification was written for this application, and is presented as Tables 62 and 63. However, no precipitators were quoted by member companies, and they are not presumed to be available.

Although specifications were written for a precipitator and one manufacturer was asked to supply cost data, none was available at the time this report was prepared. Apparently current applications of precipitators are quite rare as compared with many scrubber and filter installations.

Fabric Collector capital costs are presented in Figure 34. The primary mechanical collector cost is included with the fabric collector in the "collector only" cost. This combined cost is over half the total system cost. Turnkey prices are shown in Figure 36, along with the 75% and 95% confidence limits. The fabric collector installed costs present a reasonably consistent pattern. The "collector plus auxiliaries" figures (present in Figure 37) are not so consistent, which probably indicates varying levels of pre-assembly of the collectors supplied by the manufacturers.*

The wet scrubber pattern is considerably less consistent. The averages shown in Figure 38 are for only two of the three potential bidders, and are based on quotations quite inconsistent with one another. Significant differences in scrubbers and system design probably accounts for this variation.

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*The specifications written for fabric collectors indicated that the equipment should be portable. This requirement added about 10% to the cost of the system.

As expected, fabric collector operating costs (Table 57 and Figure 35) are lower than those for scrubbers (Table 61 and Figure 40), but on a total annual cost basis they present a competitive picture.

Table 54

FABRIC FILTER PROCESS DESCRIPTION FOR ASPHALT BATCHING PLANT SPECIFICATION

A fabric filter is to treat the effluent from a typical asphalt batching plant operation. All of the air required to ventilate the following items of equipment must be treated so as to conform to the specified particulate emission limits.

1. *Cold aggregate elevator*
2. *Rock dryer*
3. *Hot aggregate elevator*
4. *Vibrating screens*
5. *Sorted hot aggregate storage bins*
6. *Weigh hopper*

The necessary enclosures to minimize escapement of dust from conveyors, elevators, etc., will be provided by others. The vendor is to furnish all interconnecting ductwork, primary collector, baghouse proper, fans, solids collection bin, and solids conveying system. A booster fan supplying 3″ w.c. will be required for the fugitive dust sources. The air rate through this fan will be 10% of the total flow to the collector. Dust from the primary cyclone is to be returned to the bottom of the hot elevator, whereas dust collected in the filter will be used for landfill.

The plant is located outside, adjacent to a public highway, and with little likelihood of interferences of roadways, buildings, etc. with the location of pollution control equipment. The plant is considered temporary (2 to 4 years expected life in this location) and may be moved. Ability of the pollution abatement equipment to be dismantled and relocated is of prime importance.

Table 55

FABRIC COLLECTOR OPERATING CONDITIONS FOR ASPHALT BATCHING PLANT SPECIFICATIONS

Two sizes of fabric collectors are specified for each of two efficiency levels. Vendors quotations should, however, consist of one quotation for each of the two sizes, with a representation of the efficiency expected for the unit quoted. The efficiency quoted may be better than the "high efficiency" case.

	Small	*Large*
Plant Capacity, ton/hr	*100*	*200*
Process Weight, lb/hr	*204,000*	*408,000*
Gas Flow to Primary Collector		
Flow, ACFM	*31,400*	*44,000*
Temp., °F	*370*	*370*
% Moisture	*17*	*21*
Primary Collector Inlet Loading, lbs/hr	*4,000*	*8,000*
Primary Collector Outlet Loading, lbs/hr	*1,000*	*2,000*
Primary Collector Efficiency, %	*75*	*75*
Temperature Drop Primary Collector		
Inlet, °F	*370*	*370*
Outlet, °F	*350*	*350*
Gas to Fabric Collector		
Flow, ACFM	*30,600*	*42,900*
Temp., °F	*350*	*350*
% Moisture	*17*	*21*
Dew Point, °F	*173*	*176*
Outlet from Secondary Collector		
Flow, ACFM	*30,200*	*42,400*
Temp., °F	*340*	*340*
Case 1 — Medium Efficiency		
Outlet Loading, lb /hr	*40*	*40*
Outlet Loading, gr/ACF	*0.154*	*0.110*
Efficiency, Wt. %	*96*	*98*
Case 2 — High Efficiency		
Outlet Loading lb /hrs	*7.8*	*10.9*
Outlet Loading, gr/ACF	*0.03*	*0.03*
Efficiency, Wt. %	*99.28*	*99.46*

TABLE 56

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			31,400	44,000
°F			370	370
SCFM				
Moisture Content, Vol. %			17	21
Effluent Dust Loading				
gr/ACF				
lb/hr			1,000	2,000
Cleaned Gas Flow				
ACFM			30,600	42,900
°F			350	350
SCFM				
Moisture Content, Vol. %			17	21
Cleaned Gas Dust Loading				
gr/ACF			0.03	0.03
lb/hr			7.8	10.9
Cleaning Efficiency, %			99.28	99.46
(1) Gas Cleaning Device Cost			49,901	61,160
(2) Auxiliaries Cost			10,046	11,544
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost			23,687	28,485
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost			83,634	101,189

TABLE 57

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS*

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	960				
Operating Labor (if any)					
Operator	$5/hr	-	-	-	-
Supervisor	$6/hr			180	180
Total Operating Labor				180	180
Maintenance					
Labor	$8/hr	-	-	-	-
Materials	$6/hr			200	288
Total Maintenance				200	288
Replacement Parts					
Bag Replacement per yr		-	-	2,250	3,075
Total Replacement Parts				2,250	3,075
Utilities					
Electric Power	$0.011/kw-hr			792	792
Fuel				-	-
Water (Process)				-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify				-	-
Total Utilities				792	792
Total Direct Cost				3,422	4,335
Annualized Capital Charges		-	-	8,363	10,119
Total Annual Cost				11,785	14,454

FIGURE 34

CAPITAL COSTS FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

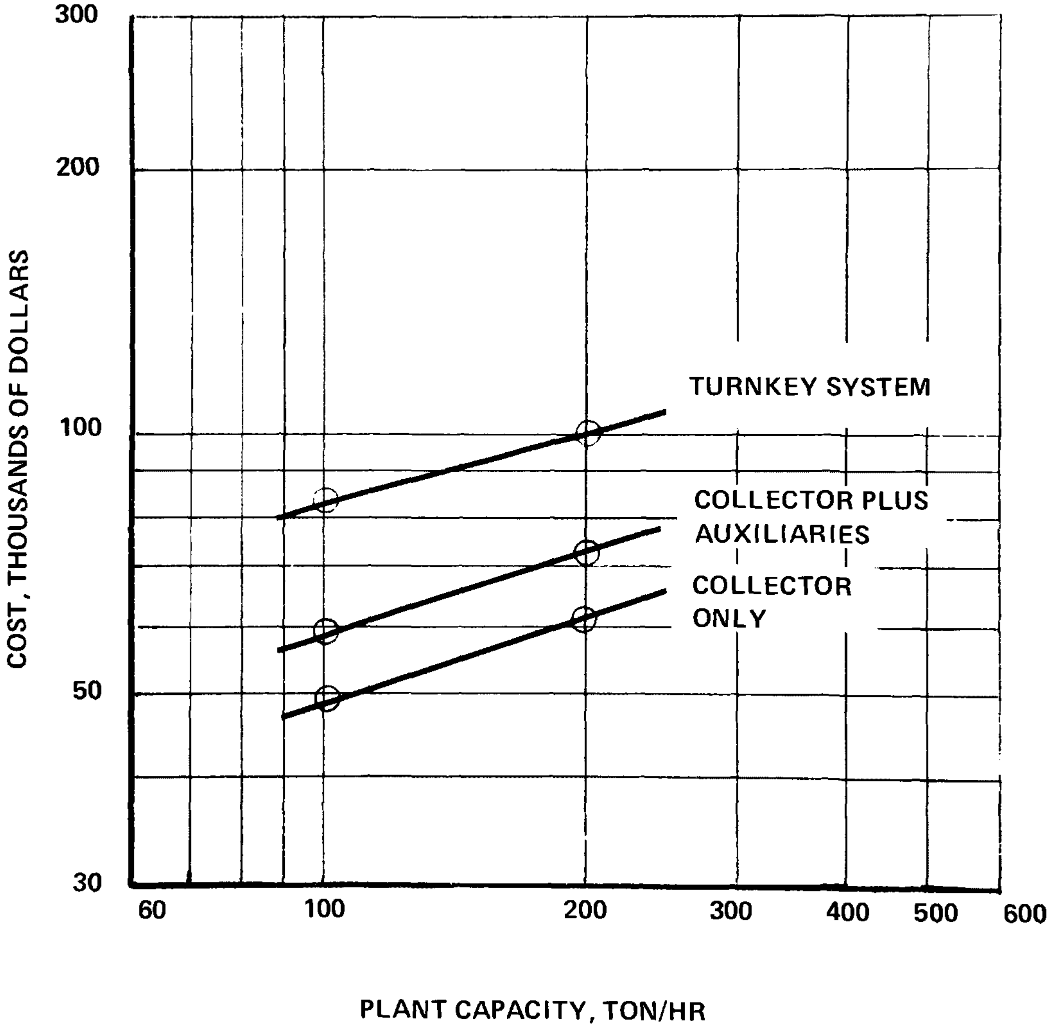


FIGURE 35
ANNUAL COSTS FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

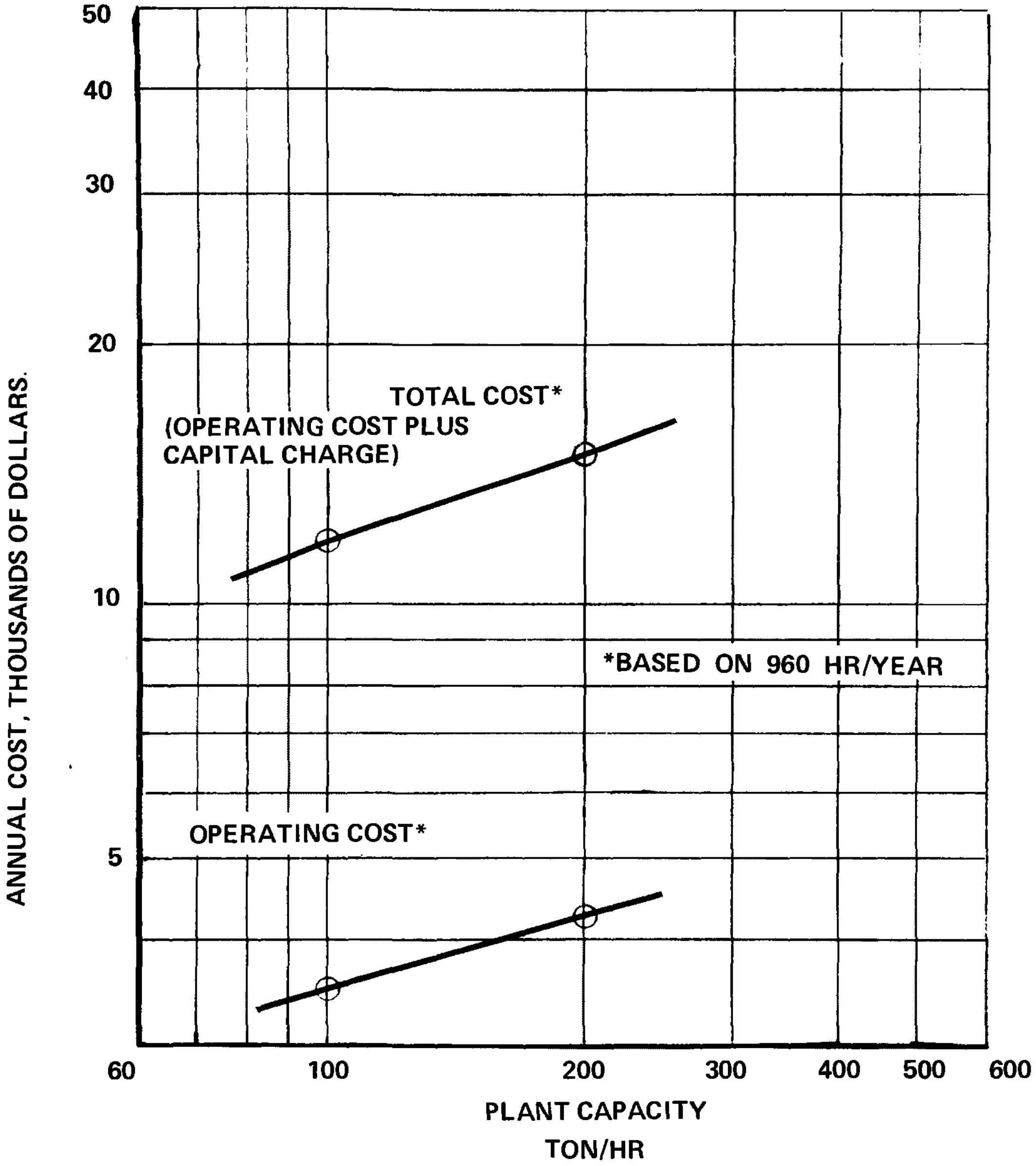


FIGURE 36

CONFIDENCE LIMITS FOR CAPITAL COST OF INSTALLED FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

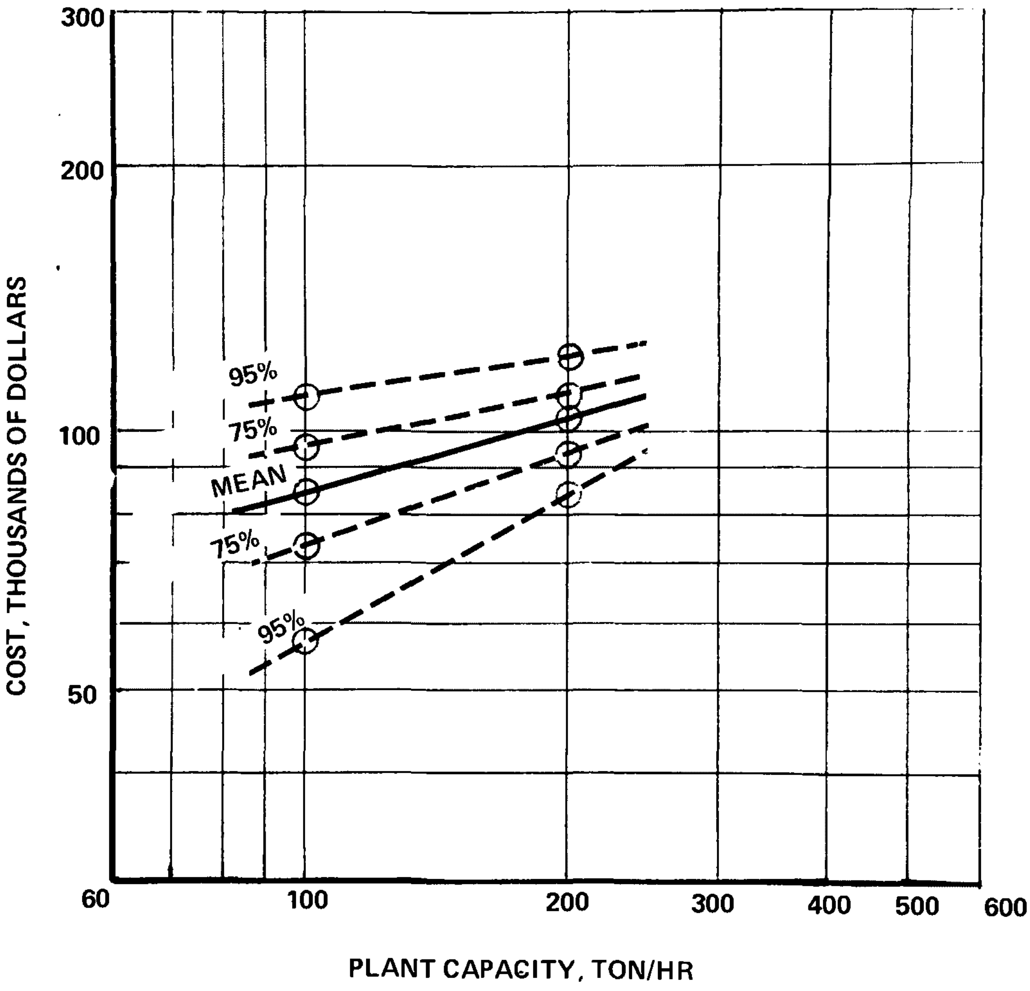


FIGURE 37

CONFIDENCE LIMITS FOR CAPITAL COST OF FABRIC COLLECTORS PLUS AUXILIARIES FOR ASPHALT BATCHING PLANTS

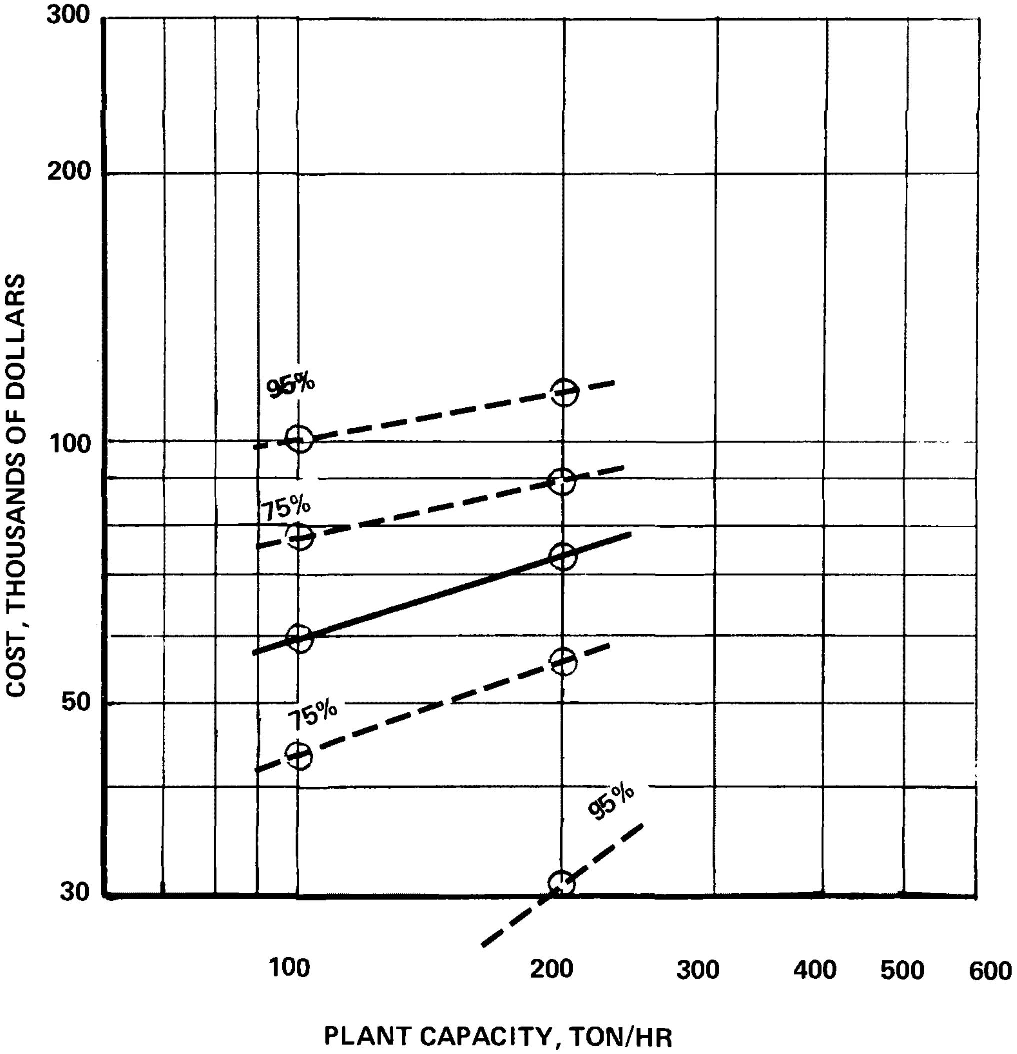


Table 58

WET SCRUBBER PROCESS DESCRIPTION FOR

ASLPHALT BATCHING PLANT SPECIFICATION

A single wet scrubber is to treat the effluent from a typical asphalt batching plant operation. All of the air required to ventilate the following items of equipment must be treated so as to conform to the specified particulate emission limits.

1. *Cold aggregate elevator*
2. *Rock dryer*
3. *Hot aggregate elevator*
4. *Vibrating screens*
5. *Sorted hot aggregate storage bins*
6. *Weigh hopper*
7. *Mixer*

The necessary enclosures to minimize escapement of dust from conveyors, elevators, etc. will be provided by others. The vendor is to furnish all interconnecting ductwork, primary collector, wet scrubber, fan, slurry pumps, settler and clarified water return pumps. Dust from the primary cyclone is to be returned to the bottom of the hot elevator, whereas dust collected in the scrubber is to be settled to approximately 60% solids content by weight and removed by truck.

The plant is located outside, adjacent to a public highway, and with little likelihood of interferences of roadways, buildings, etc. with the location of pollution control equipment. The plant is considered temporary (2-4 years expected life in this location) and may be moved. Ability of the pollution abatement equipment to be dismantled and relocated is of prime importance.

Table 59

WET SCRUBBER OPERATING CONDITIONS FOR ASPHALT BATCHING PLANT SPECIFICATION

Two sizes of wet scrubbers are to be quoted for each of two efficiency levels. Vendors quotation should consist of four separate and independent quotations.

	Small	*Large*
Plant Capacity, ton/hr	*100*	*200*
Process Weight, lb/hr	*204,000*	*408,000*
Gas to Primary Collector		
Flow, ACFM	*31,400*	*44,000*
Temp., ^{o}F	*370*	*370*
% Moisture	*17*	*21*
Primary Collector Inlet Loading, lb/hr	*4,000*	*8,000*
Primary Collector Outlet Loading, lb/hr	*1,000*	*2,000*
Primary Collector efficiency, %	*75*	*75*
Gas to Secondary Collector (Scrubber)		
Flow, ACFM	*30,600*	*42,900*
Temp., ^{o}F	*350*	*350*
% Moisture	*17*	*21*
Outlet from Secondary Collector		
Flow, ACFM	*25,000*	*35,200*
Temp., ^{o}F	*147*	*152*
Moisture Content, Vol. %	*23*	*26.2*

Case 1 – Medium Efficiency

Outlet Loading, lb/hr	*40*	*40*
Outlet Loading, gr/ACF	*0.187*	*0.133*
Efficiency, Wt. %	*96*	*98*

Case 2 – High Efficiency

Outlet Loading, lb/hr	*6.43*	*9.06*
Outlet Loading, gr/ACF	*0.03*	*0.03*
Efficiency	*99.68*	*99.77*

TABLE 60

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR SCRUBBERS FOR ASPHALT BATCHING PLANTS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	30,600	42,900	30,600	42,900
°F	350	350	350	350
SCFM				
Moisture Content, Vol. %	17	21	17	21
Effluent Dust Loading				
gr/ACF				
lb/hr	1,000	2,000	1,000	2,000
Cleaned Gas Flow				
ACFM	25,000	35,200	25,000	35,200
°F	147	152	147	152
SCFM				
Moisture Content, Vol. %	23	26.2	23	26.2
Cleaned Gas Dust Loading				
gr/ACF	0.187	0.133	0.03	0.03
lb/hr	40	40	6.43	9.06
Cleaning Efficiency, %	96	98	99.68	99.77
(1) Gas Cleaning Device Cost	9,975	12,229	12,181	15,930
(2) Auxiliaries Cost	11,013	14,539	13,062	18,210
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost	26,157	31,934	27,360	33,571
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	47,145	58,702	52,603	67,711

TABLE 61

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	960				
Operating Labor (if any)					
Operator					
Supervisor		-	-	-	-
Total Operating Labor					
Maintenance					
Labor	$6/hr	291	283	291	283
Materials		50	75	50	75
Total Maintenance		341	358	341	358
Replacement Parts		185	226	194	244
Total Replacement Parts		185	226	194	244
Utilities					
Electric Power	$0.01/kw-hr	590	885	1,162	1,730
Fuel		-	-	-	-
Water (Process)	$0.25/M gal	464	610	547	731
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		1,054	1,495	1,709	2,461
Total Direct Cost		1,580	2,079	2,244	3,063
Annualized Capital Charges		4,714	5,870	5,260	6,771
Total Annual Cost		6,294	7,949	7,504	9,834

FIGURE 38
CAPITAL COSTS FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS
(LA–PROCESS WEIGHT)

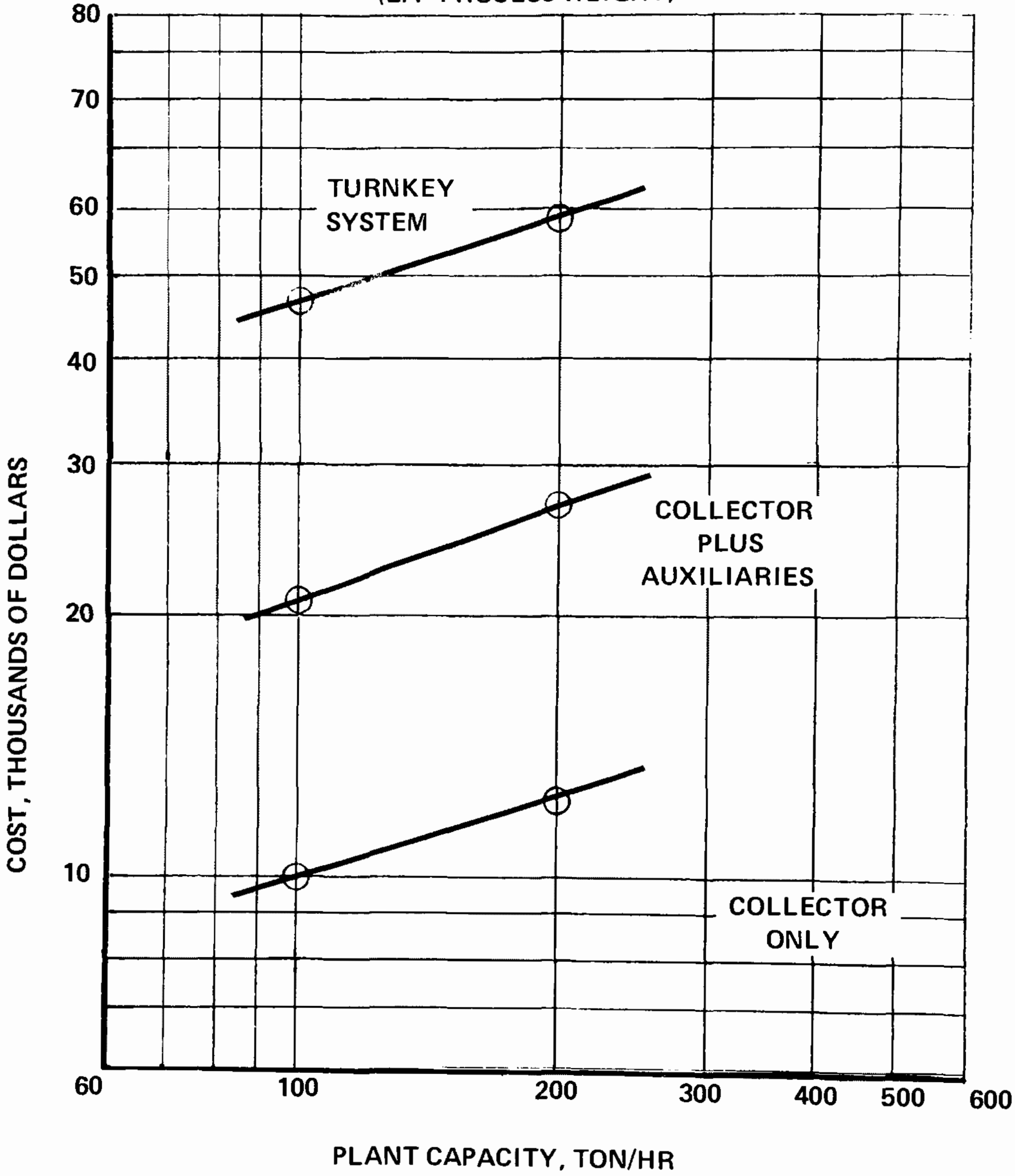
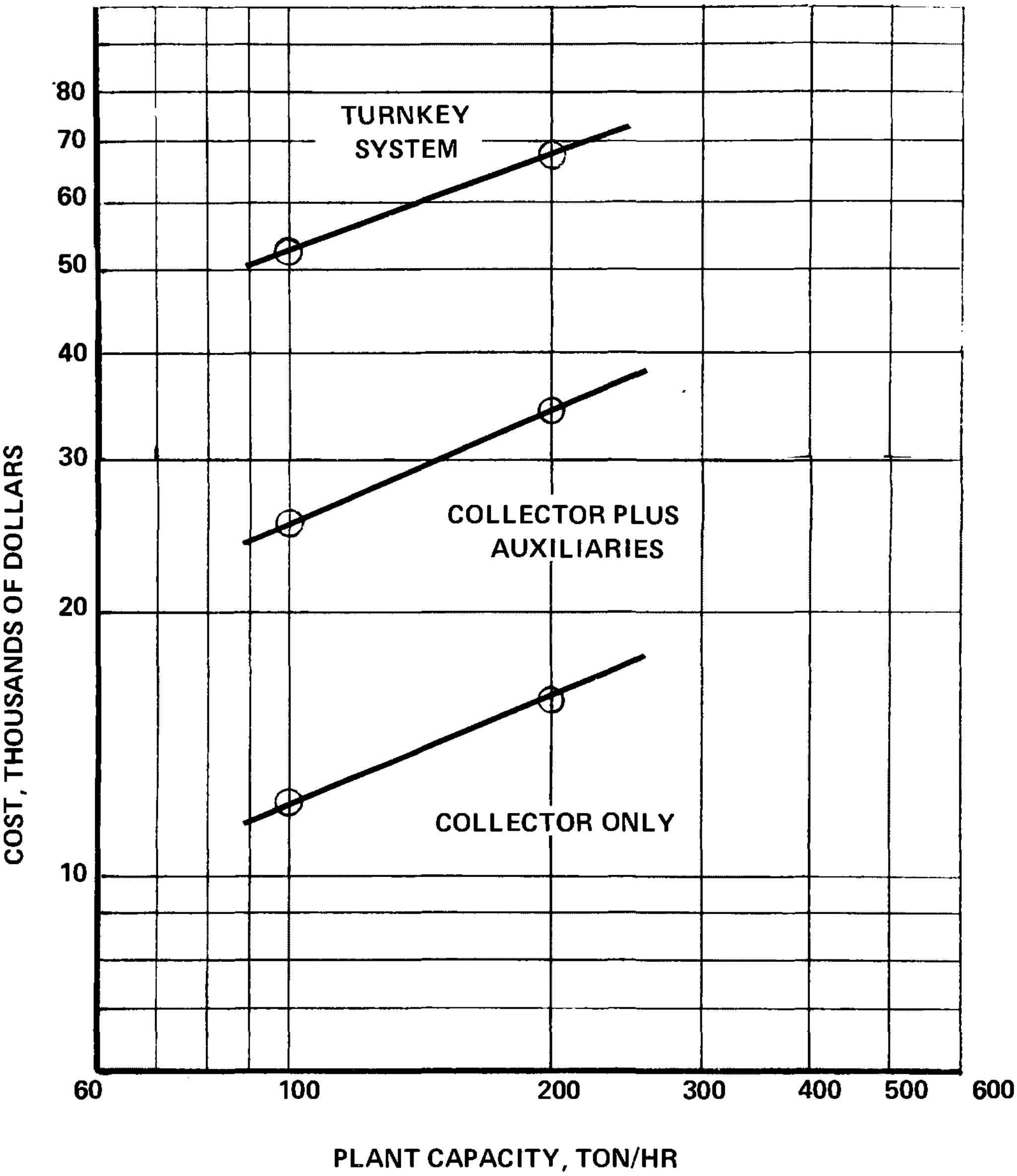


FIGURE 39

CAPITAL COSTS FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS

(HIGH EFFICIENCY CASE)



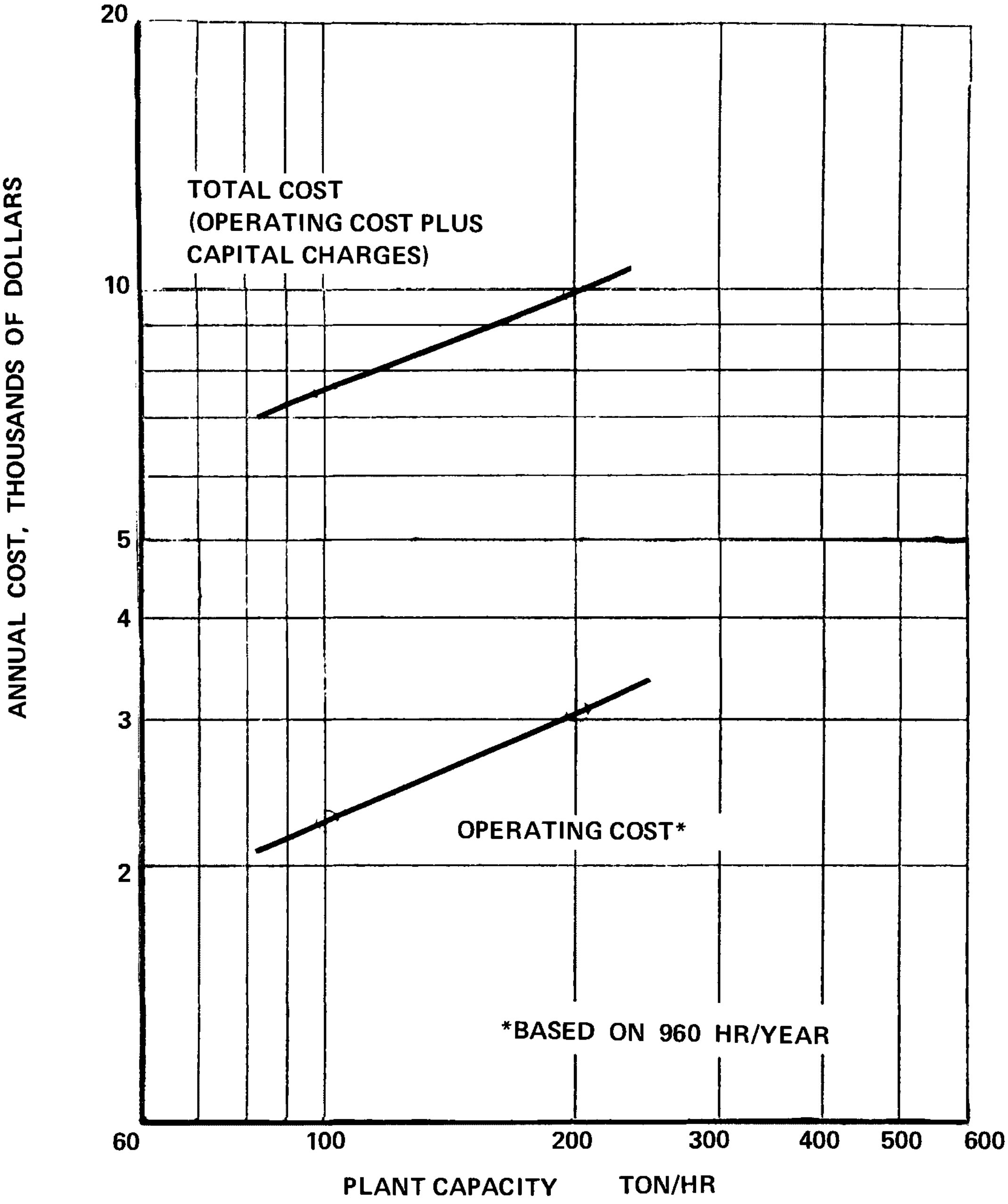


FIGURE 40

ANNUAL COSTS OF WET SCRUBBERS
FOR ASPHALT BATCHING PLANTS
(HIGH EFFICIENCY CASE ONLY)

Table 62

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR ASPHALT BATCHING PLANT SPECIFICATION

An electrostatic precipitator is to treat the effluent from a typical asphalt batching plant operation. All of the air required to ventilate the following items of equipment must be treated so as to conform to the specified particulate emission limits.

1. *Cold aggregate storage hopper*
2. *Cold aggregate elevator*
3. *Rock dryer*
4. *Hot aggregate elevator*
5. *Vibrating Screens*
6. *Sorted hot aggregate storage bins*
7. *Weigh hopper*

A booster fan supplying 3" w.c. will be required for the fugitive dust sources. The air rate through this fan will be 10% of the total flow to the collector. Dust from the primary cyclone is to be returned to the bottom of the hot elevator, whereas dust collected in the filter will be used for landfill.

Automatic voltage control shall be provided to maximize operating efficiency. Rappers shall be adjustable both as to intensity and rapping period. The precipitator shall be equipped with a safety interlock system which prevents access to the precipitator internals unless the electrical circuitry is disconnected and grounded.

The plant is located outside, adjacent to a public highway, and with little likelihood of interferences of roadways, buildings, etc. with the location of pollution control equipment. The plant is considered temporary (2 to 4 years expected life in this location) and may be moved. Ability of the pollution abatement equipment to be dismantled and relocated is of prime importance.

Table 63

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR ASPHALT BATCHING PLANT SPECIFICATION

Two sizes of electrostatic precipitators are specified for each of two efficiency levels. Vendors quotations should consist of four separate and independent quotations.

	Small	*Large*
Plant Capacity, ton/hr	*100*	*200*
Process Weight, lb /hr	*204,000*	*408,000*
Gas Flow to Primary Collector		
Flow, ACFM	*31,400*	*44,000*
Temp., °F	*370*	*370*
% Moisture	*17*	*21*
Primary Collector Inlet		
Loading, lb /hr	*4,000*	*8,000*
Primary Collector Outlet		
Loading, lb /hr	*1,000*	*2,000*
Primary Collector Efficiency	*75*	*75*
Gas to Precipitator		
Flow, ACFM	*31,400*	*44,000*
Temp., °F	*370*	*370*
% Moisture	*17*	*21*
Dew Point, °F	*173*	*176*

Case 1 — Medium Efficiency

Outlet Loading, lb /hr	*40*	*40*
Outlet Loading, gr/ACF	*0.148*	*0.106*

Case 2 - High Efficiency

Outlet Loading, lb /hr	*8.1*	*11.3*
Outlet Loading, gr/ACF	*0.03*	*0.03*
Efficiency, Wt. %	*99.29*	*99.44*

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BOF STEELMAKING

4. IRON AND STEEL INDUSTRY BASIC OXYGEN FURNACES

This section deals with one of the processes used in *integrated steelmaking*. The overall steelmaking process involves a number of basic steps, most of which are carried out in a single plant. These include(1, 8):

1. Raw material preparation (coke ovens, ore sintering, pelletizing, limestone preparation).
2. Making iron (blast furnaces and direct reduction).
3. Making steel (removal of carbon and other impurities from iron).
4. Casting steel.
5. Rolling steel into semi-finished products such as plate and rod (rolling mills, annealing, galvanizing, scarfing, vacuum degassing).
6. Manufacture of finished steel products.

These processes, taken together, constitute one of the major industries in the U.S., with a production capacity of some 155 to 160 million tons of steel per year(1).

Most important of the processes are blast furnace operation, which produces iron by the reduction of iron ore to molten iron, and steelmaking, in which the impurities in the blast furnace product (called *pig iron* when solid and *hot metal* when molten) are removed to make steel.

There are three steel making processes in use:

1. Open hearth furnaces
2. Basic oxygen furnaces (BOF)
3. Electric furnaces

In prior years most steel was produced by the open hearth process, but since the introduction of the basic oxygen furnace (BOF) process about 15 years ago, the BOF has gradually replaced the open hearth as the primary method of steel making. The output of domestic steel in 1970 was distributed as follows:(1)

Open hearths	36%
BOF	49%
Electric furnaces	15%
	100%

The growth of BOF usage in the U.S.A. is illustrated in Figure 41(8).

The BOF steelmaking process was developed at a small steel plant in Linz, Austria and at about the same time in nearby Donowitz. For a number of years it was referred to as the Linz-Donowitz or L-D process. Other names for the same process are the *top-blown oxygen process* and the *basic oxygen process.* "Basic" here refers to the composition of the lining and results in a basic slag. In order to maintain a basic slag, in which the ratio of CaO and MgO to SiO_2 is greater than one, burned lime is added to the furnace either prior to or during oxygen lancing.

The process is alternatively described as the *basic oxygen process* (BOP) and as steelmaking in *basic oxygen furnaces* (BOF), or *BOF steelmaking*. In the remainder of this section the latter terminology will be used.

PROCESS DESCRIPTION

The flow scheme for a BOF steelmaking operation is shown in Figure 42. Figure 43 illustrates the flow schemes utilizing electrostatic precipitators or high energy scrubber systems for gas cleaning.

The blast furnace operates continuously, but is tapped intermittently. The BOF operates on a batch basis, and is charged more frequently than the blast furnace is tapped. Therefore, there must be some provision for intermediate storage of the hot metal.

Steelmaking processes vary with regard to the storage of hot metal. In some plants, the hot metal retention is kept to a minimum. In others, *hot metal mixers* are employed to provide storage capacity and improve uniformity of the hot metal from one submarine car load to the next.

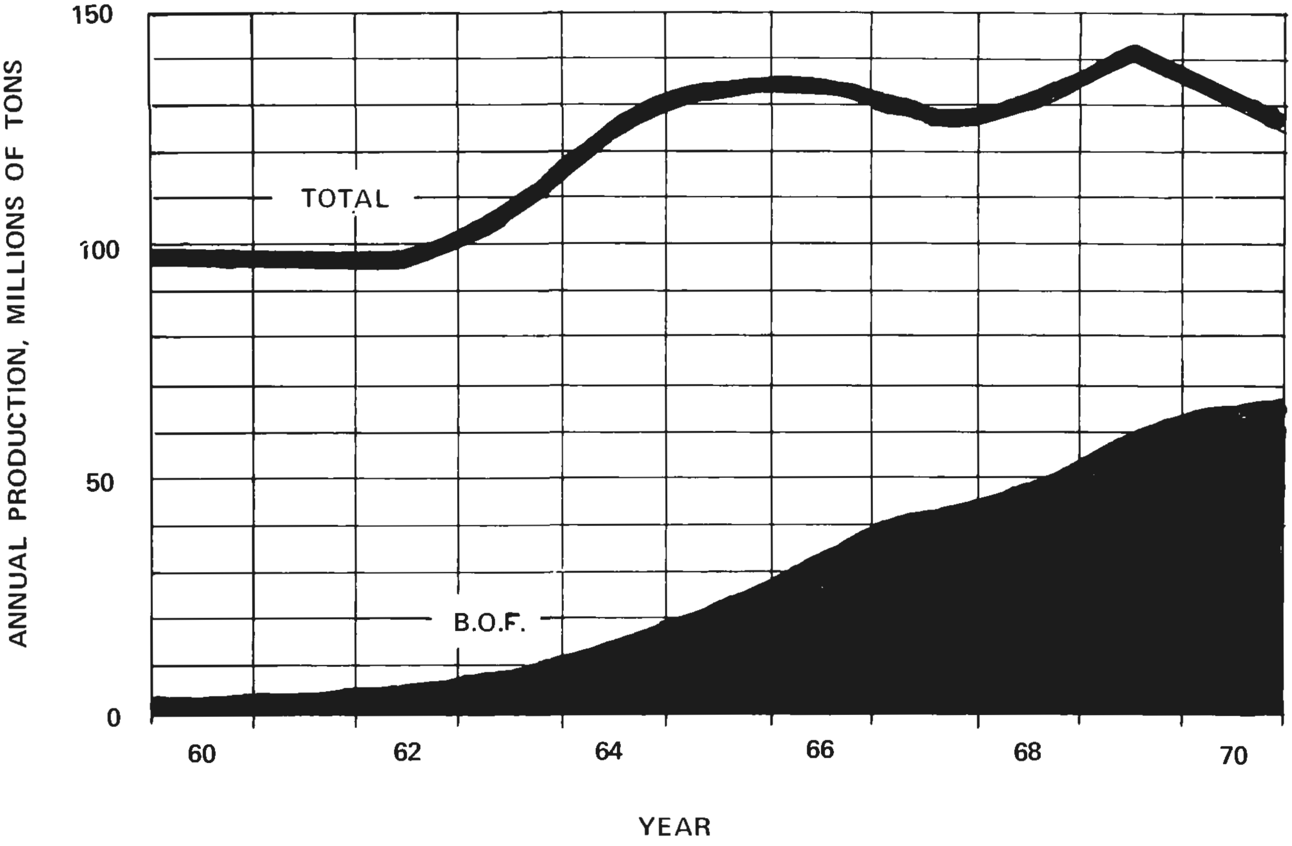
The sequence of steps in the transfer and charging operations is as follows:

1. Hot metal tapping at the blast furnace.

2. Transfer from submarine car to hot metal mixer.

FIGURE 41

STEEL PRODUCTION – UNITED STATES (IN MILLION SHORT TONS OF INGOTS)



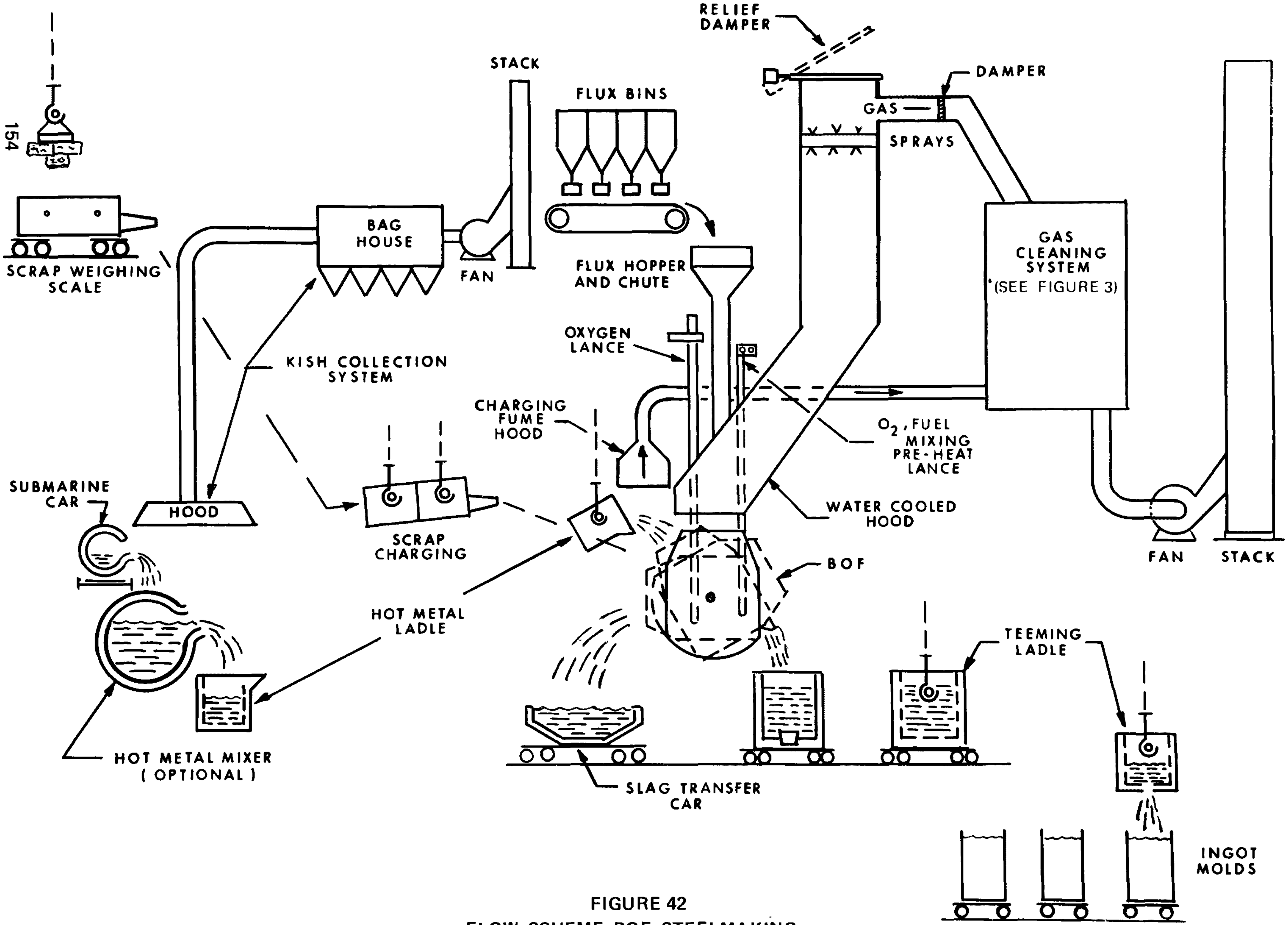
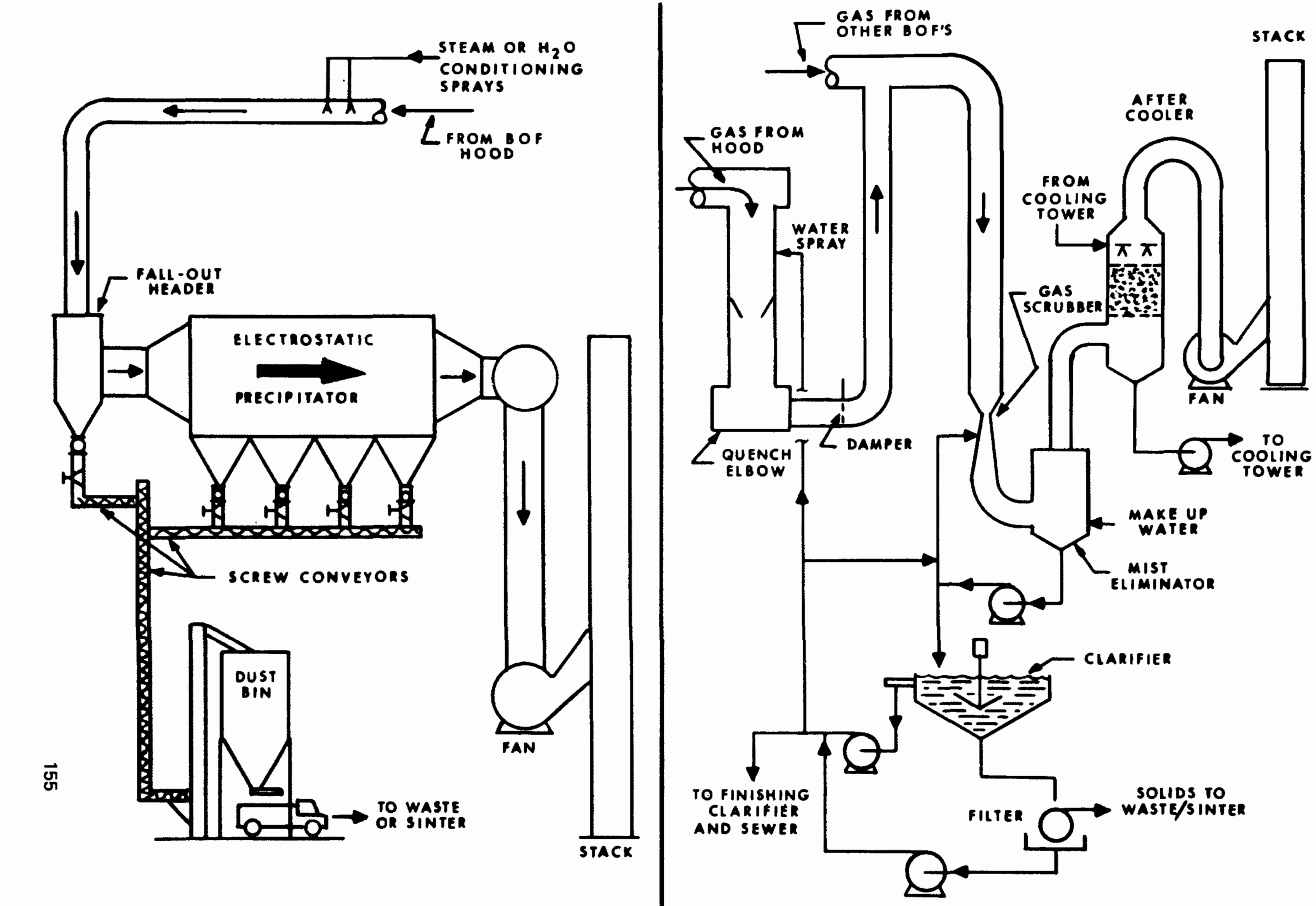


FIGURE 42
FLOW SCHEME BOF STEELMAKING



ELECTROSTATIC PRECIPITATOR GAS CLEANING SYSTEM

VENTURI SCRUBBER GAS CLEANING SYSTEM

FIGURE 43

GAS CLEANING EQUIPMENT FOR BOF STEELMAKING

3. Transfer from hot metal mixer to charging ladle.

4. Addition of scrap to BOF.

5. Addition of hot metal to BOF.

The trend is away from using hot metal mixers and many mills are taking hot metal from the blast furnace directly to the BOF without intermediate transferring.

The hot metal mixer (where it is used) serves as a reservoir from which the charging ladles are filled periodically. The charging ladle sets in a pit below the level of the mixer. To charge the ladle, the mixer is rotated slightly, and hot metal pours from the discharge opening into the charging ladle.

The BOF process is sufficiently exothermic that scrap steel can be added to the charge without preheating. Approximately 30% of the BOF furnace capacity is made up of scrap steel from various sources. Higher fractions of scrap steel can be included if the scrap is heated prior to charging. This is more common in Europe than in the U.S. The usual practice in the U.S. is to preheat the scrap in the vessel using a special O_2 fuel lance. This preheating is done before hot metal addition.

The charging process is irregular, and may take as little as a few seconds if the scrap slides in easily, or may take as much as five minutes to complete if the operator has trouble dislodging the irregular pieces.

After the scrap steel is positioned or heated in the BOF, the furnace is tilted to receive the hot metal charge. The crane operator lifts the ladle and moves it gently to the mouth of the furnace. During the transport of the ladle, little or no fuming takes place. The crane operator tips the ladle by means of a small auxiliary hook. A large amount of fuming takes place during hot metal charging. All fume control systems should provide for this but few do at this time. Secondary hooding is frequently used to capture charging fumes.

BOF Operation

The basic oxygen furnace functions to convert hot metal into steel by oxidation of carbon, phosphorus, silicon, sulfur, and other impurities in the iron. The pear-shaped vessel is lined with magnesia and has a charging opening at the top, and a small nozzle on one side near the top for tapping of finished steel.

The vessel is filled to about 1/3 of its depth with hot metal and scrap. As soon as the metal charging is completed, the furnace is rotated into an upright position and carefully measured amounts of slag-forming fluxes are added. These consist principally of burned lime, dolomite or dolomitic lime, fluorspar, and mill scale.(4) The addition of these materials takes place with the furnace vertical and positioned under the ventilating hood, so that there are no uncontrolled emissions of particulate matter during this part of the cycle. Frequently these fluxes are added after O_2 ignition is started. The sequence appears to be the operator's choice.

As soon as the furnace is in the vertical position, the oxygen lance is lowered into position through the hood. This lance consists of a water-cooled pipe through which pure oxygen gas is blown into the furnace and impinges on the surface of the melt. Oxygen pressure is generally held between 140 and 180 pounds per square inch, and the extremely turbulent impingement of the jet on the surface of the melt plays an important part in the refining process.(2)

Oxygen reacts with the surface of the bath to form carbon monoxide and also to produce substantial quantities of FeO which diffuse through the melt. The increased FeO concentrations result in carbon monoxide formation and vigorous boiling of the molten metal. Oxygen lancing continues for about 20 minutes, during which time the carbon content of the melt drops from above 3.5% to less than 0.5%. Similar reductions in the silicon and phosphorous content take place during finishing of the steel.(2)

Prior to completion of the blow, the oxygen flow is stopped, the vessel rotated, and a sample of the molten steel is taken for analysis. When the analysis is returned, it is compared to the desired analysis. If within acceptable limits the blow is finished. If the actual analysis is not as desired, a reblow is required. The furnace is brought to the vertical position, the oxygen lance relowered, and oxygen flow resumed for a very short period, usually 1 to 2 minutes. Dependent on the correction desired, measured amounts of additives, such as carbons for re-carburizing, may be manually introduced into the bath prior to oxygen or during the reblow. Metallic alloying additives, such as ferrosilicon, are added to the ladle after tapping the BOF, if the analysis so dictates. The furnace is then rotated into a near horizontal position with the mouth of the teeming side of the building, and molten steel flows through the discharge port into a teeming ladle.

The steel poured into the ladle is modified or brought to specification by the addition of other alloying agents such as ferromanganese, ferrochromium, ferrosilicon, etc.(1) These alloys are discharged into the ladle directly from ladle additive hoppers through chutes. At times substantial emission of particulate matter occurs in pouring the steel into the ladle, and creates a real problem in the shop area. Adequate and economical means of controlling this problem have yet to be developed.

As soon as the steel is poured from the BOF, the furnace is rotated quickly toward the other side of the building and the slag is poured into slag transfer cars. During rotation of the furnace and slag pouring, the furnace emits white fumes. The emission appears to be caused by thermal convection carrying air into the vessel and contacting it with the residual metal on the walls of the furnace. The rotation of the furnace and slag pouring takes 1 to 3 minutes.

The teeming ladle differs from the submarine ladles and charging ladles in that it is designed for withdrawal of the molten steel through the bottom rather than by tipping the ladle and pouring the metal out. This is accomplished by means of a nozzle at the bottom of the ladle which is equipped with a ceramic plug. The plug is lifted vertically out of the opening by means of a ceramic lined steel rod known as a stopper rod which extends through the molten metal. A lever actuator at the top of the ladle permits the operator in the teeming area to open the nozzle.

The teeming ladle is lifted by a crane and carried either to the teeming area adjacent to the BOF, or to a continuous casting machine, or to vacuum degassing to provide additional purification. The ladle shows no visible emissions of particulate matter during this transport process. The teeming area contains a number of railroad tracks on which ingot cars are lined up. The teeming ladle is transported to the far end of the line of ingot molds resting on individual ingot cars and fills each mold in turn by opening the nozzle at the bottom of the ladle while it is directly above the vertical ingot mold. A fuming problem develops in the teeming area when lead shot is added to the steel in the ingot molds for producing leaded steels. This shop problem is frequently controlled by venting to bag collectors having atmospheric exhausts.

EQUIPMENT DESCRIPTION

The BOF process is the simplest which has been devised for steelmaking.(4) The BOF is a batch reactor, in which up to 350 ton charges of hot metal and scrap steel are converted to steel by oxidation of impurities which include carbon, phosphorus, silicon and magnesium. Figure 44 is a sketch of

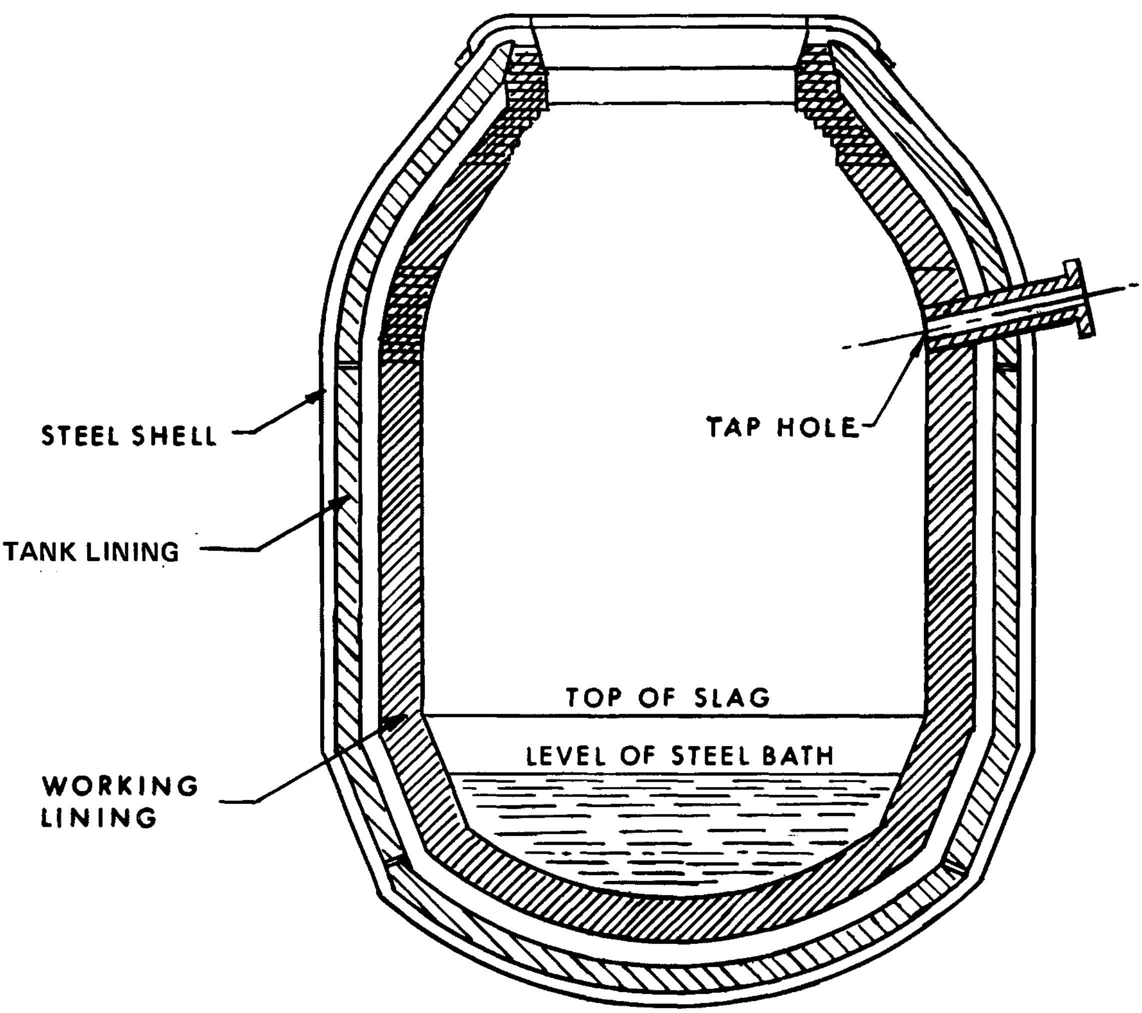


FIGURE 44

CONFIGURATION OF TYPICAL BOF VESSEL

the simple, jug-shaped vessel which is filled to about 1/3 of its depth with hot metal. This allows plenty of room for splashing of the molten metal and slag.(2)

The furnace is ordinarily a cylindrical, refractory-lined vessel. Basic (high magnesia) linings are used. A course of burned magnesite brick forms the outer layer of the lining, next to the steel shell. A middle layer of basic ramming mix supports the inner or working lining. The inner lining consists of a layer of unfired bricks of dolomite ($CaCO_3 \cdot MgCO_3$). The furnace bottom is usually built up of three courses of brick, with compositions similar to the side lining. The linings deteriorate rapidly during operation of the furnace, and must be replaced frequently. The middle and inner linings are ordinarily removed and replaced on a routine basis.(2) From 400 to 1000 heats can be obtained per lining.

High purity oxygen is introduced into the furnace through a water-cooled sparge-pipe, with a nozzle at the end, normally referred to as the oxygen lance. Oxygen under a pressure of about 150 psig passes through the lance and impinges on the molten metal surface at supersonic velocities. At the top of the lance, armored rubber hoses are connected to a pressure-controlled oxygen supply. Lance cooling water is also provided through flexible hose connections, to protect the lance when it is retracted from the hot vessel to allow furnace tipping for charging and pouring.(2)

The vessel is rotated about a horizontal axis by an electric motor and gear train. The vessel is tipped at about 45° off vertical to receive charge materials (hot metal and scrap steel). Charging of limestone and fluxes is done with the furnace vertical under the ventilating hood.

The furnace is then tipped the opposite direction to pour steel through the tap hole into the teeming ladle. The position of the furnace is rapidly reversed after pouring and molten slag is poured through the open top. The entire process is carried out in 20 to 40 minutes. When several furnaces are operated in a group, the cycle time for a single furnace is likely to be between 30 and 50 minutes.

CHEMISTRY AND PHYSICS OF THE PROCESS

The charge to a BOF furnace typically consists of about 70% hot metal from a blast furnace, and 30% scrap steel. Other ingredients are lime, fluorspar and other fluxes. These materials interact to produce ordinary low carbon steel. Additional carbon and other alloying ingredients such as ferrochromium and ferromanganese are added to individual heats to produce special alloys. However, these do not enter into the formation of air pollutants in the BOF, and will not be discussed here.

HOT METAL COMPOSITION

The hot metal leaves the blast furnace at a temperature on the order of 2450°F. The blast furnace operates at a pressure of two or three atmospheres with a high CO content in the gas phase, and produces a hot metal composition typically as follows:(5)

Component	Weight %
Fe	93.8
C	4.4
Si	0.8
P	0.25
Mn	0.75
	100.00

The hot metal withdrawn through the iron notch on the blast furnace produces several emissions whenever it is exposed to the air. These are:

1. CO
2. Red iron oxide
3. Kish

The CO evolution doesn't produce any significant pollution problem, because it burns immediately to CO_2. The iron which vaporizes does produce fuming and is responsible for emissions at the points of transfer into the ladles and furnaces. Collectors are frequently provided at reladling stations. The vapor pressure of iron is given in Figure 45. The inclusion of carbon in the liquid phase tends to reduce the boiling point and increase the vapor pressure of iron substantially. The addition of oxygen tends to have the opposite effect. (This effect is probably due in part to the formation of FeO).

Kish is a flaky, black material which is ordinarily presumed to form spontaneously whenever hot metal with a carbon content greater than the eutectoid value (4.5% C for pure iron, and less for iron containing silicon or

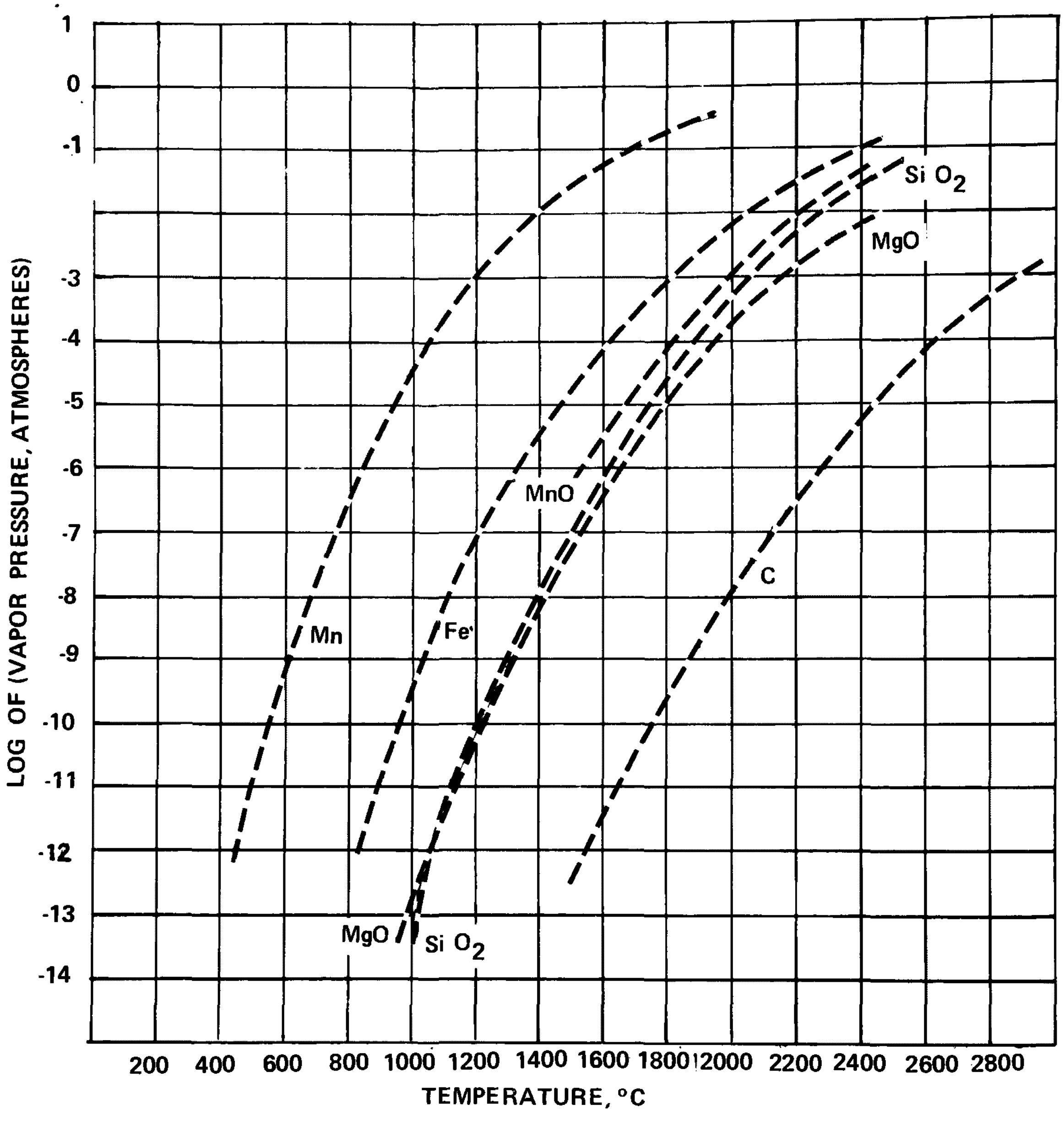


FIGURE 45

VAPOR PRESSURE OF IRON AND OTHER MATERIALS
OF IMPORTANCE IN BOF STEELMAKING

oxygen) is cooled below the liquidous temperature.(2) This results in the formation of solid Fe_3C which is unstable and decomposes into graphite and iron.(6)

Reactions Prior To Charging

The reactions taking place in the hot metal charging equipment and in the BOF prior to oxygen lancing may be represented as follows:

$$CO_{(dissolved)} \rightarrow CO \uparrow$$

and

$$CO + 1/2\ O_2 \rightarrow CO_2$$

which represent out-gassing and burning of CO.

$$Fe_{(liquid)} \rightarrow Fe_{(vapor)}$$

and

$$Fe_{(vapor)} + 1/2\ O_2 \rightarrow FeO_{(vapor)}$$

or

$$Fe_{(vapor)} + 1/3\ O_2 \rightarrow 1/2\ Fe_2O_{3(vapor)}$$

These represent the vaporization and oxidation of iron to form red fume, and finally

$$Fe_{(liquid)} + 1/3\ C_{(dissolved)} \rightarrow 1/3\ Fe_3 \cdot C_{(solid)} \downarrow$$

$$1/3\ Fe_3C_{(solid)} \rightarrow Fe + 1/3\ C_{(graphite\ solid)}$$

which represent the formation of kish.

REACTIONS IN THE BOF

The reactions taking place in the BOF during oxygen lancing are mainly involved with oxidizing carbon, phosphorus, manganese, sulfur, and silicon. The mechanism involves impinging commercial purity oxygen on the surface of the molten metal with sufficient force to penetrate the slag layer and cause violent contact with the hot metal surface. Oxygen dissolves in the molten metal and diffuses rapidly through the melt. The reactions involved in purification are:

$$Fe_{(liquid)} + 1/2\ O_2 \rightarrow FeO_{(dissolved)}$$

$$FeO_{(dissolved)} + C_{(dissolved)} \rightarrow Fe_{(liquid)} + CO \uparrow$$

$$FeO_{(dissolved)} + Si_{(dissolved)} \rightarrow Fe_{(liquid)} + SiO_{2(liquid\ slag)}$$

$$FeO_{(dissolved)} + 2/5\ P_{(dissolved)} \rightarrow Fe_{(liquid)} + 1/5\ P_2O_5 \uparrow$$

$$FeO_{(dissolved)} + 1/2\ Mn_{(dissolved)} \rightarrow Fe_{(liquid)} + 1/2\ MnO_{2(liquid\ slag)}$$

The formation of CO bubbles in the melt is responsible for a violent boiling action which adds to the turbulence created by the impingement of the liquid oxygen jet and brings about the formation of a great deal of atomized droplets of molten iron, many of which oxidize.

HEAT BALANCE

A great deal of heat is released by oxidation of the impurities in the metal. The burning of carbon is of prime importance, but oxidation of the other impurities and oxidation of a part of the iron also add significantly to the heat production. During the 20 minute lancing, the temperature increases from 2300 to 2400° F to about 2900° F, in spite of a large heat loss to the products of combustion of carbon and other components of the melt with oxygen.

In order to provide a good heat balance of the melt, it is necessary to remove some heat. This is most conveniently done by adding about 30% cold scrap steel which must be reprocessed anyway. Scrap additions are made for end point temperature control. The reasons that 30% scrap is used are economics and the availability of heat for melting. The scrap serves to "soak up" some of the heat of combustion. If more than 30% scrap is to be recycled to the melt, it is necessary to preheat the scrap. This is common practice in Europe, and is gaining in popularity in the U.S., particularly in plants where the supply of hot metal is limited or marginal. The preheating of scrap is accomplished in much the same manner as the regular blow except that a separate oxygen-fuel lance with much lower flow rates is used and the oxygen is mixed with natural gas or oil, and ignited prior to insertion into the vessel. The preheat cycle usually takes from 10 to 15 minutes.

The time-concentration relationship for each of the dissolved impurities in a typical BOF operation is shown in Figure 46(2).

Theoretical Oxygen Requirement

The quantity of oxygen required during the blow period may be estimated on the basis of an average gas composition leaving the furnace top of 87% CO and 13% CO_2. The total requirement must include sufficient oxygen to eliminate substantially all of the carbon in the melt, plus the metalloid (phosphorus, silicon, etc.) and a fraction of the iron. Between 40 and 70 lb. of Fe_2O_3 are ordinarily collected per ton of steel produced.(8) Table 64 shows a sample calculation of the total oxygen requirement and products of combustion for a 100 ton melt. The oxygen lancing is usually carried out at a steady rate throughout the blow.

However, both the flow rate and composition of emitted converter products vary during the blow period.

GAS EFFLUENT FROM BOF STEELMAKING

In addition to the products of combustion, air is drawn into the hoods to provide for combustion of CO to CO_2, and leakage of air into the system will occur. For the design of air pollution control systems, it is necessary to design for total flow as a function of furnace size, oxygen blow rate, excess air, metal composition, type of gas cooling used (steam or water), with an allowance for shop air cleaning in the vicinity of the BOF.

Figure 47 illustrates two patterns of flow rate variation with time(8), while Figure 48 is a plot of the volume of total gas discharged in ACFM at combustion temperature versus the volume of oxygen blow.(1) Gases are evolved during the blow period ranging from 200,000 to 1,200,000 ACFM at temperatures between 3,000 and 3,500° F(9). The inclusion of enough air for combustion of the CO will raise the temperature to over 4,000° F.

In Table 65 the gas composition is calculated on the basis that there is 100% conversion of blown O_2 to CO at the peak flow rates, that the tight hood draws a constant amount of infiltrated air at all periods of the blow, and that the open hood system maintains constant SCFM of products during the entire blow.

TABLE 64

CALCULATION OF OXYGEN REQUIREMENTS FOR 100 TON MELT

(70% Hot Metal, 30% Scrap Steel)

Charge		lb/Melt	Weight %
Scrap Steel		65,670	30
Hot Metal		153,230	70
Fe	143,730		(65.66)
Carbon	6,742		(3.08)
Silicon	1,226		(0.56)
Phosphorus	383		(0.18)
Manganese	1,149		(0.52)
Total	153,230	218,900	100.0

Oxygen Required For	lb oxidized	lb oxygen/ lb oxide	lb oxygen required
Fe*	3,770	0.425	1,600
Carbon	6,742	1.50	10,013
Silicon	1,226	1.14	1,400
Phosphorus	383	1.29	494
Manganese	1,149	0.58	666
			14,173

*Based on 40 lb/ton Fe or 55 lb/ton Fe_2O_3.

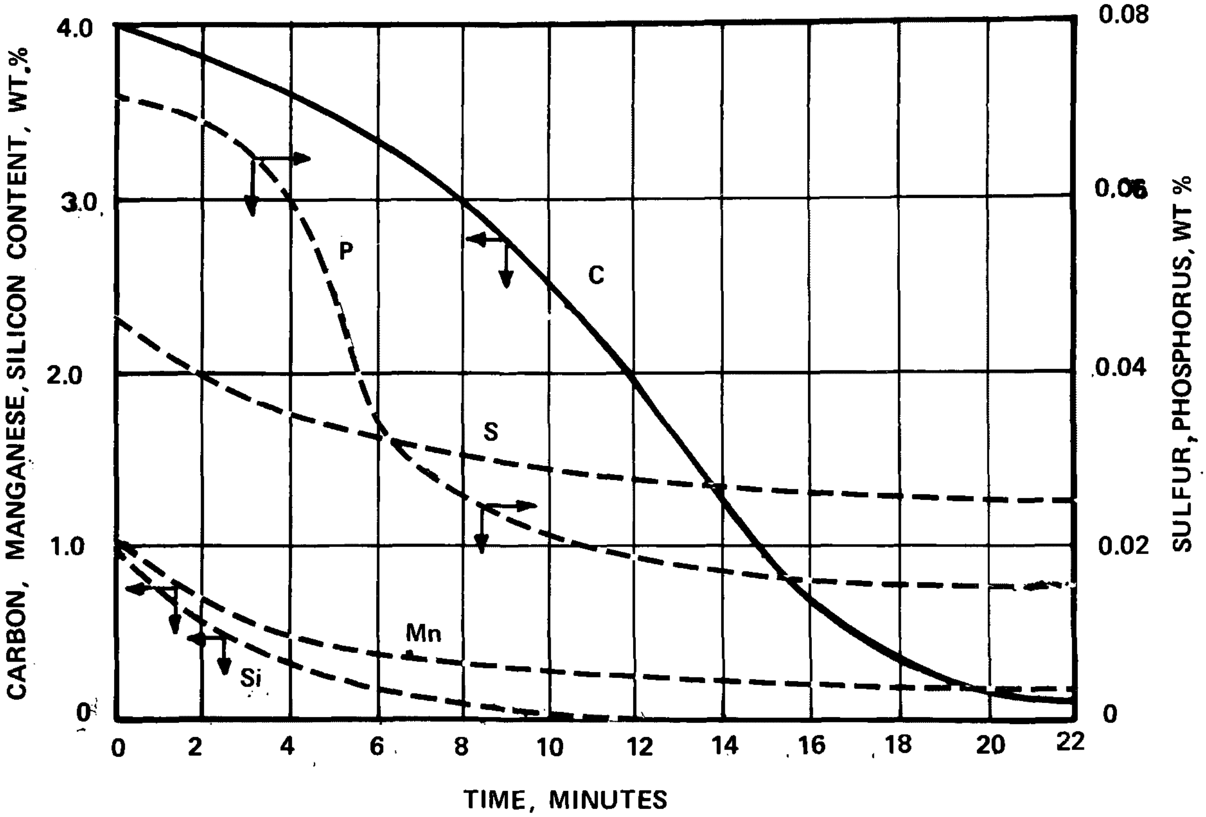
TABLE 65

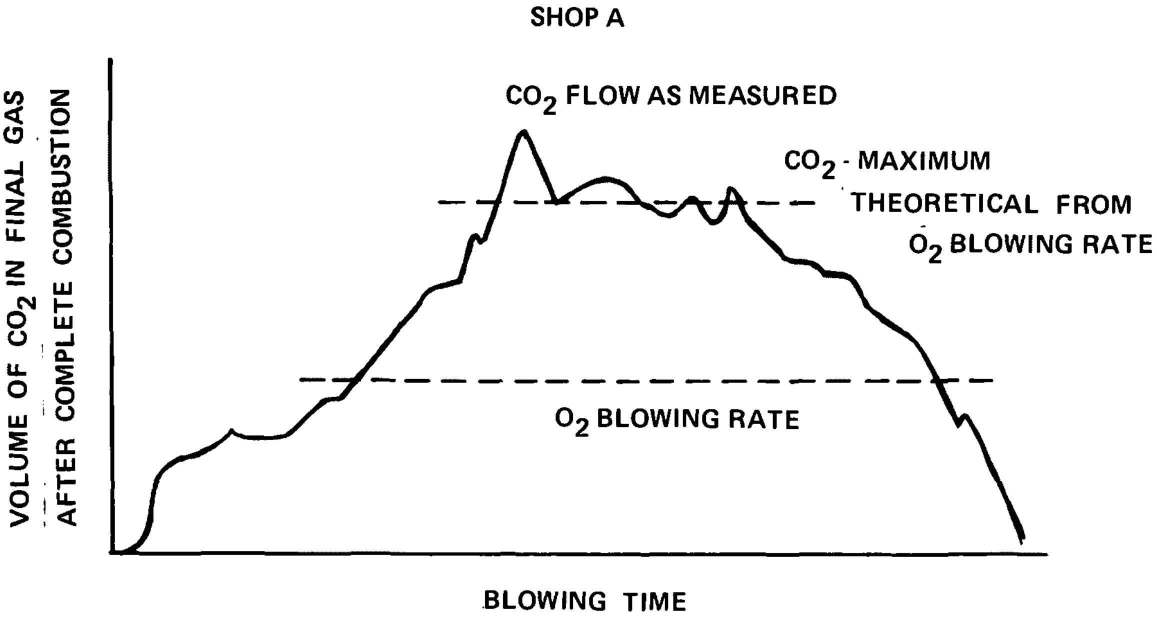
CALCULATED GAS COMPOSITION FOR 100 TON BOF BLOWN AT 12,000 SCFM O_2 RATE FOR 20 MINUTES

	Converter Emissions			Peak Gas Flow Rates After Combustion, SCFM		Peak Hood Gas Flow Rates, ACFM			
	Total/Heat		Peak Rate SCFM	Tight Hood (10% Combustion)	Open Hood (20% Excess Air)	Lower Portion of Hoods		Leaving Hoods	
	Lb	SCF				Tight at 3200F	Open at 4000F	Tight at 1800F	Open at 3000F
CO	11,800	161,000	24,000	21,600	0	152,000	0	94,000	0
CO_2	2,800	24,000	0	2,400	24,000	16,900	206,000	10,400	160,000
O_2	–	–	–	0	2,400	0	20,600	0	16,000
N_2	–	–	–	4,510	54,150	31,800	465,000	19,600	361,000
Total	14,600	185,000	24,000	28,510	80,550	200,700	691,600	124,000	537,000
Combustion Air Induced	Open Tight	1,426,000 114,200		5,710	68,550				

FIGURE 46

IMPURITY CONTENT AS A FUNCTION OF TIME DURING OXYGEN LANCING





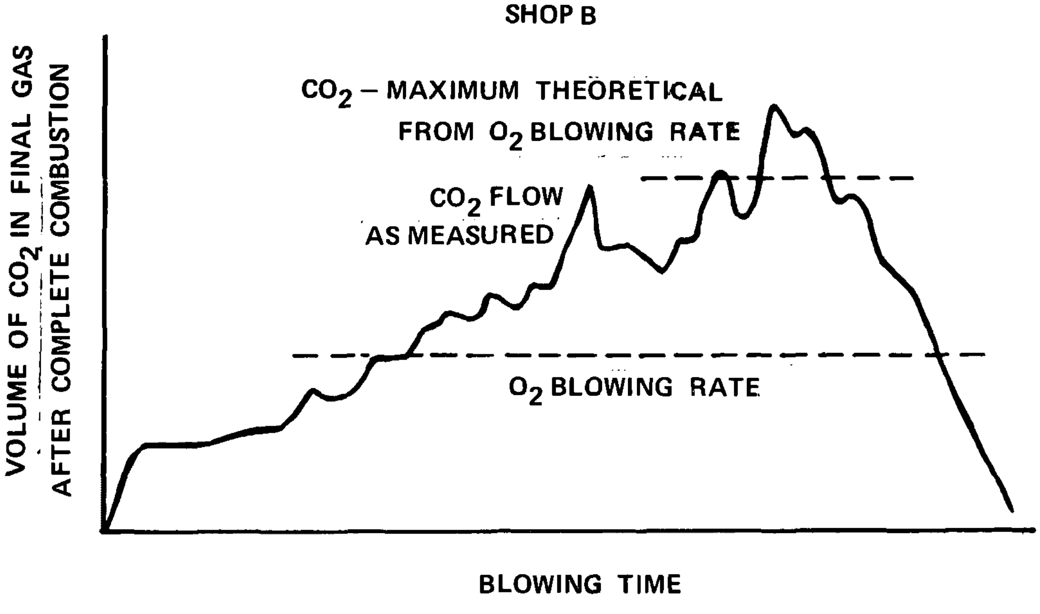


FIGURE 47

TWO PATTERNS OF FLOW RATE FROM BOF's

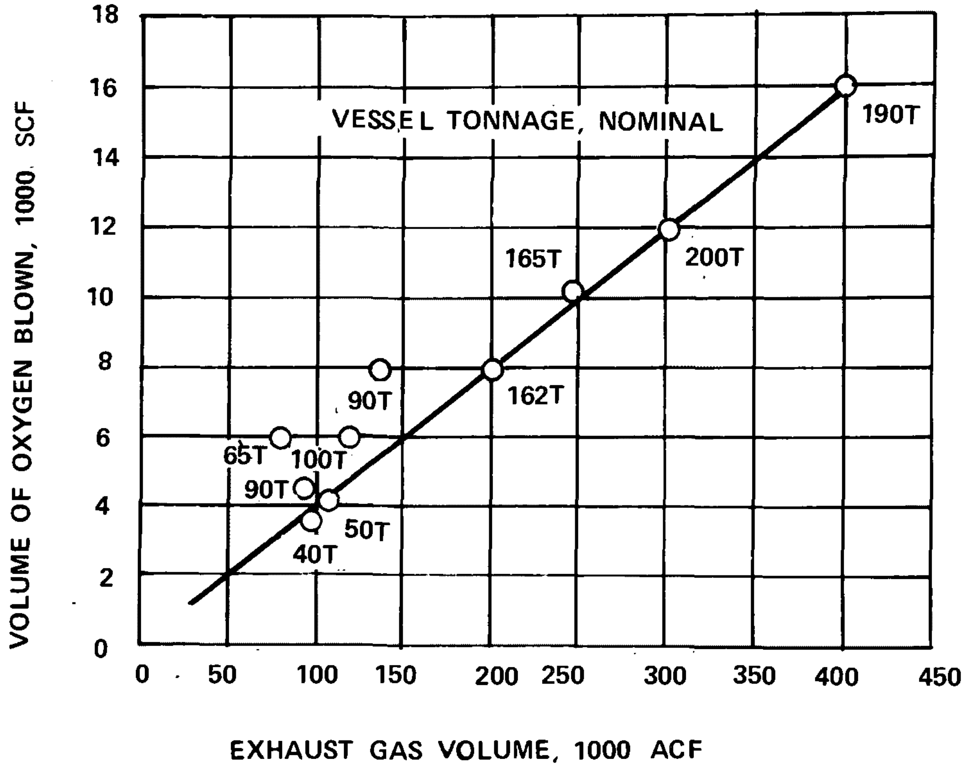


FIGURE 48

VOLUME OF BOF GAS DISCHARGE VS. OXYGEN BLOW RATE

PARTICULATE CONTAMINANTS

The particulate matter collected in BOF gas cleaning equipment consists mainly of iron oxide. Concentrations of 85 to 95% are common for an open hood or full combustion type system.(10) Most are small (less than 1 μ), rounded particles of red iron oxide (Fe_2O_3). Some particles of black oxide or magnetite (Fe_3O_4) are present, usually covered with red oxide.(1) The other constituents are mainly metalloid oxides ($MnO_2 \cdot P_2O_5$ and SiO_2) or slag components (CaO, Na_2O, etc.) (10)

Particle size is generally agreed to be very small, with reports of 95% $<$ 0.1 μ and 99% $<$ 0.2 μ .(1) Sargent(10) suggests that the primary particles formed by condensation are around 0.01 to 0.1 μ in diameter, but that they easily agglomerate, forming particles 1 μ and larger. This mechanism, which produces rapid particle growth below about 0.3 μ , would account for the large differences reported by various investigators; the growth was arrested at different stages by different experimenters according to where they took their samples.

Concentrations of dust during the blow have been reported between 6 gr/SCF and 15 gr/SCF. However, more data is available for the total rate of production than for the concentration. Values between 40 and 70 lb/ton of steel are reported.(8) It is very difficult to obtain grain loadings on an instantaneous basis because of the fluctuations in gas flow, temperature and dust content with time.

In a "partial combustion" system, oxidation of the emitted particulates to the fine red oxides is apparently arrested, due to the reducing atmosphere present in the partially combusted gas. The resultant dust is black in color, and reportedly of slightly larger size. Total solids evolution in a "closed" system is lower than in a conventional, and averages about 20 lb/ton of steel. However, because of the severely reduced gas volumes which convey it, the dust loading (gr/SCF) is greater than in a "full combustion" system where loadings are diluted by large amounts of gas.

POLLUTION CONTROL CONSIDERATIONS

In the operation of the BOF shop there are four important sources requiring pollution control:

1. Reladling or mixing operations
2. Hot metal charging

3. Furnace operation
4. Tapping

Reladling and Mixing Operations

Large amounts of kish and iron oxide are released during the transfer of hot metal to the charging ladle. This kish or oxide can be controlled by a fixed hood over the transfer station. The gases collected can be processed through the gas cleaning system for the furnace but experience has generally been that this source is better controlled by having its own small gas cleaning system.

Hot Metal Charging

During the charging of hot metal to the furnace, large amounts of dense black smoke are produced, partially released from the hot metal and partially created from the burning of surface contaminants in the scrap charge.

Because of the tilted position of the furnace during the hot metal charge, the regular furnace hood is not very effective for controlling these fumes and auxiliary hoods are required. The hood, located over the charging side of the furnace, ducts the gases to the furnace gas cleaning system.

Tapping

During tapping, iron oxide fuming occurs. If metallic alloys are added to the ladle after tapping, a white fuming emission often results. This area is also beyond the furnace hood. To date this problem has not been controlled and a workable system has yet to be developed.

HOODING SYSTEMS

Two types of hooding systems are used for BOFs. *Open hooding* systems provide a space between the bottom of the hood and the top of the furnace. This provides room for the furnace to tilt to receive charge and to pour without movement of the hood. Also, the clearance allows for infiltration of enough air to bring about complete combustion of the CO in the flue gas.(3)

Closed hooding systems provide some form of movable members to allow the hood to be attached to the furnace when it is in the vertical position, in order to prevent infiltration of air. Wheeler(3) has indicated that closed systems are capable of maintaining gas flows of as little as 20% of the flow into open systems. In addition, there is some potential for recovery of the fuel value of the CO in mills where additional fuel can be utilized economically. Fairly high quality CO gas also holds the potential for utilization in petrochemical processes.

Table 65 illustrates the difference in calculated gas flow for the two systems. Hood construction to withstand the 3,000° F and higher temperatures encountered during lancing is of extreme importance. Two systems of construction of water-cooled hoods are in common use. These are the *panel system,* in which the hood and duct are constructed of water-filled panels of steel, and the *membrane system,* which utilizes water filled tubes connected by webs. Steam production to recover some of the sensible heat in the gases has been used if the plant system can tolerate the very cyclic nature of steam formation; otherwise the steam is condensed, subcooled, and recycled into the hood. Often the steam produced is used for conditioning the gas to the precipitator.

The membrane hood is the most recently developed of the two. It offers several advantages, principal of which is that it can easily be designed to withstand internal pressure, and hence can accommodate high cooling water temperatures or steam formation. Also, it is basically a gas-tight construction which can be used to hold air leakage to a minimum in closed hood systems(11). Capital investment, though, will be higher.

The hoods are designed to conduct the hot gases to a quench section where the temperature is dropped by spraying water into the hot gas stream. Water sprays are used to bring the gas down to about 450 to 550° F in the case of precipitator installations, and 150 to 185° F for wet scrubbers.(9)

APPLICABLE POLLUTION CONTROL EQUIPMENT SYSTEMS

Venturi scrubbers and electrostatic precipitation are the two methods in use for BOF gas cleaning. Since 1957, there have been 92 BOFs installed in North America. Of these, 45 have been equipped with precipitators and 47 with high energy scrubbers.(8) Fabric collectors are considered unsuitable because of the high temperature gases and extreme variability of flow, although they have been applied in Europe.(3) These factors tend to produce temperature upsets which might destroy the bags in a conventional fabric collector. The hazard involved with possible CO combustion in electrostatic precipitators makes them less desirable for closed-hood systems, and such systems require elaborate controls. Several such installations are in operation outside the U.S.

Either precipitators or scrubbers are capable of producing the high efficiency levels required to meet air pollution regulations or to obtain color-free stacks. In either case, the application requires special considerations because of the high temperatures and intermittent nature of the operation. The system is extensive because of the large gas flows involved.

Precipitators have the advantage of operating at high enough temperatures to produce a gas stream which will not generate a steam plume except in very cold weather. Also, they do not require a high pressure drop and, hence, use much less horsepower than a scrubber. Several drawbacks also exist. The resistivity of the collected fume materials is high, and careful control of the moisture in the gas stream is required to "condition" the dust, and bring the resistivity to an acceptable level. This may require injection of steam at the beginning and end of the cycle.(3) For most precipitator installations in the U.S., the gas volumes range between 500,000 and 1,000,000 ACFM.

Scrubbers require upwards of 40 inches of water column in order to produce suitable emission levels. This requires a very large fan and high horsepower driver. In addition, the scrubber system has the potential for production of an objectionable steam plume. In order to avoid this, it is customary to install an after-cooler between the scrubber and fan which condenses a substantial fraction of the water vapor before it passes through the fan. This also reduces substantially the total quantity of gas which is reflected in a considerable reduction of fan power requirements.

The scrubber produces a slurry of iron oxide and water which cannot be discharged into rivers or lakes, and must be treated to separate the dust. Usually, clarifiers are provided to settle the dust, and frequently filters or centrifuges follow to provide a wet, but solid oxide product.

Although complex, the scrubbing system has generally given satisfactory service in BOF operation. The recovered product does not have the dusting problems involved in precipitators. Also, if there is no zinc (from galvanized scrap) in the BOF charge, the fines collected may be recycled directly through the sinter plant to provide fresh charge for the blast furnaces, whereas dust from precipitators requires wetting and pugging before going to the sinter plant.

Because of the cyclic operation of BOF steelmaking, the maintenance requirements for either scrubbers or precipitators are higher than those required for continuous industrial processes. Auxiliary equipment, such as handling systems for the collected oxides, must take into consideration the cyclic operation, and all auxiliaries must be functional to realize long term optimum performance of the pollution control system.

SPECIFICATIONS AND COSTS

Specifications were originally written for 75 ton and 300 ton furnace capacities. At the request of the EPA Project Officer, the size of the smaller unit was increased to 140 ton. In addition, the specifications were originally intended to cover only the equipment ordinarily supplied by the air pollution control equipment manufacturers. This does not include the hooding and ductwork, except in the case of the closed hood system. In order to put the equipment prices on a comparable basis, the specifications were modified to include both hoods and ductwork.

Precipitator specifications are given in Tables 66 and 67. These are only for the open hood arrangement. The cost data submitted is listed in Tables 68 and 69. The data is plotted in Figures 49 through 52 for both the intermediate efficiency (LA–process weight) case and high efficiency cases.

The precipitators quoted do not show detailed breakdowns for the cost of auxiliaries. This is because the costs in most cases were scaled from actual bid prices of recent installations. This process did not permit the scaling of individual prices of the auxiliary equipment.

The specifications for scrubbing equipment are given in Tables 70 and 71 for the open hood system, in which air is induced into the hoods over the furnaces to complete the combustion of CO. The first costs and operating costs are given in Tables 73 and 74 and plotted in Figures 55 and 56.

Figures 55 and 56 represent costs for the high efficiency cases only. The operating cost figures are probably less accurate than the first cost values because the manufacturers do not have direct responsibility for operating costs as they do have for the cost of equipment.

The closed hood systems are specified in Tables 70 and 72, and the capital and operating costs given in Tables 75 and 76.

In these systems, the flow of air into the furnace is limited and the CO produced in the furnace remains unburned in the gas cleaning system. This presupposes that the gas will be used for fuel within the plant and will NOT be discharged into the atmosphere without some further processing in a furnace. The specifications were, however, written as though it would be discharged from the fan, and the grain loadings set accordingly. One of the bidders stated that he would not be willing to guarantee performance at the high efficiency level in either the open or closed hood case.

The pressure levels are given in the specifications at various points in the system. This was done in order to establish the flowing volumes and other properties of the gas streams at the fan, the scrubber, etc. There was no intention here to guide the manufacturers with respect to the pressure levels required for the scrubber and other equipment items. The responses were based on the manufacturers estimates of the most suitable pressure drop. One of the manufacturers wished to keep the pressure drop requirement confidential. Another responded with the following pressure drop information.

	Required Δ P, in w.c.	
	Open Hood	Closed Hood
Scrubber for		
LA–Process wt		
small	44	23
Large	51	27
High Efficiency	61	42
Cooler for		
LA–Process wt	7	6
High Efficiency	8	5

Costs for abatement equipment operating at removal efficiencies better than the "high efficiency" cases were solicited from the same sets of bidders as those who provided the original costs. Table 77 shows the capital costs for scrubbers operating at 0.005 gr/ACF outlet grain loading. Table 78 shows comparable data for precipitators operating at outlet grain loadings of 0.005 gr/ACF and 0.0025 gr/ACF. These data represent estimates only. The manufacturers who quoted the numbers would be reluctant to guarantee performance at these levels due to the lack of operating data.

TABLE 66

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION

FOR BOF STEELMAKING SPECIFICATION

The air pollution abatement system is to serve a new BOF shop in which two furnaces will be installed. The operating cycle is to involve operation of one furnace at any given time, with the second out of service for relining, or on standby. The precipitator shall be designed to accommodate the gas flow produced by lancing a single furnace at any one time.

The system shall be quoted complete including all of the following as detailed in our drawings: *

(1) Dirty gas mains

(2) Gas conditioning equipment

(3) Inlet header

(4) Electrostatic precipitator(s)

(5) Dust transfer and storage hoppers

(6) Fans, dampers, and pressure control system

(7) Outlet ductwork and stack

(8) Auxiliary equipment

**NOTE: It is customary for integrated steel companies to undertake major system design projects with their own engineering personnel. Detailed drawings might well accompany requests for final contract bids.*

In addition to the design specifications for the precipitator given in Section 3, the following operating data is given for the BOF shop:

	Small		*Large*
Capacity, ton/melt	*140*		*250*
Oxygen lance rate, lb/hr	*86,000*		*152,000*
Oxygen lance rate, SCFM	*16,800*		*30,000*
Operating cycle, minutes		*50*	
Charge scrap		*5*	
Charge hot metal		*3 Throttled flow*	
Charge lime		*1*	
Blow		*20*	
Sample		*3 Full flow*	
Finish blow		*2*	
Tap		*3*	
Pour slag		*3 Throttled flow*	
Idle		*5-10*	

TABLE 66 (cont.)

The cycle for the two furnaces shall be timed in such a way that both are not being blown at one time. Therefore, the dust collection system will be required to handle the maximum flow from one furnace plus throttled flow from the other during lining burn-in.

Membrane hoods and evaporation chambers shall be provided by others on each furnace so that for the purposes of this specification, the scope of the gas cleaning installation shall begin at the outlet of the hood evaporation chamber. The volumes and gas temperatures given in Section 3 shall apply at this point. The bidders shall take into account all temperature losses and gas conditioning through the system furnished by them.

1. Dirty Gas Mains from the outlet of each hood shall be provided to a common main carrying the gases to the inlet header of the precipitator. Each individual main shall be 120′ long running from the top of the mill building to the main on the eave of the building, and shall contain an isolation damper with controls for full flow, throttled flow and closed operating conditions. A motor operated isolation gate shall also be provided downstream of each damper to facilitate repairs to the dampers, while the rest of the system is operating. The common main to the precipitator inlet header shall be sized to maintain carrying velocities during one furnace operation, and yet not have so great a velocity under two furnace operations as to create excessive pressure drops. It will be 350′ long.

2. Gas Conditioning Equipment in the form of steam sprays, shall be furnished in the common dirty gas main to provide for additional moisture during the periods at the start and finish of each blow, when the quenching water may not be sufficient to provide the proper moisture content for efficient precipitation.

3. Inlet Header shall be provided to receive the gases from the dirty gas main and assist in distribution to all the precipitator chambers.

4. Precipitators shall be single stage, plate type units, with a minimum of two fields in the direction of gas flow for the intermediate efficiency case, and three fields in the direction of gas flow for the high efficiency case. Inlet face velocity shall not exceed 4 FPS in either case.

The precipitator shall be divided into gas tight chambers parallel to gas flow and shall be sized to have one spare chamber when operating one furnace. Each chamber will have slide gates at inlet and outlet, in order to isolate the chamber for repairs while the remainder of the precipitators are operating. Dampers or similar flow balancing device shall be furnished for each chamber.

Automatic controls shall be provided to continuously optimize the voltage level in each independent field. All control circuits shall be energized through a safety interlock system so that no access to high voltage equipment can be made without first de-energizing all fields.

Hoppers shall be separate for each field, or shall be equipped with partition plates to prevent bypassing of uncleaned gas through the hoppers. Hopper capacity shall be such that operation can be maintained for 8 hours after failure of any piece of dust transfer equipment.

All materials of construction are to be carbon steel. The minimum plate thickness shall be 3/8″, except for collecting electrodes.

TABLE 66 (cont.)

5. Dust Removal & Storage equipment shall be provided for continuous removal of dust from the precipitator hoppers and conveyed to a dust storage bin. The dust storage bin shall have sufficient capacity for storage of all dust from 48 hours of continuous operation and shall be arranged to facilitate clean removal by truck.

6. Fans and dampers shall be provided to move and control the volume of gas called for in Section 3. The fans shall develop sufficient static pressure to adequately draft the furnace hoods without puffing. Three (3) fans shall be provided and sized so that any two fans can provide adequate draft for handling the full flow conditions from one furnace and the throttled flow from the other furnace. The arrangement will be compatible for the future addition of fans to move the volume of gas generated by two furnaces blowing simultaneously. A pressure control system shall be provided to balance the flow between precipitator chambers and balance the load between fans while maintaining a system set pressure by controlling fan inlet dampers.

7. Outlet ductwork and stack will be required to convey the cleaned gases to the atmosphere. The discharge from each fan should go to a common header leading to a common stack. The stack should be 200′ in height.

The precipitator, hoppers, inlet header and all ductwork from the beginning of the system to the outlet flange of the fans shall be insulated with three (3) inches of insulation and covered with 24 ga. galvanized steel.

8. Auxiliary equipment required for the operation of the system, shall be furnished. This will include Control Room building for the gas cleaning equipment, control room, 440V motor control center, systems controls, instrumentation and lighting.

TABLE 67

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR BOF STEELMAKING SPECIFICATION

Two efficiency levels are to be quoted for each of two sizes for the open hood system described. The high efficiency case is listed first.

	Small	*Large*
Process Capacity, ton/melt	*140*	*250*
Oxygen Blowing Rate, SCFM	*17,000*	*30,000*
Waste Gas Volume @ design Blowing Rate @ 650° F, ACFM	*530,000*	*950,000*
Gas Temperature @ Inlet to Gas Cleaning System, °F	*650*	*650*
Precipitator Design Pressure, in.w.c.	*-15*	*-15*
Inlet Dust Loading, gr/SCF, dry	*12*	*12*
Inlet Dust Loading, lb/hr	*23,200*	*41,000*
Outlet Residual, gr/ACF	*0.010*	*0.010*
Outlet Dust Loading, lb/hr	*45.6*	*81.5*
Required Efficiency, %	*99.80*	*99.80*
% Moisture @ 90 sec. after 0_2 & up to last 2 min. of blow	*15*	*15*
Gas Volume @ throttled operation and vessel lining burn in, ACFM	*55,000*	*100,000*
Gas Volume for leakage through dampers of idle vessels		*by bidder*

The system is to be designed for an operating volume of 530,000 or 950,000 ACFM @ 650 degrees entering the system from one active furnace plus the leakage from the two other furnaces.

As an alternate, the bidder shall describe the additional equipment necessary to handle the full flow from one furnace and the throttled volume from another furnace, which may be being charged at the same time.

For the purpose of fan sizing, the following pressure drops will be used:

a.	*Hood and evaporation chamber, in.w.c.*	*2*
b.	*Ductwork from evaporation chamber to inlet header, in.w.c.*	*4*
c.	*Inlet Header through precipitator to fan*	*By Vendor*
d.	*Fan to stack outlet*	*By Vendor*

Alternatively, the intermediate efficiency level should be quoted for the same inlet conditions, but with the following loadings and efficiency:

Solids, lb/hr	*40*	*40*
Solids, gr/ACF	*0.0088*	*0.0049*
Required Efficiency, %	*99.83*	*99.9*

TABLE 68

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)

FOR ELECTROSTATIC PRECIPITATORS FOR BOF STEELMAKING

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow (2)				
ACFM	600,000	1,020,000	600,000	1,020,000
°F	650	650	650	650
SCFM	286,000	535,000	286,000	535,000
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF	4.5	4.5	4.5	4.5
lb/hr	23,200	41,000	23,200	41,000
Cleaned Gas Flow (2)				
ACFM	600,000	1,020,000	600,000	1,020,000
°F	650	650	650	650
SCFM	286,000	535,000	286,000	535,000
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF (2)	0.0078	0.0046	0.01	0.01
lb/hr	40	40	51.5	51.5
Cleaning Efficiency, %	99.83	99.9	99.8(3)	99.8(3)
(1) Gas Cleaning Device Cost	747,000	1,249,250	700,400	1,140,800
(2) Auxiliaries Cost				
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment	5,202,000	6,551,475	5,162,330	5,862,730
(3) Installation Cost	(Includes 1,940,000 for hoods)	(Includes 2,330,000 for hoods)	(Includes 1,940,000 for hoods)	(Includes 2,330,000 for hoods)
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	5,949,000	7,800,725	5,862,730	7,003,530

(1) Based upon two quotations.
(2) Includes leakage through non-lancing furnace hood
(3) Prices below correspond to 99.88% efficiency

TABLE 69

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR ELECTROSTATIC PRECIPITATORS FOR BOF STEELMAKING

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7850				
Operating Labor (if any)					
Operator	$6/hr	-	-	-	-
Supervisor	$8/hr	-	-	-	-
Total Operating Labor					
Maintenance (2)					
Labor					
Materials					
Total Maintenance		147,400	167,400	147,400	167,400
Replacement Parts (3)					
Total Replacement Parts		29,900	34,200	29,900	34,200
Utilities					
Electric Power	$.011/kw-hr	83,675	131,700	83,675	131,700
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		83,675	131,700	83,675	131,700
Total Direct Cost		260,975	333,300	260,975	333,300
Annualized Capital Charges		594,900	780,072	586,273	757,560
Total Annual Cost		855,875	1,113,372	847,248	1,090,860

(1) Based upon two quotations.
(2) Based on 5% of system cost
(3) Based on 1% of system cost

FIGURE 49

CAPITAL COSTS FOR PRECIPITATOR SYSTEMS FOR BOF STEELMAKING (INTERMEDIATE EFFICIENCY)

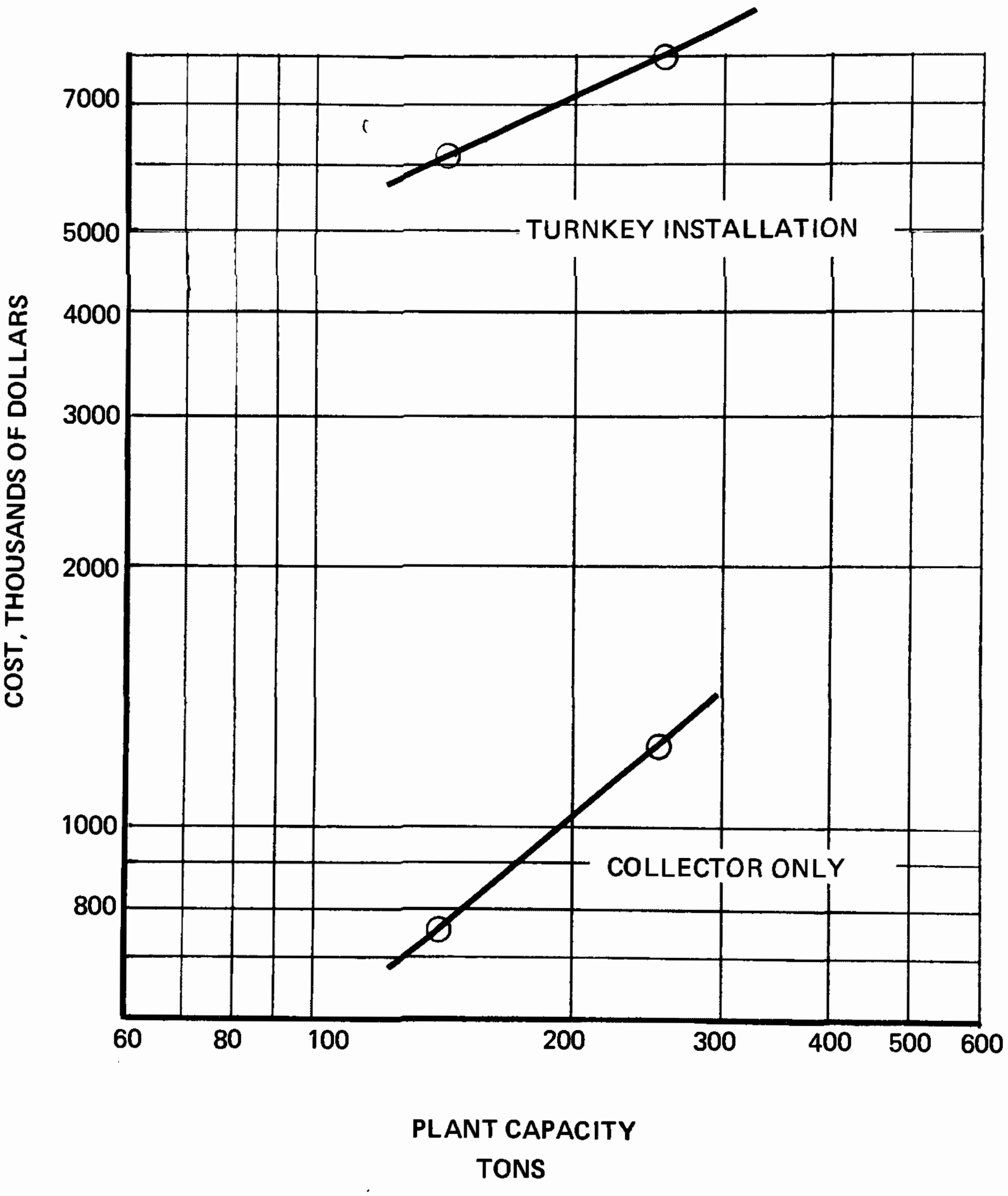


FIGURE 50

ANNUAL COSTS FOR PRECIPITATORS FOR BOF STEELMAKING (INTERMEDIATE EFFICIENCY)

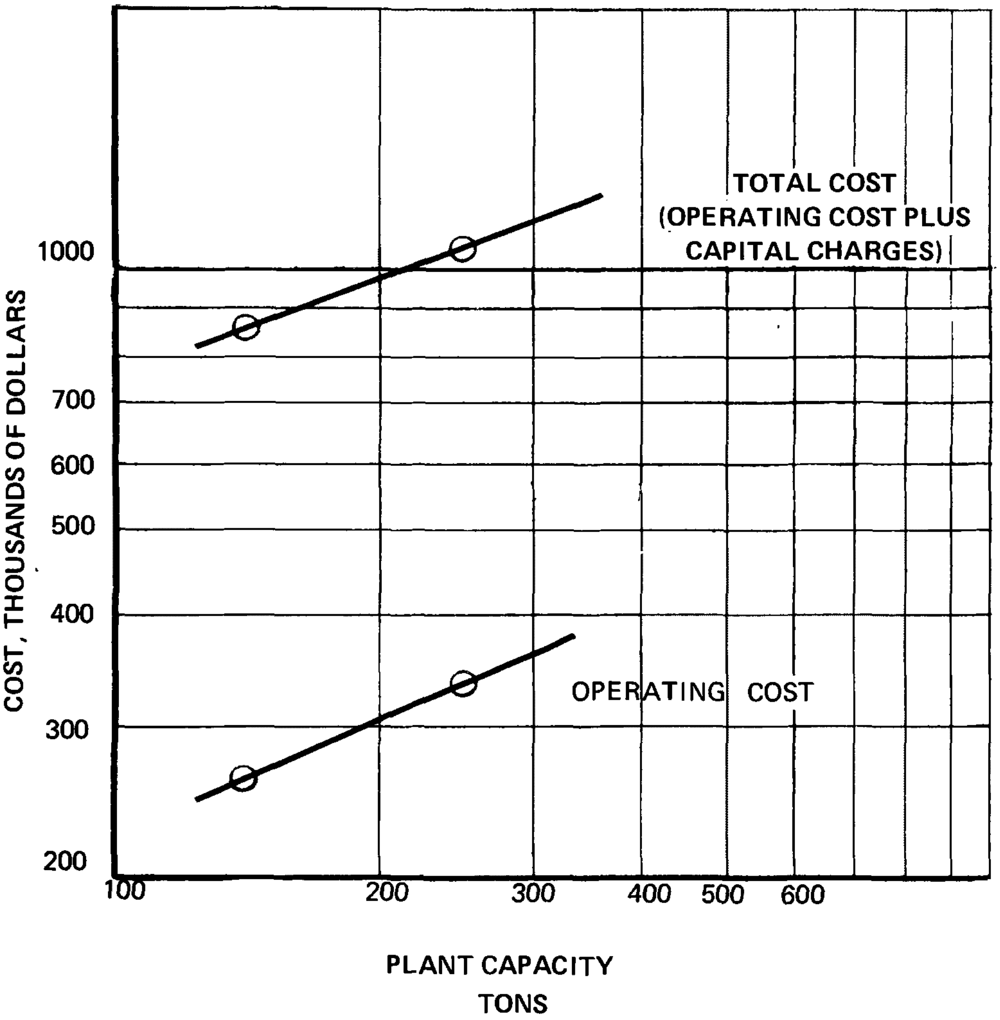
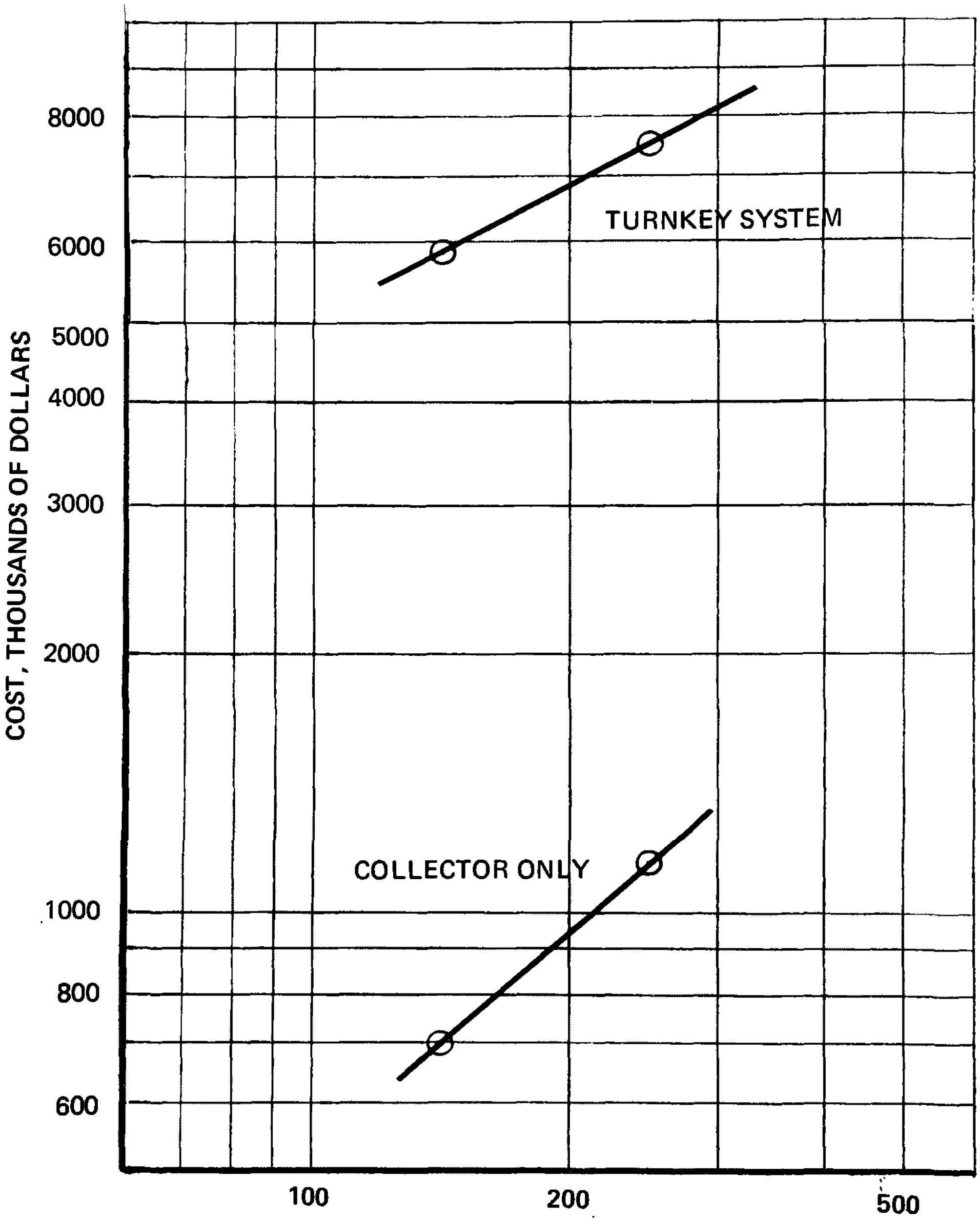


FIGURE 51

CAPITAL COSTS FOR PRECIPITATOR SYSTEMS FOR BOF STEELMAKING (HIGH EFFICIENCY)

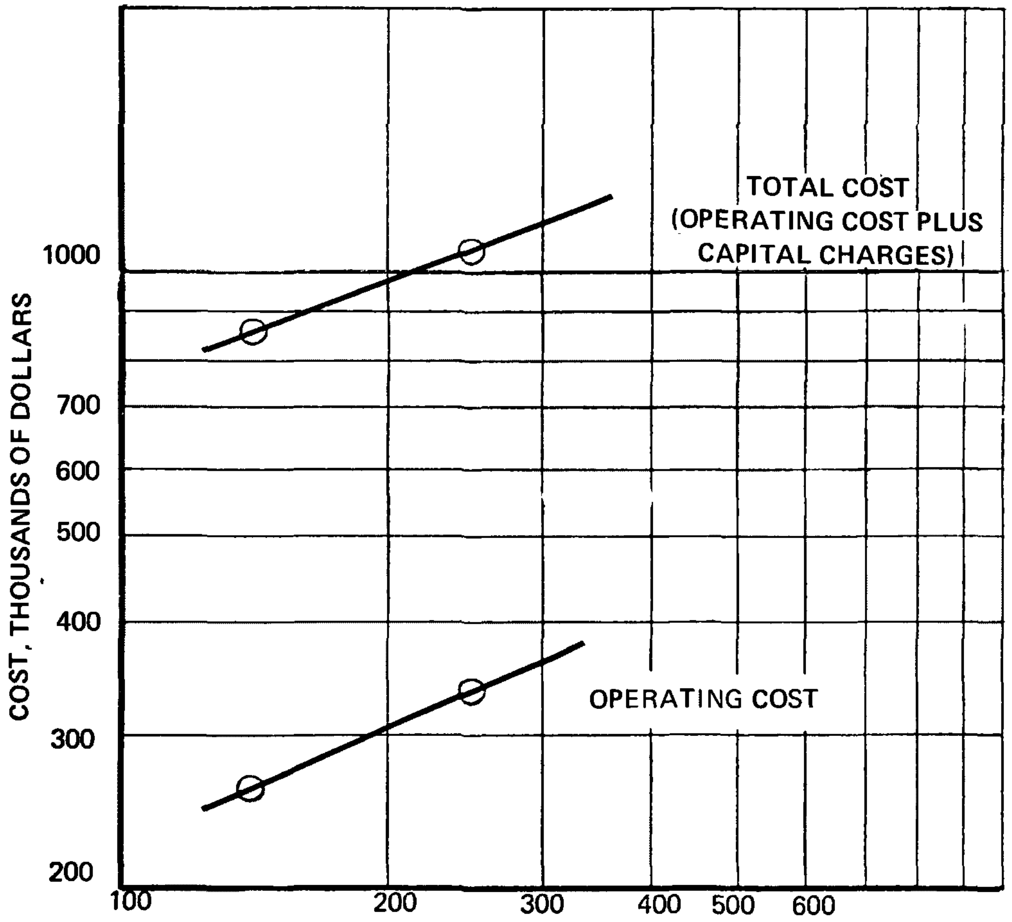


PLANT CAPACITY

TONS

FIGURE 52

ANNUAL COSTS FOR PRECIPITATORS FOR BOF STEELMAKING (HIGH EFFICIENCY)



PLANT CAPACITY
TONS

FIGURE 53

CONFIDENCE LIMITS FOR CAPITAL COSTS OF PRECIPITATORS FOR BOF STEELMAKING (LA–PROCESS WEIGHT)

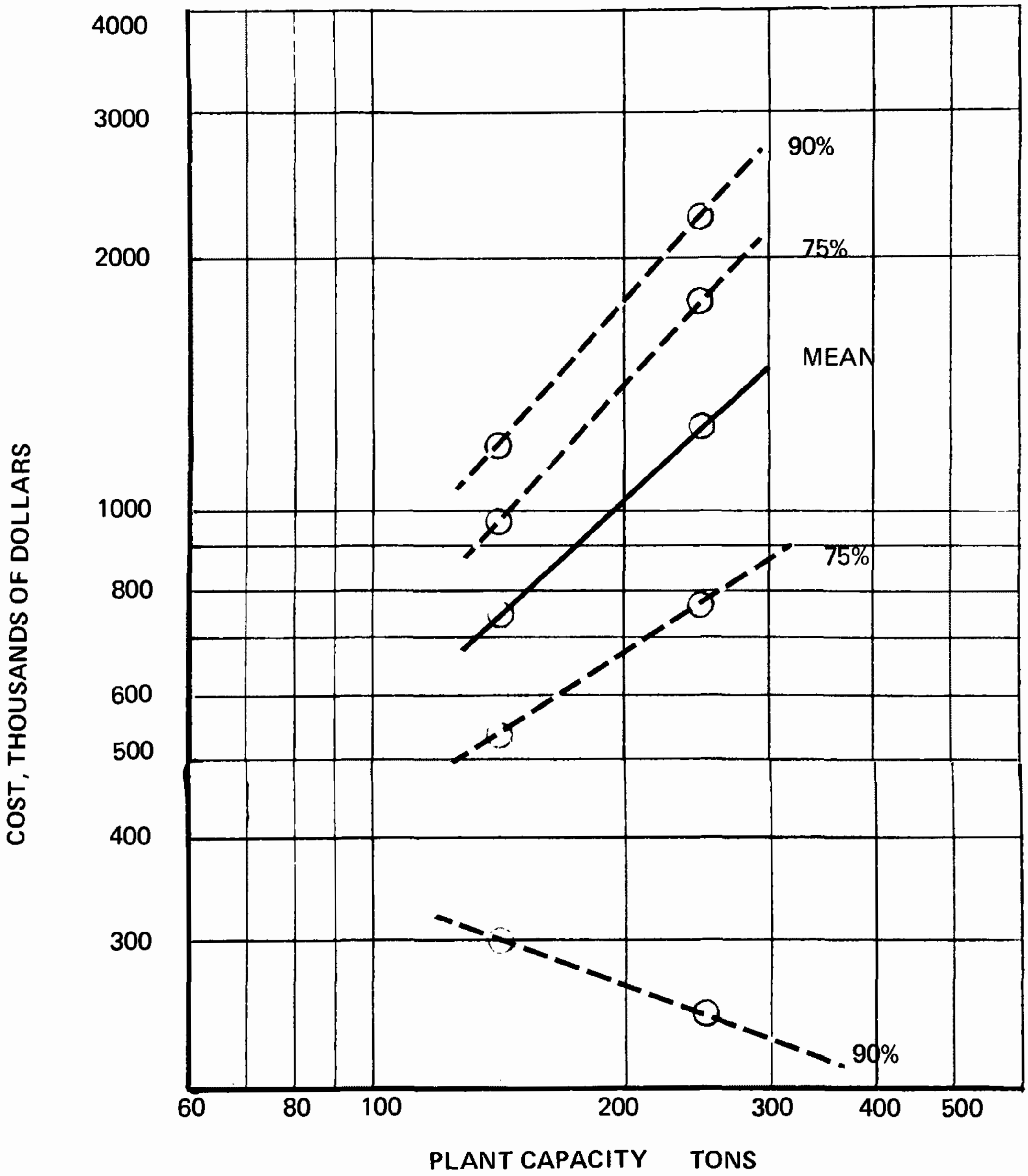


FIGURE 54

CONFIDENCE LIMITS FOR CAPITAL COSTS OF PRECIPITATORS FOR BOF STEELMAKING (HIGH EFFICIENCY)

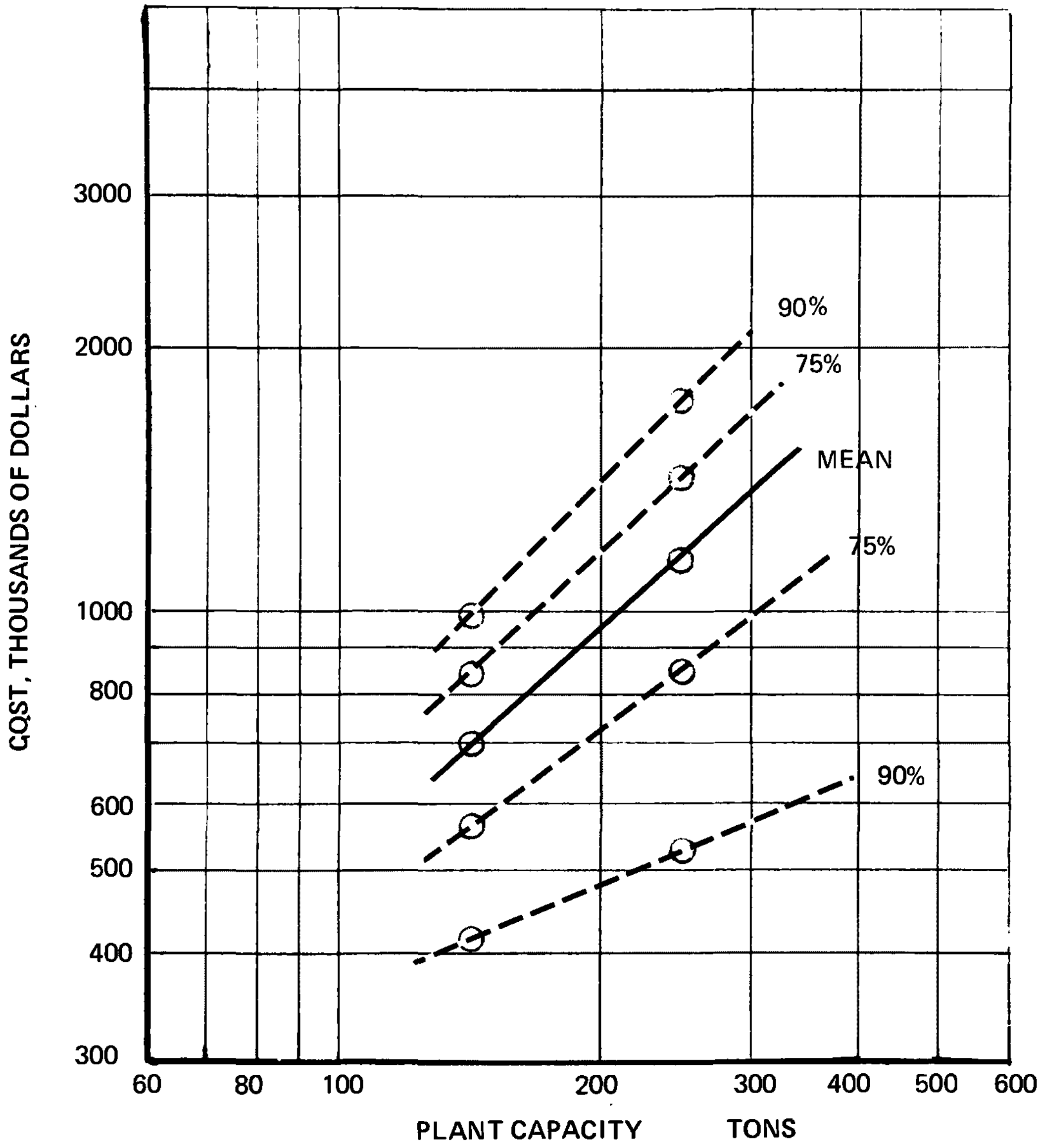


TABLE 70

WET SCRUBBER PROCESS DESCRIPTION

FOR BOF STEELMAKING SPECIFICATION

The air pollution abatement system is to serve a new BOF shop in which two furnaces will be operated. The scrubbing system shall be designed for oxygen lancing of a single furnace at any one time, but provision for future gas cleaning equipment to handle two lancing operations simultaneously shall be made.

The system shall be quoted complete including all of the following items as detailed in our drawings: *

(1) Interconnecting ductwork

(2) Quench chamber(s)

(3) Venturi scrubber(s) with mist eliminators

(4) After-cooling chamber(s)

(5) Cooling tower(s)

(6) Fan(s)

(7) Single 200 foot stack

The system shall be quoted on each of the following bases:

(1) Scrubber(s) only

(2) Complete equipment, consisting of

  (a) Scrubbers

  (b) Cooling chambers and towers

  (c) Fans

**NOTE: It is customary for integrated steel companies to undertake major system design projects with their own engineering personnel. Detailed drawings might well accompany requests for final contract bids.*

(3) Complete turnkey system

In addition to the design specifications for the scrubber given in Section 3, the following operating data is given for the BOF shop:

	Small			*Large*
Capacity, ton/melt	*140*			*250*
Oxygen lance rate, lb/hr	*85,000*			*152,000*
Oxygen lance rate (SCFM)	*16,800*			*30,000*
Operating cycle, minutes		*50*		
Charge scrap		*5*		
Charge hot metal		*3*	*Throttled flow*	
Charge lime		*1*		
Blow		*20*		
Sample		*3*	*Full flow to scrubber*	
Finish Blow		*2*		
Tap		*3*		
Pour slag		*3*	*Throttled flow*	
Idle		*5-10*		

The cycle for the two furnaces shall be timed in such a way that both are not being blown at one time. Therefore, the scrubbing system will be required to handle the maximum flow from one furnace, plus throttled flow from the other during lining burn-in.

Scrubbers shall be Venturi-type with sufficient pressure drop to perform as specified in Section 3. The liquid-gas ratio shall be specified by the vendor but shall in no event be lower than 5 GPM per 1,000 ACFM (saturated). Vendor shall specify the actual pressure drop at which the scrubbers will operate.

Aftercoolers shall reduce the temperature of the gas exiting the scrubbers to 95°F. by counter-current contact with 90°F. cooling water. The aftercoolers and cooling towers shall be provided as a part of the turnkey proposal.

Fans shall be capable of overcoming the system pressure drop at the design flow rate while operating at no more than 90% of "red-line" speed. Motors shall be capable of driving fans at "red-line" speed and the corresponding pressure differential at 20% over the design flow rate.

Slurry Settler(s) shall be capable of producing a reasonably thickened underflow product while returning water fully treated to minimize solids content.

Filters shall be provided to dewater the slurry product. Filters shall produce a cake with a minimum of 70% solids, suitable for transportation by open truck. A minimum of two filters shall be provided, such that one may be out of service for repair at any time without interfering with normal operation.

TABLE 71

WET SCRUBBER OPERATING CONDITIONS

FOR BOF STEELMAKING SPECIFICATION

(OPEN HOOD SYSTEM)

Two efficiency levels are to be quoted for each of two sizes for the open hood system described. The high efficiency case is listed first:

	Small	Large
Process Capacity, ton/melt	140	250
Process Weight, ton/hr*		
Scrap Steel	110	197
Hot Metal	258	460
Fluxes	22	41
Total	390	698
Gas from Furnace		
Temp., °F	4,000	4,000
Pressure, psia	14.7	14.7
Pressure, in w.c.	-1	-1
Flow ACFM	970,000	1,730,000
Gas to Scrubber**		
Temp., °F	3,000	3,000
Pressure, psia	14.6	14.6
Pressure, in w.c.	-3	-3
Flow ACFM (Avg. over blow)	750,000	1,340,000
Composition, mol %		
CO	0.0	0.0
CO_2	29.8	29.8
N_2	67.2	67.2
O_2	3.0	3.0
H_2O	0.0	0.0
Solids loading, lb/hr	23,200	41,000
Solids loading, gr/ACF	3.6	3.6
Solids loading, gr/DSCF	24	24
Gas from Scrubber		
Temp., °F	180	180
Pressure, psia	13.1	13.1
Pressure, in w.c.	-45	-45
Flow ACFM (Avg. over blow)	366,000	655,000
Composition, Mol %		
CO	0.0	0.0
CO_2	12.7	12.7
N_2	28.6	28.6
O_2	1.3	1.3
H_2O	57.4	57.4
	100.0	100.0

* *Based on two blow periods per 50 minute cycle*
***Prior to water contact*

Solids loading, lb/hr	11.1	20.3
Solids loading, gr/ACF	0.0036	0.0036
Solids loading, gr/DSCF	0.0117	0.0117
Scrubber Efficiency, %	99.95	99.95
Gas from Cooling Tower		
Temp., °F	105	105
Pressure, psia	12.9	12.9
Pressure, in w.c.	-50	-50
Flow, ACFM	151,000	270,000
Gas Comp. Mol %		
CO	0.0	0.0
CO_2	27.6	27.6
N_2	62.3	62.2
O_2	2.7	2.7
H_2O	7.5	7.5
	100.0	100.0
Solids loading, lb/hr	11.1	20.3
Solids loading, gr/ACF	0.009	0.009
Solids loading, gr DSCF	0.0117	0.0117
Gas from Fan		
Temp., °F	130	130
Pressure, psia	14.7	14.7
Pressure, in w.c.	0	0
Flow, ACFM	132,000	235,000
Solids loading, lb/hr	11.1	20.3
Solids loading, gr/ACF	0.010	0.010
Solids loading, gr/DSCF	0.0117	0.0117

Alternatively, the intermediate efficiency case should be quoted for the same inlet conditions as specified previously, but with the following outlet loadings from the scrubber.

	Small	Large
Gas from scrubber		
Temp., °F	180	180
Pressure, psia	13.1	13.1
Pressure, in w.c.	-45	-45
Flow, ACFM	366,000	655,000
Water Content, Mol %	57.4	57.4
Solids loading, lb/hr	40	40
Solids loading, gr/ACF	0.0122	0.00715
Solids loading, gr/DSCF	0.0412	0.023
Scrubber Efficiency, %	99.83	99.9

TABLE 72

WET SCRUBBER OPERATING CONDITIONS

FOR BOF STEELMAKING SPECIFICATION

(CLOSED HOOD SYSTEM)

Two efficiency levels are to be quoted for each of two sizes for the closed hood system described. The high efficiency case is listed first.

	Small	*Large*
Process Capacity, ton/melt	140	250
*Process Weight, ton/hr**		
Scrap Steel	110	197
Hot Metal	258	460
Fluxes	22	41
	390	698
Gas from Furnace		
Temp., ^{o}F	3,200	3,200
Pressure, psig	14.7	14.7
Pressure, in w.c.	-1	-1
Flow, ACFM	282,000	502,000
Gas to Scrubber		
Temp., ^{o}F	1,800	1,800
Pressure, psig		
Pressure, in w.c.	-2	-2
Flow, ACFM	174,000	310,000
Gas Composition, Mol %		
CO	75.8	75.8
CO_2	8.4	8.4
N_2	15.8	15.8
O_2	—	—
H_2O	0.0	0.0
	100.0	100.0
Solids loading, lb/hr	23,200	41,000
Solids loading, gr/ACF	15.5	15.5
Solids loading, gr/DSCF	67.5	67.5
Gas from Scrubber		
Temp., ^{o}F	170	170
Pressure, psia	12.7	12.7
Pressure, in w.c.	-55	-55
Gas Flow, ACFM	100.000	177.000
Moisture Content, Vol. %	47.3	47.3
Solids loading, lb/hr	4.2	7.45
Solids loading, gr/ACF	0.0050	0.0050
Solids loading, gr/DSCF	0.012	0.012
Scrubber Efficiency, %	99.98	99.98

TABLE 72 (cont.)

Gas from Cooling Tower		
Temp., ^{o}F	*105*	*105*
Pressure, psia	*12.5*	*12.5*
Pressure, in w.c.	*-60*	*-60*
Flow, ACFM	*46.400*	*102.000*
Gas Comp., Mol %		
CO	*70.1*	*70.1*
CO_2	*7.8*	*7.8*
N_2	*14.6*	*14.6*
O_2	–	–
H_2O	*7.5*	*7.5*
	100.0	*100.0*
Solids loading, lb/hr	*4.2*	*7.45*
Solids loading, gr/ACF	*0.087*	*0.087*
Solids loading, gr/DSCF	*0.012*	*0.012*
Gas from Fan		
Temp., ^{o}F.	*125*	*125*
Pressure, psia	*14.7*	*14.7*
Pressure, in w.c.	*0*	*0*
Flow, ACFM	*48,500*	*87,000*
Solids loading, lb/hr	*4.2*	*7.45*
Solids loading, gr/ACF	*0.010*	*0.010*
Solids loading, gr/DSCF	*0.012*	*0.012*

TABLE 73

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS FOR BOF STEELMAKING

(OPEN HOOD)

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	970,000	1,730,000	970,000	1,730,000
°F	3,000	3,000	3,000	3,000
SCFM	121,000	200,000	121,000	200,000
Moisture Content, Vol. %	0	0	0	0
Effluent Dust Loading				
gr/ACF	3.6	3.6	3.6	3.6
lb/hr	23,200	41,000	23,200	41,000
Cleaned Gas Flow (1)				
ACFM	132,000	235,000	132,000	235,000
°F	130	130	130	130
SCFM	121,000	202,000	121,000	202,000
Moisture Content, Vol. %	9.7	9.7	9.7	9.7
Cleaned Gas Dust Loading				
gr/ACF	0.034 (2)	0.020 (2)	0.0117	0.0117
lb/hr	24.0	40.0	9.1	20.3
Cleaning Efficiency, %	99.83	99.9	99.95	99.95
(1) Gas Cleaning Device Cost	287,133	411,167	287,133	411,167
(2) Auxiliaries Cost (3)	2,592,200	3,351,063	2,603,434	3,364,433
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost	2,280,867	2,745,970	2,287,267	2,749,834
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	5,160,200	6,508,200	5,177,834	6,525,434

(1) At fan discharge.

(2) Lower outlet loadings quoted by one manufacturer as "highest reasonable".

(3) Includes cooling tower, ductwork and hoods.

TABLE 74

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING

(OPEN HOOD)

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$6/hr	8,690	8,690	8,690	8,690
Supervisor	$8/hr	-	-	-	-
Total Operating Labor					
Maintenance (1)					
Labor	$6/hr	285,500	367,100	286,500	367,800
Materials					
Total Maintenance		285,500	367,100	286,500	367,800
Replacement Parts (2)					
Total Replacement Parts		57,150	73,810	57,300	73,970
Utilities					
Electric Power	$.011/kw-hr	247,000	484,000	377,300	606,100
Fuel		-	-	-	-
Water (Process)	$.25/M Gal	222,500	404,500	222,500	404,500
Water (Cooling) (3)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		469,500	888,500	599,800	1,010,600
Total Direct Cost		820,840	1,338,100	952,290	1,461,060
Annualized Capital Charges		571,500	738,100	573,000	739,700
Total Annual Cost		1,392,340	2,076,200	1,525,290	2,200,760

(1) Based on 5% of system cost.
(2) Based on 1% of system cost.
(3) Closed cooling systems are used. Pump HP is in power cost.

TABLE 75

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS FOR BOF STEELMAKING

(CLOSED HOOD)

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	174,000	310,000	174,000	310,000
°F	1,800	1,800	1,800	1,800
SCFM	41,000	73,500	41,000	73,500
Moisture Content, Vol. %	0	0	0	0
Effluent Dust Loading				
gr/ACF	15.5	15.5	15.5	15.5
lb/hr	23,200	41,000	23,200	41,000
Cleaned Gas Flow (1)			Note (2)	
ACFM			80,000	143,000
°F			160	160
SCFM (Dry)			41,000	73,500
Moisture Content, Vol. %			40	40
Cleaned Gas Dust Loading				
gr/ACF			0.010	0.010
lb/hr			7.0	12.6
Cleaning Efficiency, %			99.97	99.97
(1) Gas Cleaning Device Cost			111,850	207,900
(2) Auxiliaries Cost				
(a) Fan(s)			2,250,000	2,900,000
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost				
(a) Engineering			4,400,000	5,300,000
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost			6,761,850	8,407,900

(1) At discharge to atmosphere.

(2) OG systems are not ordinarily quoted with cooling towers.

TABLE 76

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)

FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING (CLOSED HOOD)

← Note 1 →

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$6/hr			8,690	8,690
Supervisor	$8/hr			-	-
Total Operating Labor				8,690	8,690
Maintenance (2)					
Labor	$6/hr			338,100	420,400
Materials					
Total Maintenance				338,100	420,400
Replacement Parts (3)				67,600	84,100
Total Replacement Parts				67,600	84,100
Utilities					
Electric Power	$.011/kw-hr			435,000	660,000
Fuel				255,000	255,000
Water (Process)	$.25/M Gal			47,200	88,500
Water (Cooling)				-	-
Chemicals, Specify					
Nitrogen	$2/Ton			17,500	17,500
Total Utilities				754,700	1,021,000
Total Direct Cost				1,169,090	1,534,190
Annualized Capital Charges				573,000	739,700
Total Annual Cost				1,742,090	2,273,890

(1) O.G. system quoted without cooling tower, but with auxiliary cleaning system for tilted furnace.

(2) Based on 5% of system cost.

(3) Based on 1% of system cost.

FIGURE 55

CAPITAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING

(OPEN HOOD – HIGH EFFICIENCY)

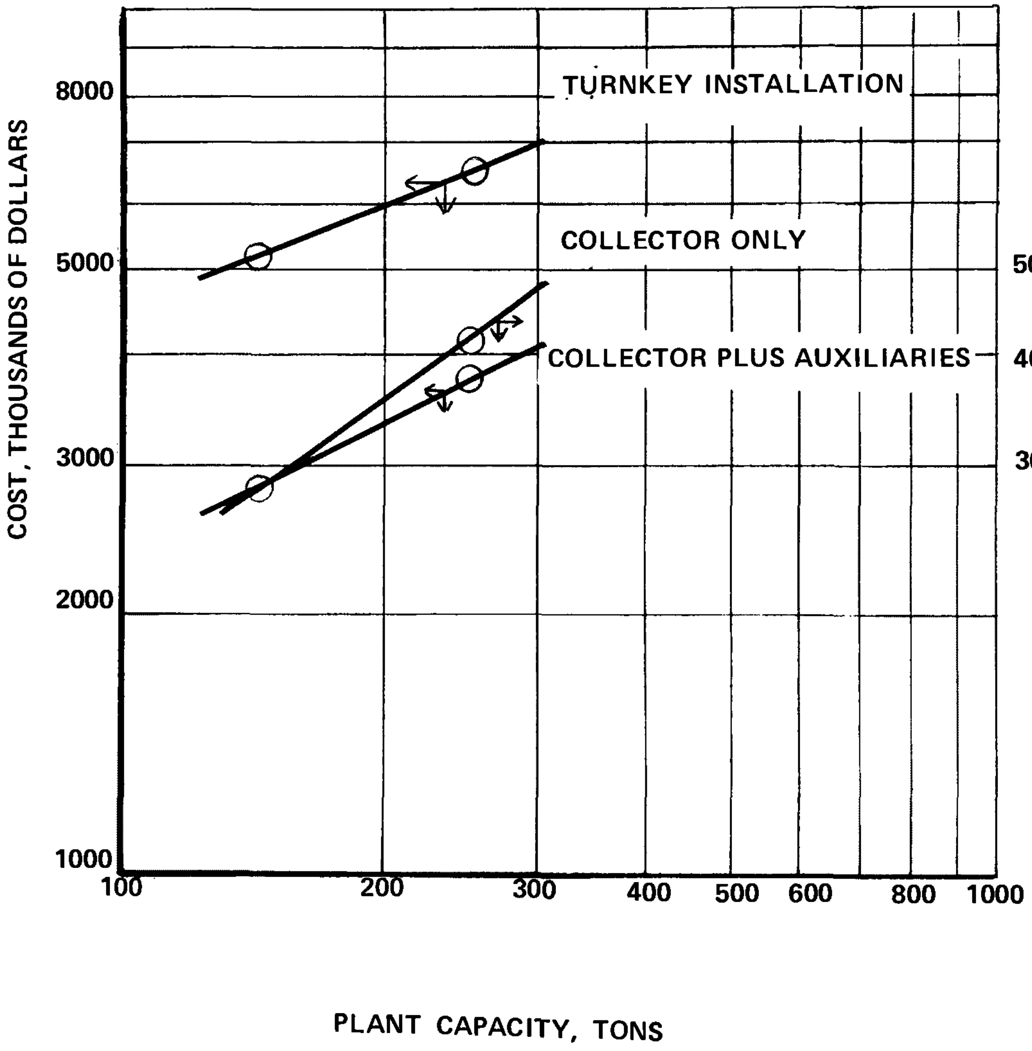


FIGURE 56

ANNUAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING

(OPEN HOOD – HIGH EFFICIENCY)

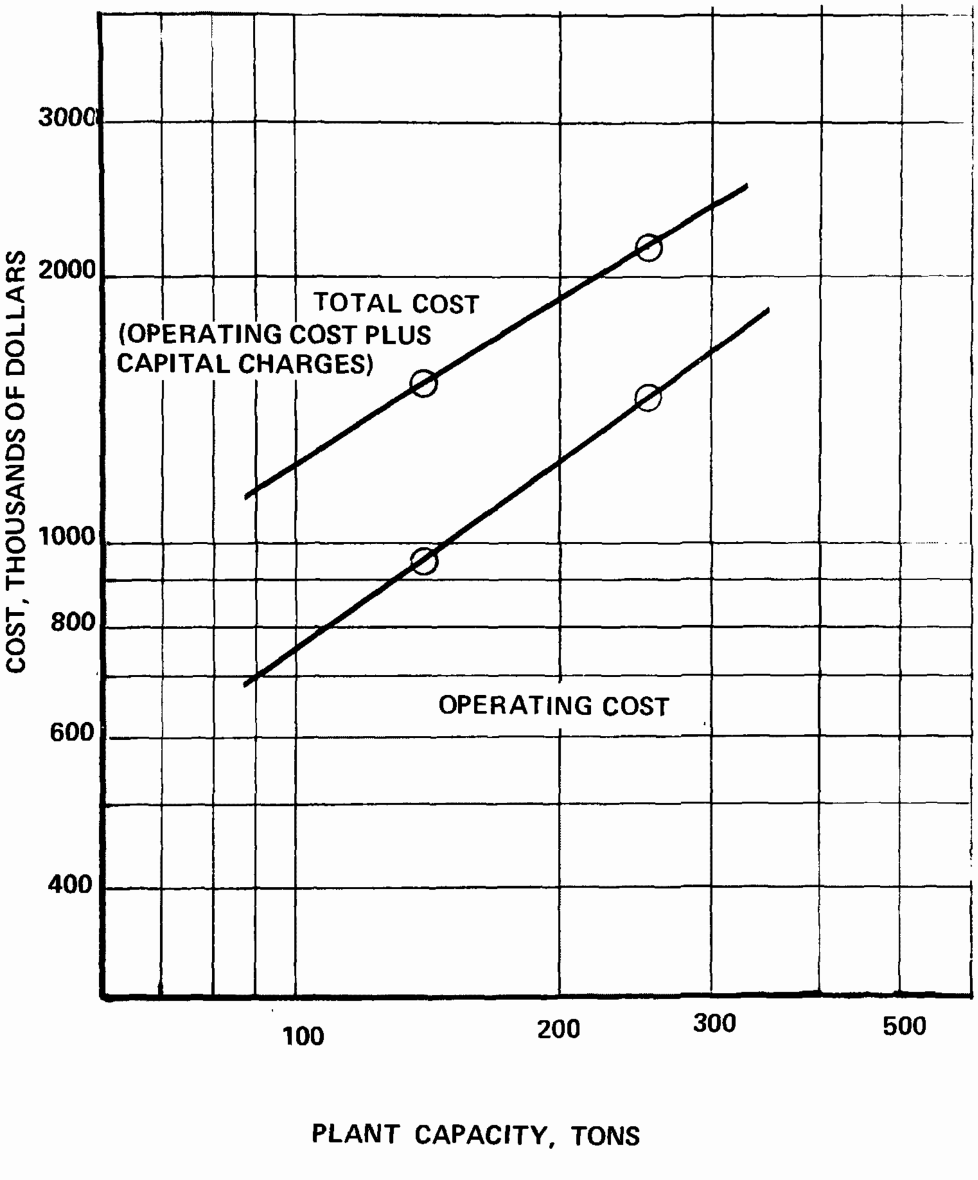


FIGURE 57

CONFIDENCE LIMITS FOR WET SCRUBBER CAPITAL COST DATA, BOF STEELMAKING

(OPEN HOOD – HIGH EFFICIENCY)

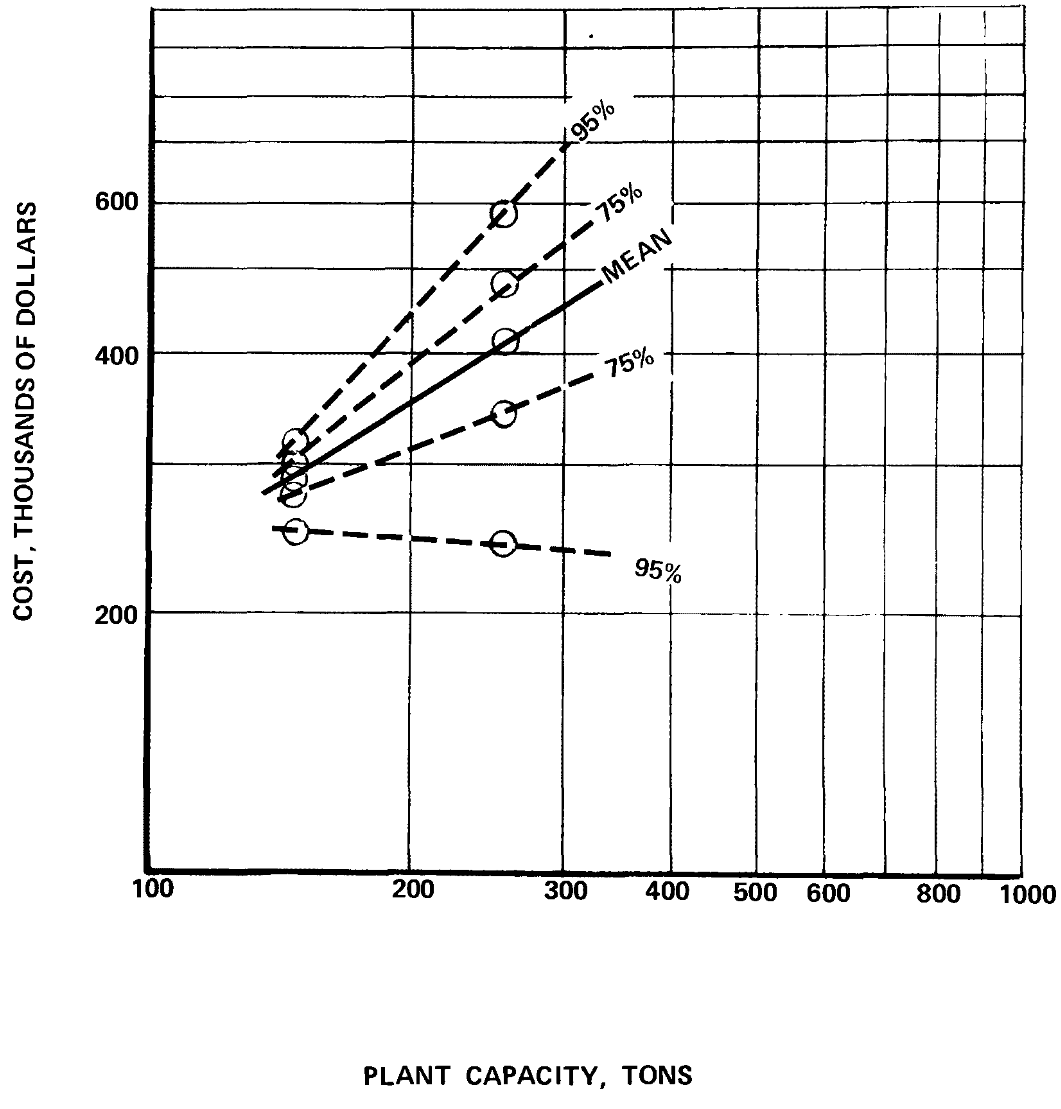


FIGURE 58

CAPITAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING

(CLOSED HOOD – HIGH EFFICIENCY)

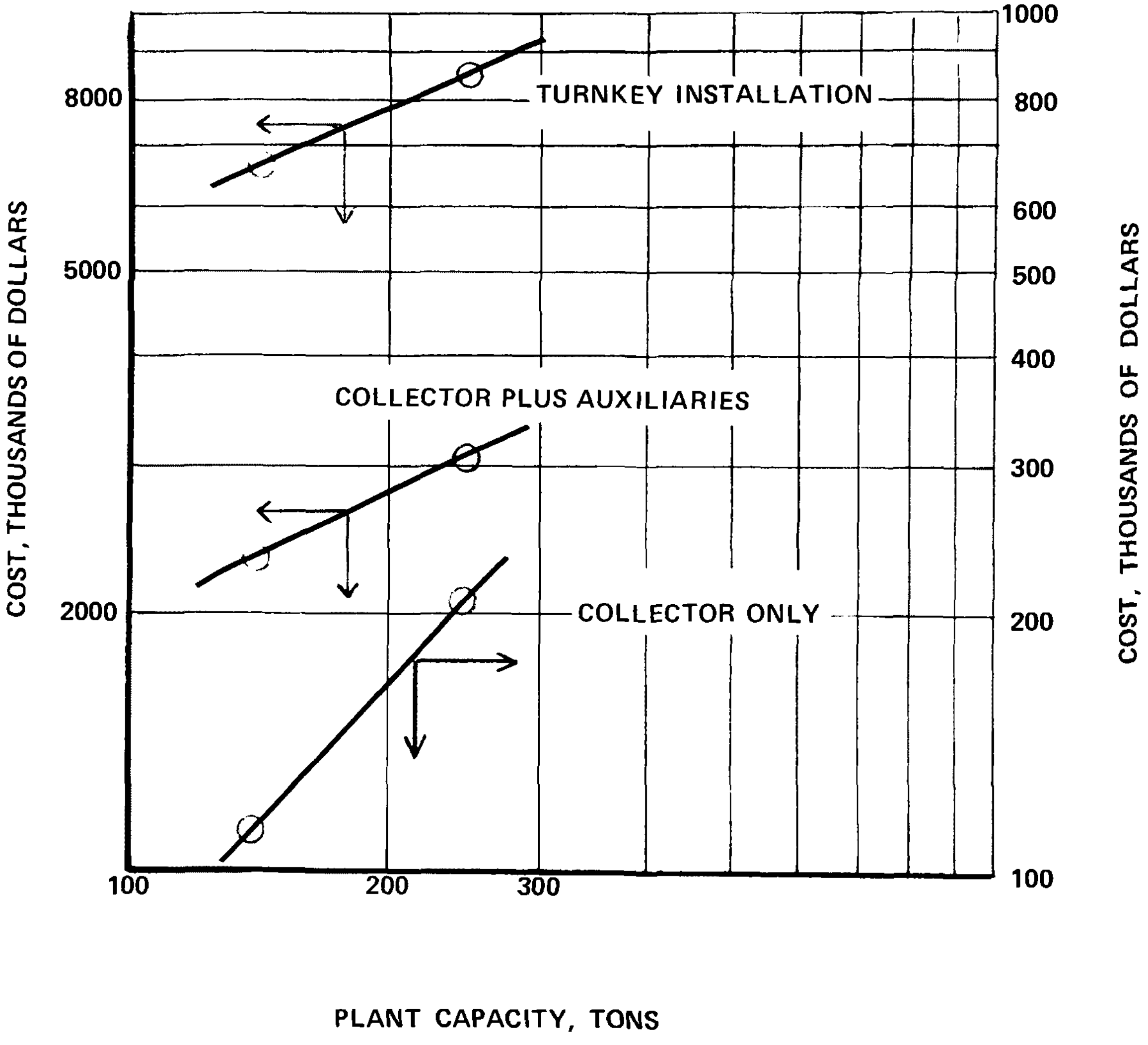
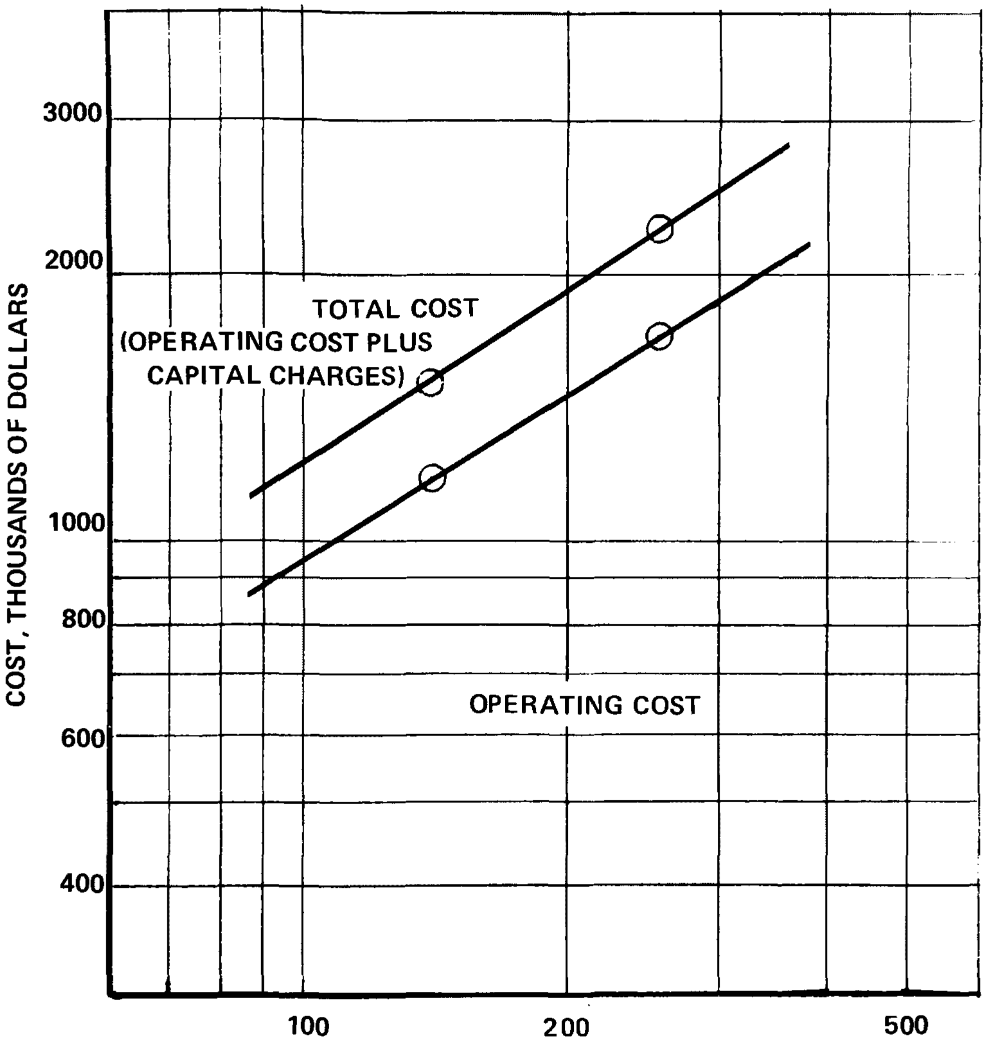


FIGURE 59

ANNUAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING

(CLOSED HOOD – HIGH EFFICIENCY)



PLANT CAPACITY, TONS

FIGURE 60

CONFIDENCE LIMITS FOR CAPITAL COST OF WET SCRUBBERS ONLY FOR BOF STEEL MAKING

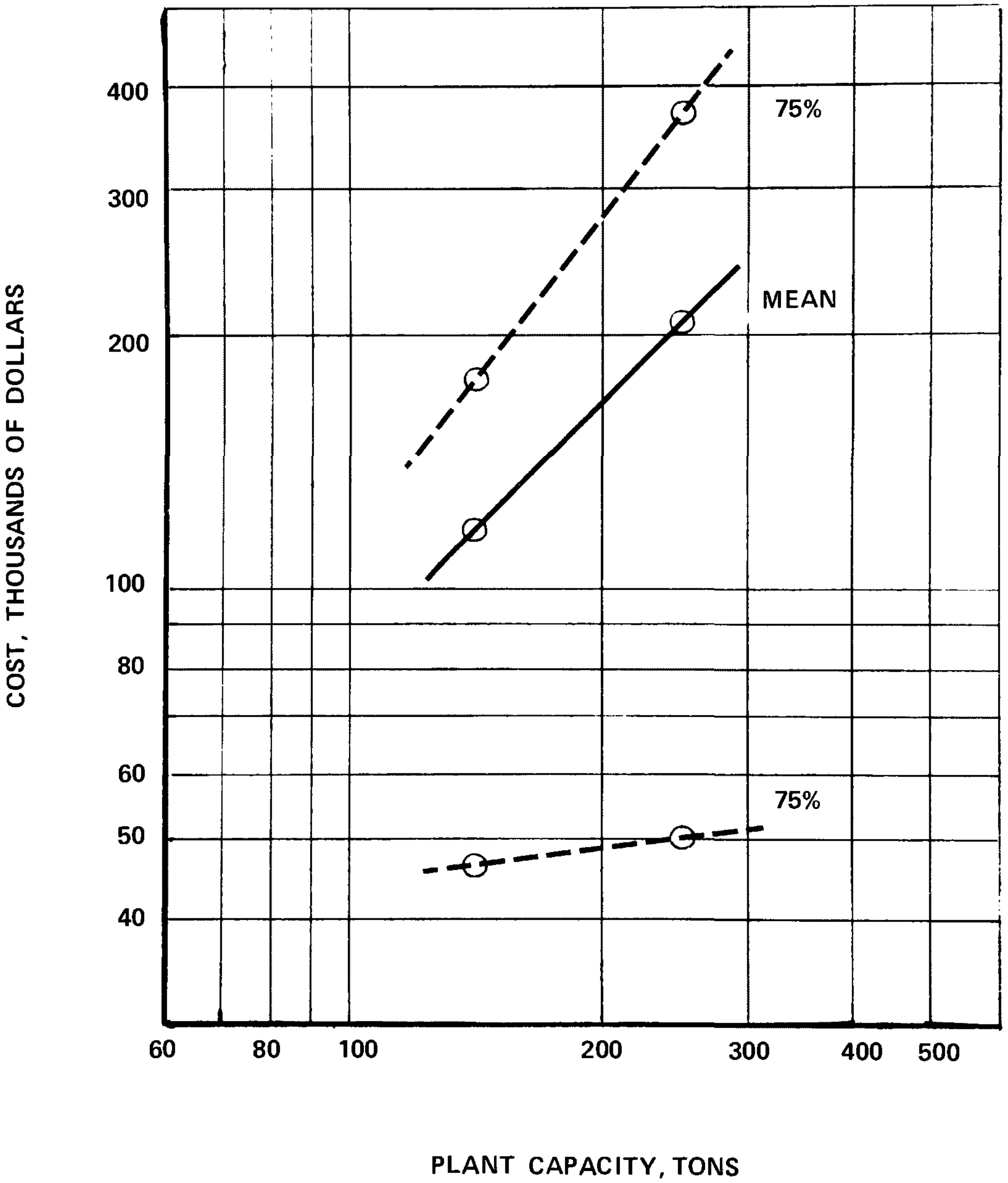


TABLE 77

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS FOR BOF STEELMAKING
AT VERY HIGH EFFICIENCY
(OPEN HOOD)

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			970,000	1,730,000
°F			3,000	3,000
SCFM			121,000	200,000
Moisture Content, Vol. %			0	0
Effluent Dust Loading				
gr/ACF			3.6	3.6
lb/hr			23,200	41,000
Cleaned Gas Flow (1)				
ACFM			132,000	235,000
°F			130	130
SCFM			121,000	202,000
Moisture Content, Vol. %			9.7	9.7
Cleaned Gas Dust Loading				
gr/ACF			0.005	0.005
lb/hr			5.66	10.09
Cleaning Efficiency, %			99.98	99.98
(1) Gas Cleaning Device Cost			398,200	609,250
(2) Auxiliaries Cost (2)			2,845,100	3,797,800
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost			2,784,650	3,403,850
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost			6,027,950	7,810,900

(1) Based upon two quotations.

(2) Includes leakage through non-lancing furnace hood.

TABLE 78

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR ELECTROSTATIC PRECIPITATORS FOR BOF STEELMAKING
AT VERY HIGH EFFICIENCY
(OPEN HOOD)

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	600,000	1,020,000	600,000	1,020,000
°F	650	650	650	650
SCFM	286,000	535,000	286,000	535,000
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF	4.5	4.5	4.5	4.5
lb/hr	23,200	41,000	23,200	41,000
Cleaned Gas Flow				
ACFM	600,000	1,020,000	600,000	1,020,000
°F	650	650	650	650
SCFM	286,000	535,000	286,000	535,000
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF	0.005	0.005	0.0025	0.0025
lb/hr	25.7	43.6	12.8	21.8
Cleaning Efficiency, %	99.89	99.89	99.94	99.95
(1) Gas Cleaning Device Cost	799,800	1,286,750	839,650	1,371,400
(2) Auxiliaries Cost				
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment	5,236,000	6,551,475	5,248,160	6,586,195
(3) Installation Cost				
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	6,035,800	7,838,225	6,087,810	7,957,595

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COAL CLEANING

5 COAL CLEANING

Coal as recovered from the mine contains waste materials which must be removed before it is marketed. The coal also must be crushed and sorted into standard sizes. The process of removing these wastes and crushing and sorting the coal is called coal preparation or coal cleaning.

The growth and importance of coal cleaning is illustrated by the increase in the annual processing rate from 5 percent of the coal mined in 1927 to almost 64 percent in 1966. This increase has resulted from the need to produce a higher quality fuel, with higher heating values, containing less ash, from mines with lower quality deposits. There is also increased emphasis on removal of waste materials before the coal is burned so that they are not subsequently released to the atmosphere as pollutants.(4) Since 1966, the production of cleaned coal has decreased somewhat.

A typical coal cleaning plant employs any one of, or combination of, methods for removing waste materials. Table 79 lists the various methods which are in common use, together with the tons cleaned and the percentage processed by each. Approximately 93% of the coal cleaning is done by wet methods. Of the available wet methods, the most popular are jigs, dense-medium processes and concentration tables. These three account for approximately 88 percent of the total coal cleaned.

Coal cleaning plants range in size from 100 to 1000 ton/hr with an average size of about 500 ton/hr.

PROCESS DESCRIPTION

The principal purposes of cleaning plants are to crush the coal, classify it into standard sizes and to remove the waste materials mined with the coal. Because of the economies to be realized in reduced shipping costs for coal without waste materials, most coal cleaning operations are located at the mine.

The flow diagram for a typical coal cleaning plant is shown in Figure 61. Coal recovered from the mine is first conveyed to a storage pile or silo. The coal is then conveyed to a double screen where the very large and very small pieces are separated from the rest of the coal. The very large pieces (the size of which varies with each mine) are discarded as refuse. The very small pieces (approximately 1/2 inch and smaller) are either conveyed to a clean coal pile or sent to the cleaning circuit, again varying from mine to mine. That portion of the coal passing through the large screen but not the smaller – the "middling" – is then conveyed to the crusher where it is reduced to the desired size and

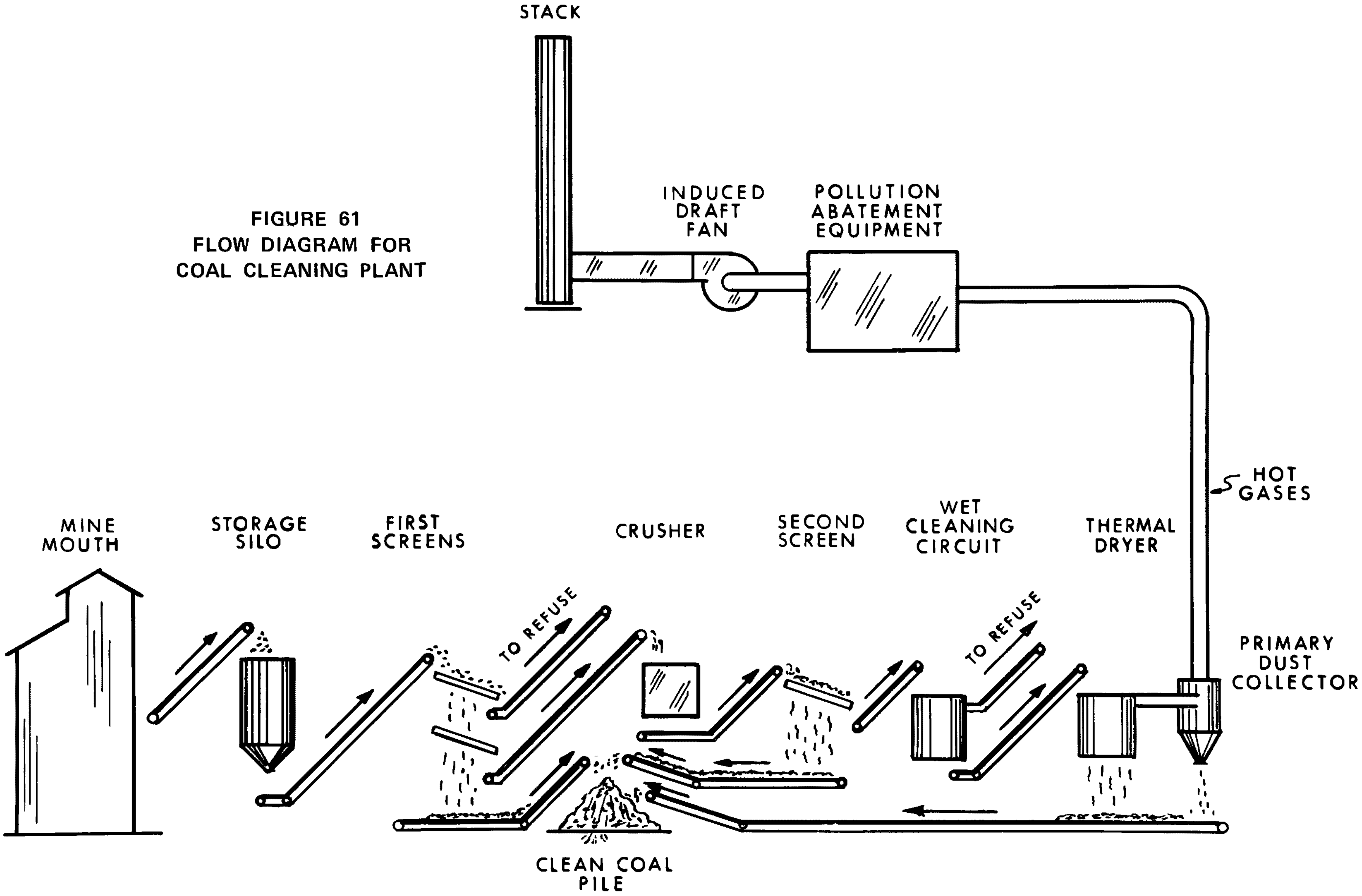
TABLE 79

COAL CLEANING METHODS AND CORRESPONDING PRODUCTION RATES

Cleaning Methods	Coal Cleaned (net tons)	Percentage Cleaned
Cleaning Methods		
Wet Types		
Jigs	156,789,000	46.0
Dense-medium process	97,301,000	28.6
Concentration tables	45,427,000	13.3
Froth Flotation	7,438,000	2.2
Classifiers	4,775,000	1.4
Launders	4,691,000	1.4
Sub Total	316,421,000	92.9
Dry Types		
Pneumatic	24,205,000	7.1
Total	340,626,000*	100.0

*Represents 63.8 percent of the total net tons of coal produced in 1966.

FIGURE 61
FLOW DIAGRAM FOR
COAL CLEANING PLANT



rescreened. The coal retained on the screen is conveyed to the cleaning circuit while that passing through is conveyed to the clean coal pile.(5)

Separation Equipment

A typical wet cleaning circuit includes one or more of the following types of separation equipment.

1. Jigs
2. Dense-Medium Process
3. Concentration Tables

Jigs separate materials of different specific gravities by the pulsation of a stream of liquid flowing through a bed of the materials. The up and down or "jigging" action of the liquid causes the heavier materials to work their way to the bottom of the bed, thereby allowing the different materials to be drawn off separately. The pulsing action is caused by alternately applying and exhausting air of a pressure of approximately 2.5 lb/sq. in. from the pulsion chamber.(2)

Jigs can be used for washing unsized coal as coarse as 7 inches. A typical Jeffrey-Baum type coal jig will process 3 ton/hr/sq ft of active screen area when cleaning coal 4 inches and less, with the capacity decreasing with a decrease in the size of the raw feed stock. In 1966 about 157,000,000 tons of coal were processed by jigs. This amounts to 46 percent of all the coal cleaned during that year.(1)

Jigs are simple to operate and can be constructed with a low initial cost. Power and water consumption rates, however, are high with power requirements of about 0.1 hp/sq ft of screen, and water requirements of about 1500 gal/ton of material processed. Direct operating costs vary with the type of feed stock and its size, the number of stages and the annual capacity of the plant. Operating costs for a large plant will be in the range of 15 cents per ton.

The second most widely used separation method, the dense-medium process, accounted for 97,000,000 tons or about 29 percent of the coal cleaned in 1966.(1) This method is used where there is an appreciable difference in the specific gravities of the coal and the waste material.

The separation is accomplished by placing the mined product in a liquid suspension of finely divided high gravity solids which forms the dense medium. The most widely used solids are ferrosilicon and magnetite. Coal cleaning plants use magnetite to form a dense medium with a specific gravity of approximately 2.20.

A typical dense-medium plant operates in the following manner. The mined material is fed to a vessel containing the dense medium. The lighter portion of the mined product floats, while the heavier material sinks. The floaters, in this case, the coal, overflow a weir and are transferred to a drain screen for rinsing and de-watering. The heavy waste, which sinks, is removed by a conveyor and similarly de-watered and rinsed before being discarded. The water drained from both the floaters and the sinkers is sent to a storage tank where the magnetite is recovered for reuse by magnetic separation.

Dense-medium plants are capable of processing up to 30 ton/hr of raw coal per foot of vessel width when the feed material is +1/4 inch in size. While separation vessels have been designed to handle materials up to 12 inch, the usual size range is 3 to 6 inch. A typical plant processing 3 x 1/8 coal with 50 percent in the 1/4 to 1/8 inch size would have a feed rate of about 20 ton/hr.(2)

The third most commonly used wet cleaning method is the concentration table, which accounted for 45,000,000 tons or 13 percent of the coal processed in 1966.(1)

The separation is accomplished by flowing the mined material across a riffled plane surface inclined slightly from the horizontal. The plane is differentially shaken in the direction of the long axis while washed with an even flow of water at right angles to the direction of motion. As with the dense-medium process, the separation is a function of the specific gravities, and to a lesser extent of the sizes and shapes of the material.

The heavier materials are least affected by the wash water and collect in, and move across, the riffles on the high side of the table. The lighter materials on the other hand ride over the heavier materials and collect on the low side of the table. Launders are located at the end of the low side to separate the large pieces from the middlings, and the middlings from the fines. To improve the quality of the separation some of the middlings are returned to the head of the circuit for reprocessing. The amount of middlings recirculated may be as high as 25 percent of the weight of the feed to the table.

In a coal cleaning plant using multiple-deck tables with a single operator, as much as 1200 ton/hr can be processed with low power and maintenance cost. The principal cost associated with a concentration table is that of the labor to operate it.

Dryers

After the coal has been cleaned by one of the above methods it proceeds to the next step which is the thermal drying operation. It is during this operation that flue gases are contacted with the coal and entrained particulate matter can be discharged to the atmosphere as a pollutant.

The dryer is simply a contacting device in which hot flue gases and air are used to heat the wet coal, evaporate much of the moisture, and transport the water vapor out of the system. While simple in principal, the large weight of materials handled continuously poses some interesting problems.

Several types of dryers have been used, of which the most popular is the fluidized bed dryer. In fluidized bed dryers, the coal is suspended in a fluid state above a perforated plate by a rising column of hot gases. The dried coal is discharged from the dryer by an overflow weir.

The second most widely used dryer in coal processing plants is the direct-fired "flash dryer". Here hot gases generated by burning fuel in a furnace are used to transport the coal up a riser. The time of transport is very short, but highly turbulent contact of the gases and coal particles brings about good drying with a minimum of coal volume in the drying system.

Usually the flue gas is used on a once-thru basis; that is, the flue gas passes through the dryer once, becomes saturated with water (or nearly so) and is discharged into the atmosphere. In theory the volume of gas could be reduced somewhat by recirculating some of the cooled gas back to the furnace. However, this is not done in practical drying applications.

Gas volumes from fluidized bed dryers will range from 50,000 to 250,000 ACFM as a function of the rated throughput. The exit temperatures will average around 150° F with 5 to 10 percent moisture. The specific gravity of the gases exiting the dryer will range between 0.90 and 0.95 when related to air.

A typical particle size distribution(3) for the feed to a fluidized bed dryer is shown in Figure62. The "minus 200 mesh" material is carried over to the primary collector while the remainder is recovered as product.

The hot gases leaving the thermal dryer are sent to a cyclone-type primary collector for the purpose of product recovery and to clean the stack gases before they are discharged to the atmosphere. Typical particle size distributions(3) for material entering and exiting primary collectors from flash dryers and fluidized bed dryers are shown in Figure 63. A typical collector uses a large number of 9 to 12 inch diameter tubes in a common housing.

Most coal cleaning plants are adding higher efficiency secondary collectors in

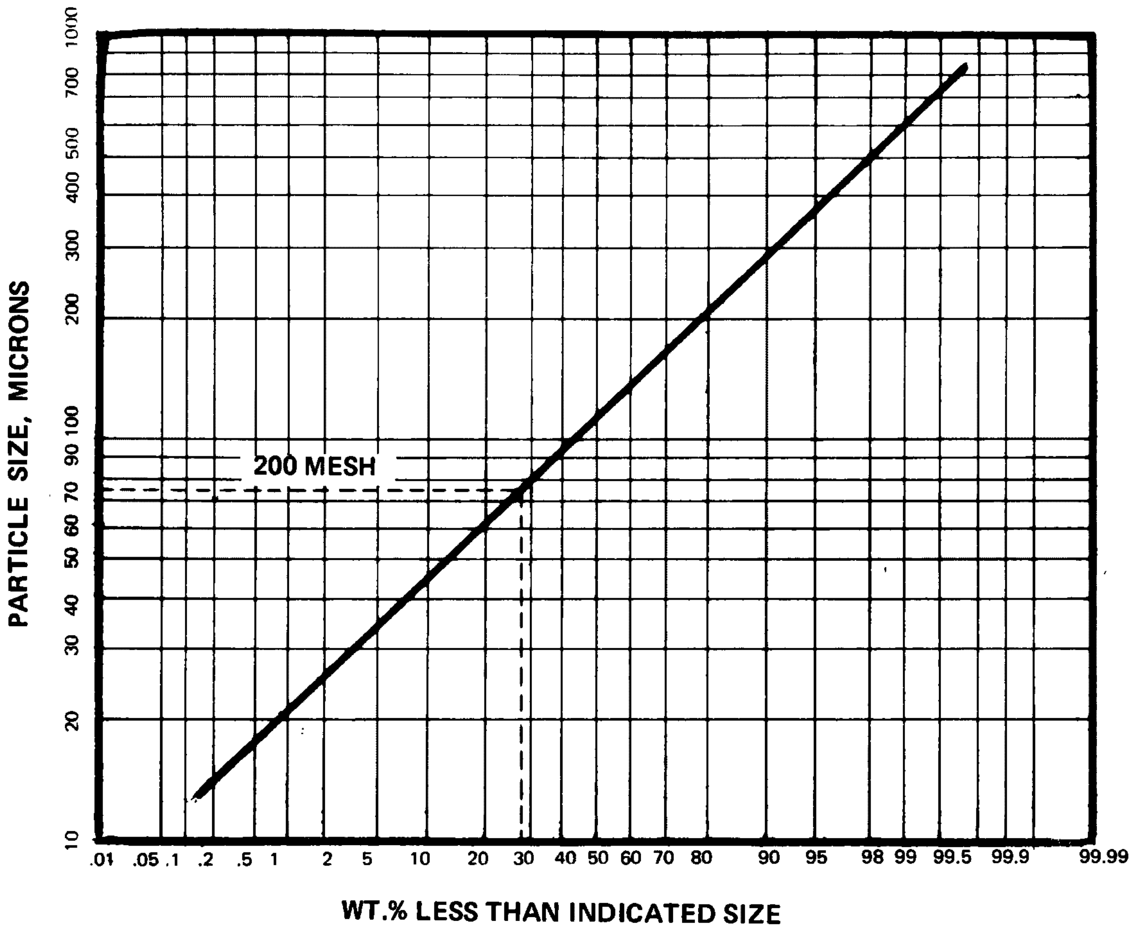


FIGURE 62

PARTICLE SIZE DISTRIBUTION OF FEED TO FLUIDIZED BED DRYER

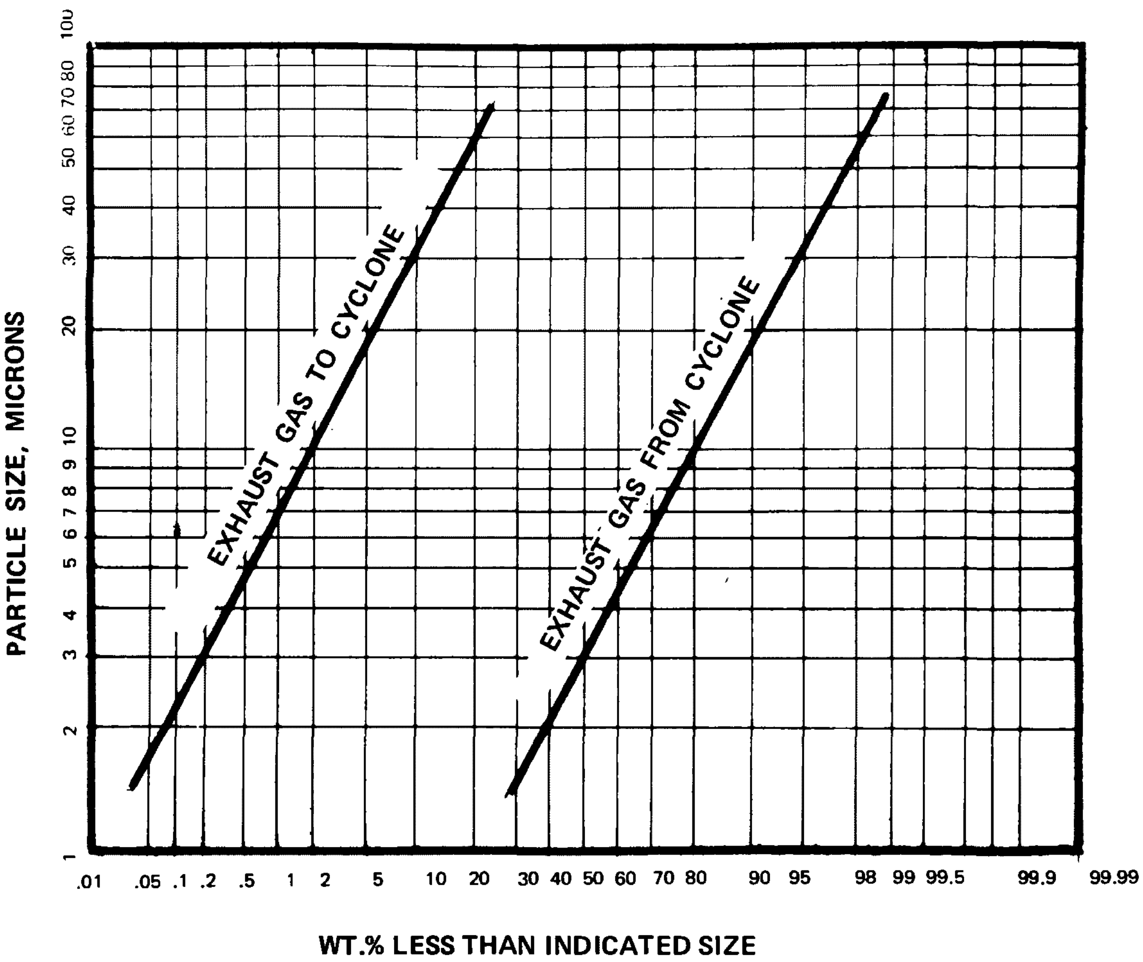


FIGURE 63

PARTICLE SIZE DISTRIBUTION
BEFORE AND AFTER CYCLONE

series with the primary collectors. The reasons for this are twofold; the secondary collector can improve product recovery and reduces air pollution. The type of secondary collector used is most often a wet scrubber.

The final piece of equipment in the typical coal cleaning plant is the induced draft fan, which provides for the movement of the exhaust gas from the thermal dryer through the primary and secondary collectors and finally through the stack to the atmosphere.

NATURE OF THE GASEOUS DISCHARGE

The gaseous discharge from a typical coal cleaning plant originates from the thermal dryers(6) and consists mainly of products of combustion and water vapor.

Because thermal dryers are used in coal mining operations, it is natural that coal is the fuel used to produce the heat required for operation. The gaseous discharge from either flash dryers or fluidized bed dryers utilizing coal consists of the products of combustion of the coal plus the moisture removed from the coal passing through the dryer. The composition of the flue gas produced by burning coal with sufficient excess air to reduce the temperature of the furnace gases to 1000° F is given in Table 80.

This gas is generated in sufficient quantity that it can heat the coal to an exit temperature of 150 to 190° F and supply the latent and sensible heat requirements to drive off most of the moisture in the coal being dried. A typical heat balance of a dryer with 17 wt% moisture prior to drying and an exit temperature of 190° F is shown in Table 81.

From Table 81 it can be seen that 230.8 Btu are required to dry a pound of coal. Now, the flue gas loses about 800° F x 0.24 Btu/lb–°F or 192 Btu/lb of gas as it cools off in the dryer. The gas rate required is therefore

$$\frac{230.8}{192} = 1.20 \text{ lb flue gas/lb coal dried}$$

For a 500 Ton/hr unit:

$$500 \times 2000 \times 1.20 = 1{,}200{,}000 \text{ lb/hr}$$

of flue gas are liberated, along with 150,000 lb/hr water vapor. The gaseous discharge is given in Table 82 for a hypothetical 500 Ton/hr dryer.

TABLE 80

THEORETICAL COMBUSTION PRODUCTS

Ultimate Analysis of Coal		Combustion Products per lb Coal				
Component	Wt %	Component	Theoretical Air, SCF	Combustion Products,SCF	Excess Air, SCF	Total SCF
C	81.0	CO_2	–	25.7	–	25.7
H	2.4	H_2O	–	4.6	–	4.6
O	5.9	O_2	28.2	–28.2	121.4	121.4
N	0.0	N_2	106.3	–	456.9	563.2
S	1.1	SO_2	–	0.1	–	0.1
Ash	9.6	–	–	–	–	–
	100.0		134.5	2.2	578.3	715.0

TABLE 81

CALCULATED HEAT REQUIREMENTS FOR COAL DRYING
(Basis one pound dry weight of product)

Coal Feed	lb	Temp., °F	Btu/lb	Btu/lb dry coal
Fines	0.06	60	0	0
Coal	1.00	60	0	0
Water	0.22	60	0	0
	1.28			0

Product	lb	Temp., °F	Btu/lb	Btu/lb dry coal
Fines	0.06	190	39.0	2.3
Water Vapor	0.17	190	1114.0	190.0
Dry Coal	1.00	170	33.0	33.0
Water	0.05	170	110.0	5.5
	1.28			230.8

TABLE 82

GASEOUS DISCHARGE FROM A HYPOTHETICAL 500 TON/HR DRYER

	Flue Gas SCFM	Water from Coal SCFM	Total Discharge SCFM	Total Discharge ACFM @ 190°F
N_2	186000		186000	228000
O_2	49300		49300	60500
CO_2	12400		12400	15200
SO_2	50		50	60
H_2O	2250	60000	62250	76360
	250000	60000	310000	380120

From Table 82 it is apparent that the gas exhausted from the dryer contains enough water vapor to bring about an increase in gas flow by a factor of about 25%.

The composition of the discharge gas will vary somewhat with the analysis of the fuel being fired. In some instances oil or gas may be substituted for coal as the dryer fuel. This may be true where high sulfur coal is being processed and strict regulations exist with respect to SO_2 emission. The quantity of flue gas will vary little with the fuel type, and will be nearly proportional to the rate at which water must be evaporated. This is, in turn, proportional to the product of the coal feed rate and the moisture content.

POLLUTION CONTROL CONSIDERATIONS

As indicated in Figure 63, the particles in the dryer feed which are less than 200 mesh are assumed to be carried over to the primary collector. This carryover represents grain loadings in the range of 100 to 300 gr/ACF which is about 28 percent by weight of the total feed to the dryer.

When an average loading of 200 gr/ACF is applied to dryers having gas flows in the 50000 to 250000 ACFM range, emissions of 1400 to 7000 lb/min are possible. It is obvious that some form of collection equipment must be provided to recover this product and to reduce atmospheric emissions.

Cyclones are the most commonly installed equipment. However, alone they are not capable of the high collection efficiency required; their selection and design is normally confined to providing the best product recovery consistent with the lowest maintenance and operating costs. Typical emissions from a cyclone are about 10 gr/ACF which corresponds to an atmospheric discharge of 70 to 350 lb/min. Grain loadings may vary greatly from one installation to another.

Current national, state and local air pollution regulations require that further gas cleaning be provided before the cyclone exhaust gases can be discharged to the atmosphere.

The gases from the cyclones following the thermal drying step constitute the principle source of air pollutants. The high dust loading of these gases (as high as 10 gr/ACF) results in a dense visible plume when discharged to the atmosphere. Coal dust is visible to the eye in concentrations exceeding 0.05 gr/ACF for stacks of moderate size.

In addition to the obvious need to clean the gases to limit atmospheric pollution, it is also desirable to process the cyclone gases for product recovery. A collector removing 10 gr/ACF of coal dust from 250,000 ACFM discharge from a cyclone, will recover almost 11 ton of product per hour. This represents a recovery of 2 percent of the total feed.

Because the emission problem is one of providing a clean stack and product recovery, the applicable control system is wet scrubbing. Filters are seldom used because of the high humidity of the gas stream, and electrostatic precipitators are not ordinarily used.

Wet Scrubbing

The most widely used control system is wet scrubbing. Several types of scrubber designs have been applied, including the impingement tray, Venturi, and impingement baffle scrubber. Figure 64 illustrates the configuration of each as it is applied in coal cleaning.(3)

The impingement tray scrubber has been used for many years. However, this type of scrubber is subject to plugging and has a relatively low collection efficiency. It is not ordinarily good enough to meet either set of regulations covered in this study.

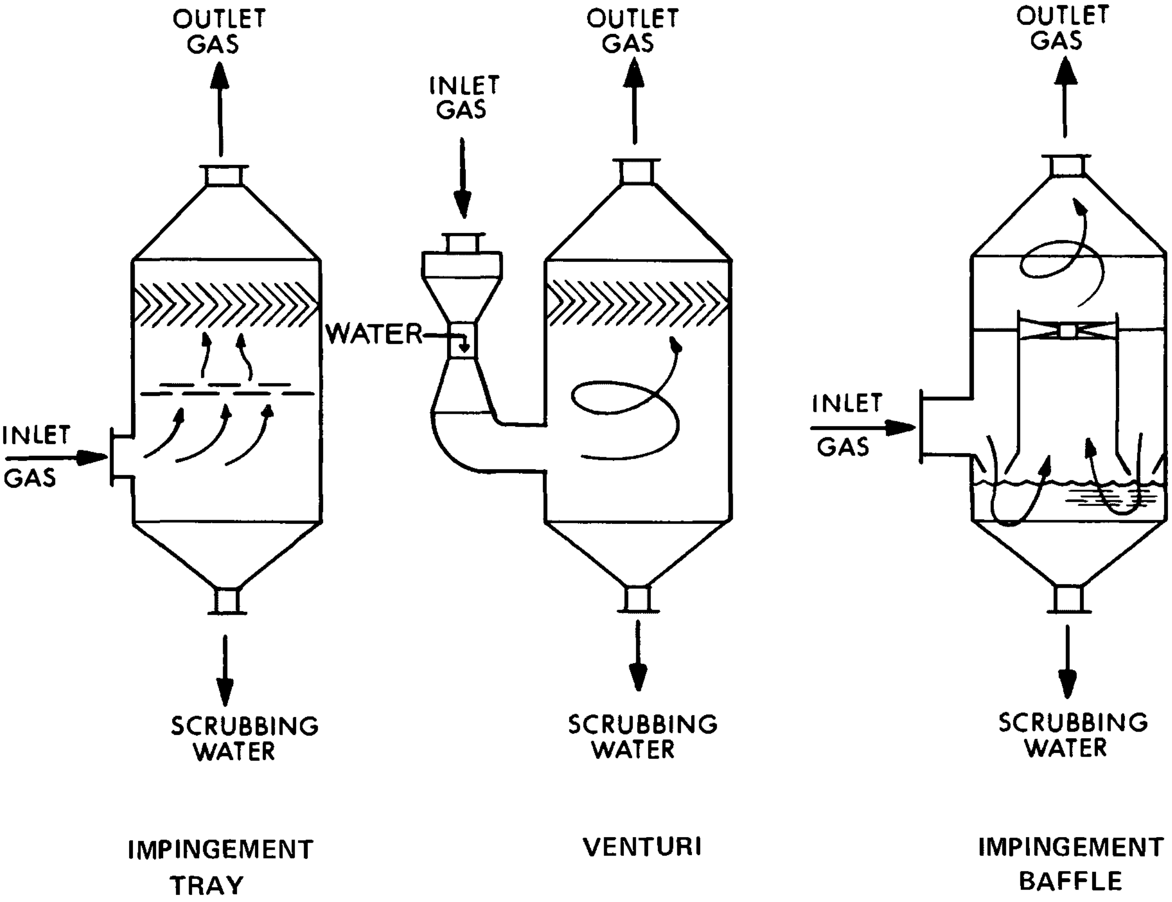
The second type of scrubber which has found use in this service is the Venturi. The Venturi scrubber type is virtually free from plugging problems, even when a high solids content is built up in the scrubbing liquid. Another advantage of this type of scrubber is that the scrubbing liquid can be recirculated, thereby keeping water usage to a minimum. The Venturi scrubber provides the highest collection efficiency when operated at high pressure drop.

Disadvantages of the Venturi scrubber include the high operating cost, when high pressure drop across the throat section is required.

The impingement baffle scrubber combines a relatively high collection efficiency with lower pressure drop requirements than the Venturi. Dust emission levels of 0.10 gr/ACF or less have been reported for systems operating with less than 15 inches w.g.

FIGURE 64

BASIC TYPES OF WET SCRUBBERS
USED FOR COAL CLEANING



Some of the advantages of scrubbing systems include their resistance to fire and explosion and adaptability to absorption of SO_2 from the combustion gases.

Bag Filters

Bag filters have an inherently high collection efficiency, provide for dry product recovery, and they are relatively simple in their construction and operation.

Disadvantages of bag filters include susceptibility to fire and explosion, and high bag replacement cost. Gas inlet temperature to the filter must be kept above the dew point to prevent the formation of a mud which will blind the filter. This is particularly difficult on dryer effluents, where the dew point of the exit gas approaches the gas temperature. Bag houses on coal cleaning plant dryers would require extraordinary precautions to prevent condensation, such as steam traced hoppers, heavy insulation, and systems for diverting gases around the bag house if the temperature drops below a predetermined limit. For these reasons, they are seldom used.

SPECIFICATIONS AND COSTS

Specifications were prepared for wet scrubbing equipment to meet two levels of efficiency for two equipment sizes. Because the rate of material handled in coal cleaning processes is very high, the process weight specification provides a more stringent requirement for emission control than does the "high efficiency" case. These specifications are shown in Tables 83 and 84.

The large size of the process equipment poses another problem in the specification of the scrubbing equipment. That is, the largest plants process more coal than can be handled in a single fluidized-bed drier. Although a single scrubber system was specified for the largest plant, the quotations received were based on two complete scrubbing units. This is likely to be the case in all plants designed for more than about 500 ton/day, and for smaller plants if more than one dryer train is included for flexibility.

All of the scrubbers quoted in response to these specifications were Venturis. These have generally supplanted impingement-type scrubbers which were widely used in the past as emission limitations became more stringent.

The cost data obtained in response to the specifications are presented in Tables 85 and 86. Plots of first cost versus plant size are given in Figures 65 and 67 and operating cost versus plant size is plotted in Figures 66 and 68.

TABLE 83

WET SCRUBBER PROCESS DESCRIPTION FOR COAL CLEANING SPECIFICATIONS

The air pollution abatement system is to serve a new coal cleaning plant in which one or two fluid bed thermal dryers will be operated.

The system shall be quoted complete, including all of the following items as detailed in our drawings. *

1. *Interconnecting ductwork*
2. *Wet scrubber(s) complete with mist eliminator(s) and stack*
3. *Fan(s)*

The system shall be quoted on each of the following bases.

1. *Scrubber(s) only*
2. *Complete equipment, consisting of*
    - a. *Scrubber(s)*
    - b. *Pump(s)*
    - c. *Fan(s)*
    - d. *Dampers*
3. *Complete turnkey system*

Scrubbers shall be designed for sufficient pressure drop to meet the performance specified. The liquid-gas ratio shall be specified by the vendor, but in no event shall the ratio be lower than 5 GPM per 1000 ACFM (saturated). Vendor shall specify the actual pressure drop at which the scrubbers will operate.

Fans shall be capable of overcoming the system pressure drop at the design flow rate while operating at no more than 90% of the maximum recommended speed. Motors shall be capable of driving fans at maximum recommended speed and the corresponding pressure differential at 20% over design flow rate.

Scrubbing water supply and disposal. Scrubbing water shall be taken from the cleaning plants refuse thickener overflow. The spent scrubbing water will be returned to the refuse thickener. During normal scrubbing operations the expected solids content of the slurry will be less than 5% by weight leaving the scrubber. The vendor shall include in his proposal the cost of the piping, valves, fittings, hanger and support required to connect the scrubbing system with the plant refuse thickener.

**NOTE: It would be reasonable to assume that the engineering company designing the entire plant would specify the abatement equipment as a part of their work.*

TABLE 84

WET SCRUBBER OPERATING CONDITIONS FOR COAL CLEANING SPECIFICATION

Two efficiency levels are to be quoted for each of the two sizes.

	Small	*Large*
Plant Capacity, ton/hr	*600*	*1800*
Dried coal product, ton/hr	*250*	*750*
*Process weight, ton/hr**	*305*	*915*
Gas to Scrubber		
Flow, ACFM	*190,000*	*570,000*
Temp, °F	*190*	*190*
Pressure, psia	*14.16*	*14.16*
Pressure, in w.c.	*–15.0***	*–15.0***
Composition, mol %		
CO_2	*4.00*	*4.00*
O_2	*15.90*	*15.90*
N_2	*60.00*	*60.00*
H_2O	*20.10*	*20.10*
	100.00	*100.00*
Molecular Weight	*27.28*	*27.28*
Solids loading, lb/hr	*16,300*	*48,900*
Solids loading, gr/ACF	*10*	*10*
Solids loading, gr/DSCF	*15.3*	*15.3*
Gas from Scrubber		
Flow, ACFM	*180,000*	*540,000*
Temp, °F	*143*	*143*
Pressure, psia	*13.62*	*13.62*
Pressure, in w.c.	*–40.0*	*–40.0*
Composition, mol %		
CO_2	*3.91*	*3.91*
O_2	*15.58*	*15.58*
H_2	*58.75*	*58.75*
H_2O	*21.76*	*21.76*
	100.00	*100.00*
Molecular Weight	*27.07*	*27.07*

**Process weight is greater than dryer capacity because only a fraction of the cleaned coal is dried.*

***The value specified includes the furnace draft, thermal dryer, and the primary collector pressure drop.*

Case 1 – LA-Process Weight

Outlet loading, lb/hr	*40*	*40*
Outlet loading, gr/ACF	*0.026*	*0.009*
Efficiency, wt. %	*99.75*	*99.95*

*Case 2 – "High Efficiency"**

Outlet loading, lb/hr	*77*	*139*
Outlet loading, gr/ACF	*0.05*	*0.03*
Efficiency, wt. %	*99.53*	*99.72*

**This case is less restrictive than the "Medium Efficiency" or Process Weight basis.*

TABLE 85
ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	190,000	570,000	190,000	570,000
°F	190	190	190	190
SCFM	116,980	350,950	116,980	350,950
Moisture Content, Vol. %	20.1	20.1	20.1	20.1
Effluent Dust Loading				
gr/ACF	10	10	10	10
lb/hr	16,300	48,900	16,300	48,900
Cleaned Gas Flow				
ACFM	172,720	518,150	172,720	518,150
°F	144	144	144	144
SCFM	116,980	350,950	116,980	350,950
Moisture Content, Vol. %	21.5	21.5	21.5	21.5
Cleaned Gas Dust Loading				
gr/ACF	0.027	0.009	0.05	0.03
lb/hr				
Cleaning Efficiency, %				
(1) Gas Cleaning Device Cost	114,100	340,425	112,600	337,425
(2) Auxiliaries Cost				
(a) Fan(s) *	55,345	190,405	50,078	144,205
(b) Pump(s)	4,630	12,840	4,338	12,040
(c) Damper(s)	1,800	4,250	1,700	3,935
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost				
(a) Engineering	19,700	21,950	19,700	21,950
(b) Foundations & Support	22,950	46,500	22,450	42,350
(c) Ductwork	45,000	110,500	46,300	113,725
(d) Stack	-	-	-	-
(e) Electrical	38,200	97,250	37,600	82,800
(f) Piping	22,050	58,000	23,550	58,000
(g) Insulation	3,725	7,900	3,750	7,900
(h) Painting	1,890	3,350	1,890	3,350
(i) Supervision	6,650	12,150	6,650	12,150
(j) Startup	2,100	3,550	2,100	3,550
(k) Performance Test	1,850	2,250	1,850	2,250
(l) Other	16,750	42,700	16,600	40,050
(4) Total Cost	356,740	954,020	351,156	885,680

Data based upon two bids.

* Fan cost adjusted to attribute 37½% to process, 62½% to abatement.

TABLE 86
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,500				
Operating Labor (if any)					
Operator	$6/hr	750	750	750	750
Supervisor					
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance		1,426	3,604	1,437	3,408
Replacement Parts					
Total Replacement Parts		832	2,870	794	2,258
Utilities					
Electric Power *	$011/kw-hr	27,569	95,425	26,297	83,566
Fuel		-	-	-	-
Water (Process)	$.25/M gal	4,244	12,731	4,244	12,731
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		31813	108156	30,541	96,297
Total Direct Cost		34,821	115,380	33,522	102,713
Annualized Capital Charges		35,674	95,402	35,116	88,568
Total Annual Cost		70,495	210,782	68,638	191,281

Data based upon two bids.

* Power cost adjusted to attribute 37½% to process, 62½% to abatement.

FIGURE 65
CAPITAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

(LA – PROCESS WEIGHT)

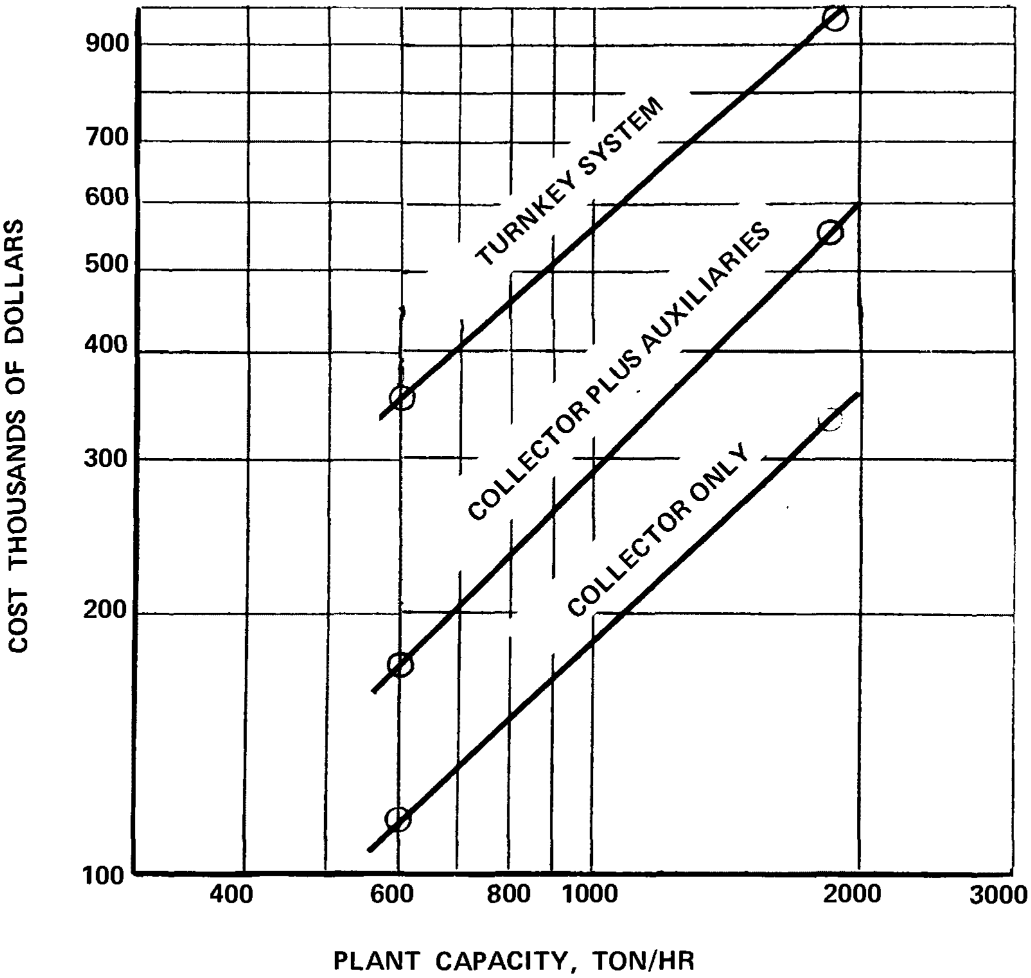


FIGURE 66
ANNUAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

(LA–PROCESS WEIGHT)

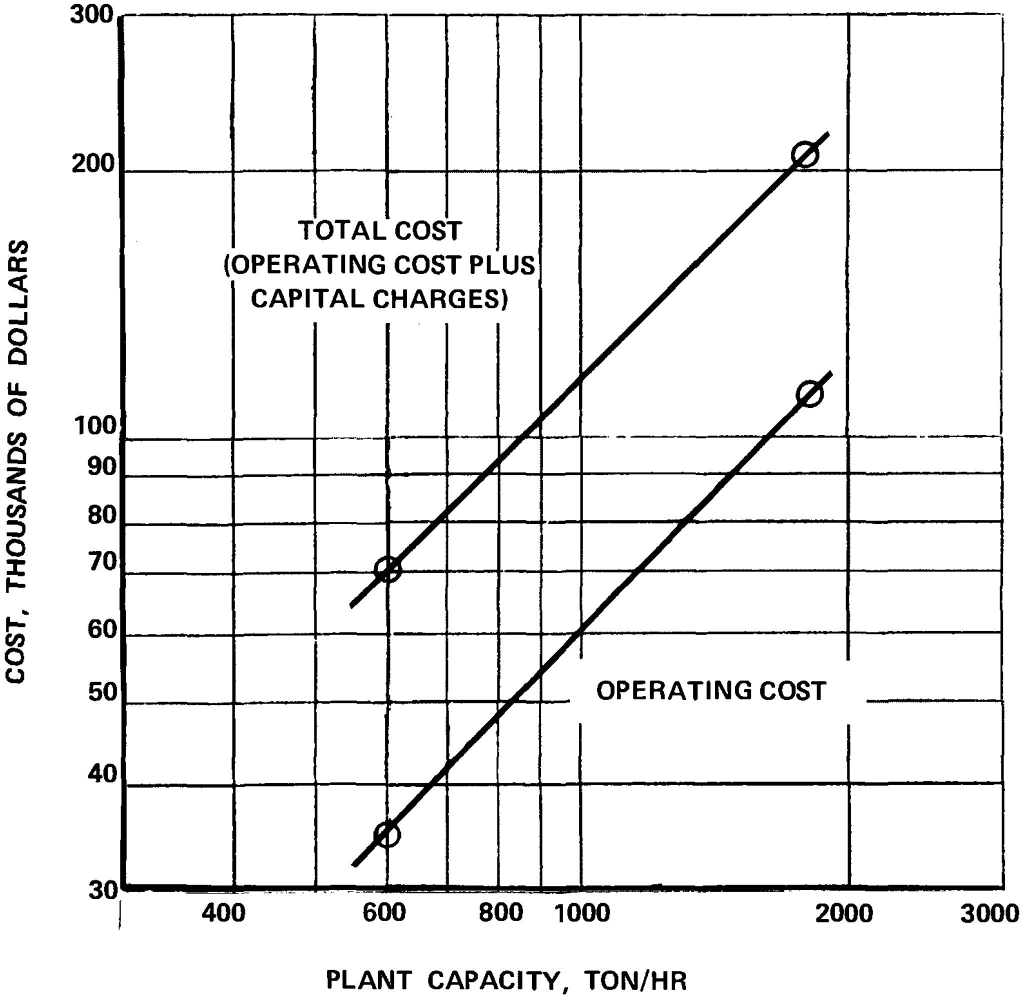


FIGURE 67
CAPITAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS
(HIGH EFFICIENCY)

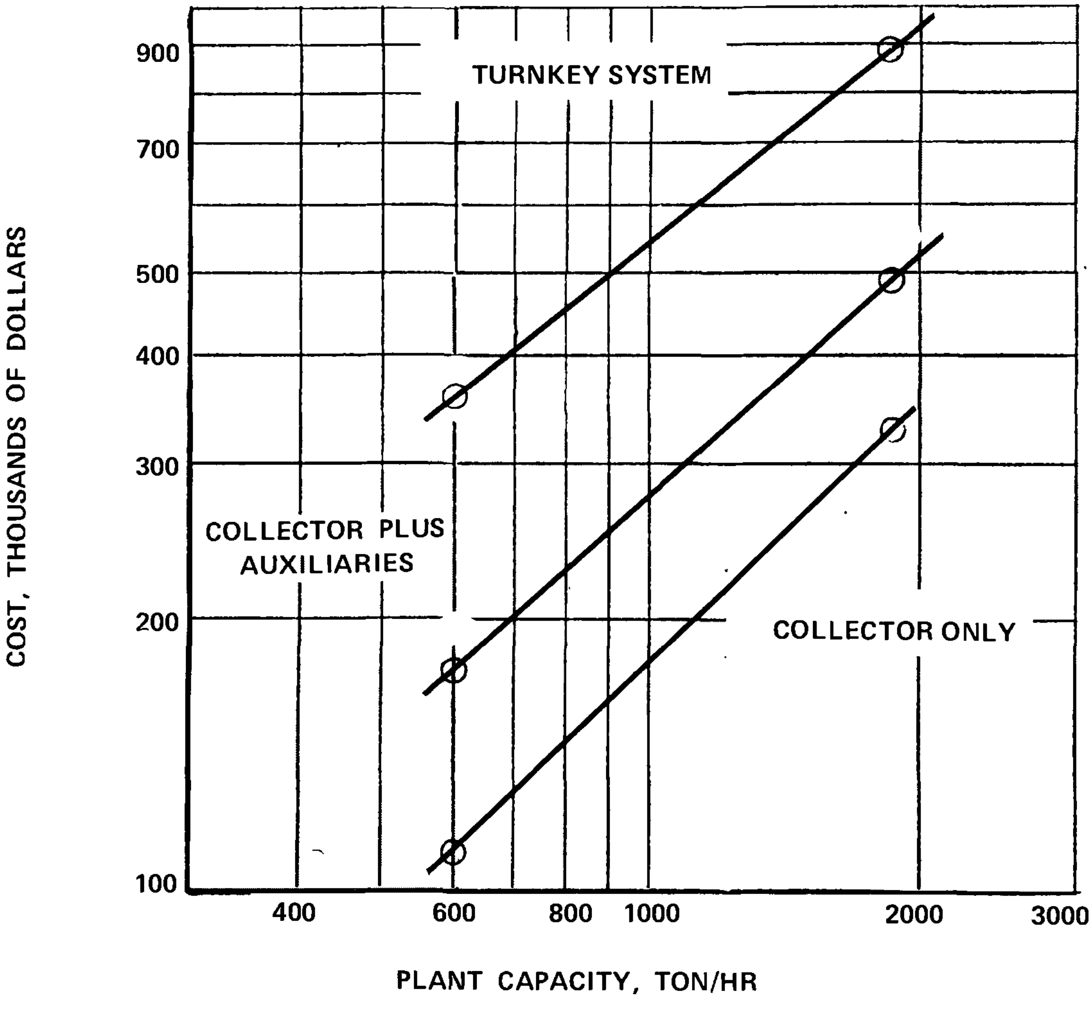
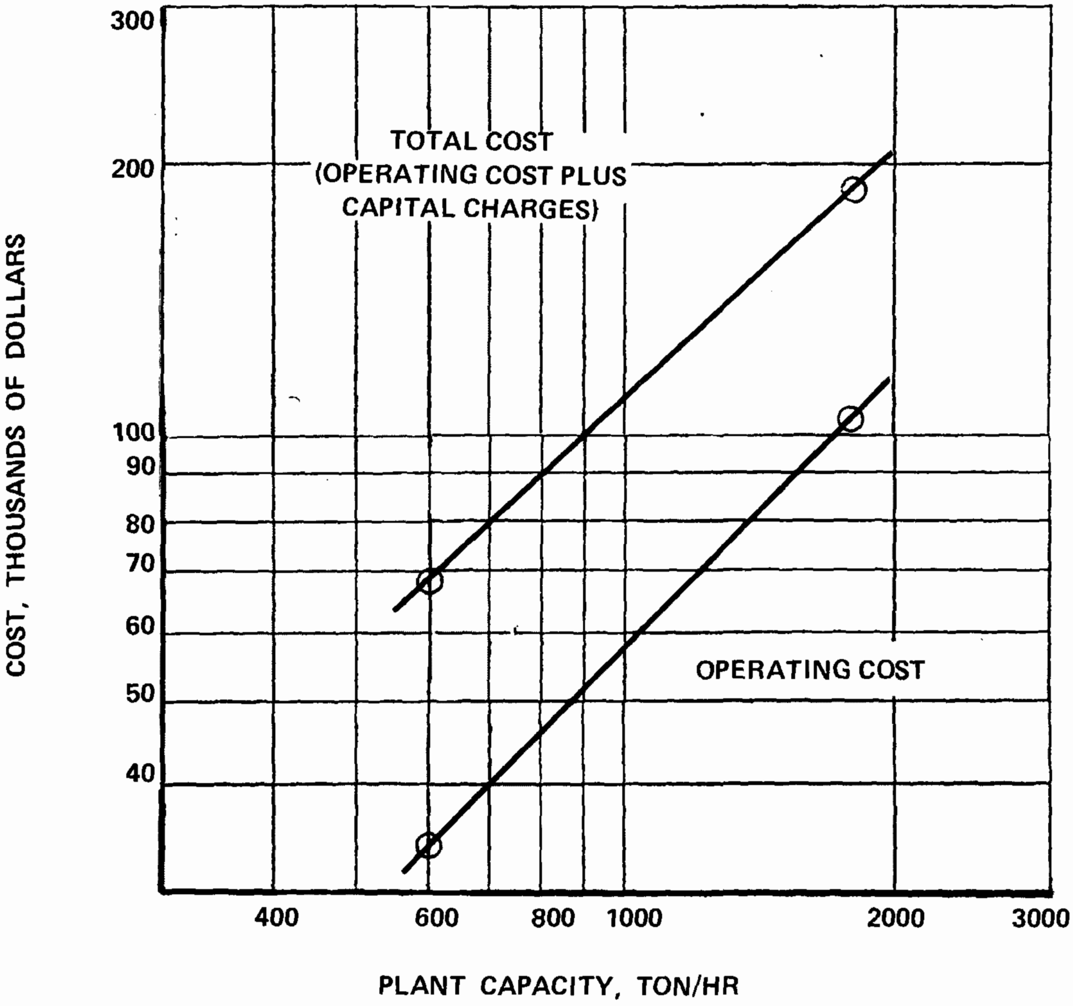


FIGURE 68

ANNUAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS (HIGH EFFICIENCY)



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BRICK and TILE KILNS

6. BRICK AND TILE KILNS

Brick manufacture dates back thousands of years. Bricks were formed by hand or in crude molds and baked in the sun. The art of baking or *burning* brick to produce a hard, durable product was developed prior to 500 B.C.(1) The two basic operations in the manufacture of brick or tile, the forming of the *ware,* and *firing,* persist to this day.

The basic raw material is, as it was in the earliest times, naturally occuring clay. The properties of clay products depend upon the shape into which they are formed, and to a very large extent upon the nature of the clay from which they are produced.

Clays comprise natural earth materials which form plastic self-adherent masses when wet, and after drying form hard, brittle structures. All clays are the result of decomposition of rock, and consist of very fine, water-insoluble particles which have been carried in suspension in ground water and deposited in geologic basins according to their specific gravity and degree of fineness.(1)

Chemically, the clays are hydrates of alumino-silicates with various impurities such as powdered feldspar, quartz, sand, limestone, carbonaceous materials such as coal, and pyrites.

While the crushing and grinding of clay materials in preparation for forming the ware may produce significant particulate emissions, the burning of brick and clay products, with which this section is concerned, produces air pollution emission only when the raw material contains impurities which lead to generation of contaminants. Such impurities may produce fluoride emissions when substances such as fluorite and fluoapetite are present, sulfur oxides when iron pyrites or other sulfur bearing minerals are present, and carbonaceous soot when fossilized organic matter such as coal is present as an impurity. Because of the importance of these trace materials in the consideration of air pollution problems in the brick and tile industry, a great deal of stress will be laid upon the chemical composition of the clay used in any given location.

Throughout most of the narrative, reference will be made to the manufacture of brick. It should be understood throughout, that the processing steps are substantially identical for the manufacture of structural clay products generally grouped under the name *tile*. Some of the products included in this category are drainage tile, floor tile, roof tile, and multiple duct tile used as underground utility conduit.

FORMING BRICK AND TILE PRODUCTS

Brick and tile are manufactured by two basic forming processes. These are the *dry press method* and the *stiff mud method.* These are not significantly different, however, from the standpoint of air pollution emissions and the description of the forming processes serves only to provide some background for the discussion of kiln operation.

In the dry press method, the clay is usually ground in a relatively dry state and taken directly to the brick forming machinery without the addition of any water. The brick making machine, generally called a *dry press machine,* exerts an enormous amount of pressure on the clay to form a dense product. The ware produced by a dry press machine can be taken directly to the kiln for firing without any intermediate drying step. This method is frequently used for clays which tend to crack on drying.

In the stiff mud process the clay is ground very thoroughly and mixed in a *pug mill.* It is then conveyed to an *auger machine,* or *stiff mud machine.* The stiff mud machine consists of a section in which further mixing and tempering of the clay are carried out, followed by an auger which compresses the plastic clay through a die. The column of clay extruded through the die is then passed through a *ware cutter* which cuts the column to the desired brick length. The standard size for common brick is 8" x 3-3/4" x 2-1/4". The cross section of the clay column is not quite rectangular and the top is slightly wider than the bottom. This makes it slightly easier for masons to handle the bricks when setting them up. The stiff mud machine can be used for extruding any shape of clay product. This method is ordinarily used for the production of drain tile, roof tile, etc.

In either case, the final step in the processing of the brick is heating of the ware in a kiln. This is alternately known as burning or firing the ware. In the case of dry press method manufacture, no drying step is required. When the stiff mud or stiff plastic method is used for forming, the bricks are sometimes dried prior to burning.

Several changes occur during the firing of the ware:(1)

1. The "free" or chemically uncombined water is driven off.

2. Decomposition of the clay, with liberation of the combined water, or water of hydration, takes place.

3. Combustion and removal of combustible matter occurs.

4. Decomposition of impurities (see Table 87[2]) is completed.

5. Partial combination of some of the impurities with the silica and alumina from the clay occurs, and a molten glassy material is formed.

6. Upon cooling, this glassy material bonds the solid particles together, forming a tough hard product.

The temperature of the ware should be raised slowly to allow the water and products of combustion to escape without damaging the structure of the ware. Also, the highest temperature reached and the time the ware is held at this temperature determine the amount of glassy material formed. Table 88 gives firing temperatures for various materials.

Practically all modern brick and tile plants use a tunnel kiln to fire their ware.[2] The configuration of a typical tunnel kiln is shown in Figure 69. The ware is placed on cars and charged to the left end of the kiln and moves continuously to the right. As it moves it is gradually heated, reaching a maximum temperature in the hot zone between the furnaces. The charge is then cooled as it passes out of the kiln. Air is passed through the kiln countercurrent to the direction of movement of the ware. Cold air is forced in the right end of the kiln and passes through the charge, cooling it by exchanging heat. Some air is withdrawn from this section for use as the primary air for combustion in the burners. The remaining air continues to the left into the combustion zone, mixes with the combustion gases, and then passes through the incoming charge, losing heat to it. The temperature of the flue gases ranges from 150 to 300°C, depending on the length of the preheating zone and the amount of air recirculated. Air is drawn out the left end of the kiln with a suction fan. Air locks are used at both ends so that the flow conditions in the kiln will not be disturbed by the entrance or exit of cars.

The output of tunnel kilns varies from 100 to 250 ton/day with an air flow of 15,000 to 37,000 ACFM. The exact operating parameters of a kiln are determined by the raw material used and the nature of the product desired.

RAW MATERIAL

Clays are classified according to the use for which they are best suited, and according to their chemical properties. Clays may be alternately described as brick clay, fire clay, potters clay, etc. or categorized as to marls, loams, shales, fire clays and boulder clays.

TABLE 87

BREAKDOWN TEMPERATURES OF CLAY IMPURITIES

	Temperature °C	Temperature °F
$FeS_2 + O_2 \rightarrow FeS + SO_2$	350-450	660-840
$4FeS + 7O_2 \rightarrow 2Fe_2O_3 + 4SO_2$	500-800	930-1470
$Fe_2(SO_4)_3 \rightarrow Fe_2O_3 + 3SO_3$	560-775	1040-1430
$C + O_2 \rightarrow CO_2$	350	660
$S + O_2 \rightarrow SO_2$	250-920	480-1690
$CaCO_3 \rightarrow CaO + CO_2$	600-1050	1110-1920
$MgCO_3 \rightarrow MgO + CO_2$	400-900	750-1650
$FeCO_3 + 3O_2 \rightarrow 2Fe_2O_3 + 4CO_2$	800	1470
$CaSO_4 \rightarrow CaO + SO_3$	1250-1300	2280-2370

TABLE 88

TEMPERATURES ATTAINED IN BURNING

	Temperature, °C
Clays rich in lime and iron	790-1080
Gault clays	855-940
Red-burning clays and shales	900-1140
Clinkers, pavers, vitrified bricks	1100-1300
Stoneware; salt glaze	1180-1300
Majolica glazes	900-1000
Glazed bricks (hard fire)	1200-1280
Fire clays	1230-1530
Silica bricks; High-alumina bricks, magnesia bricks and chromite bricks	1460-1670

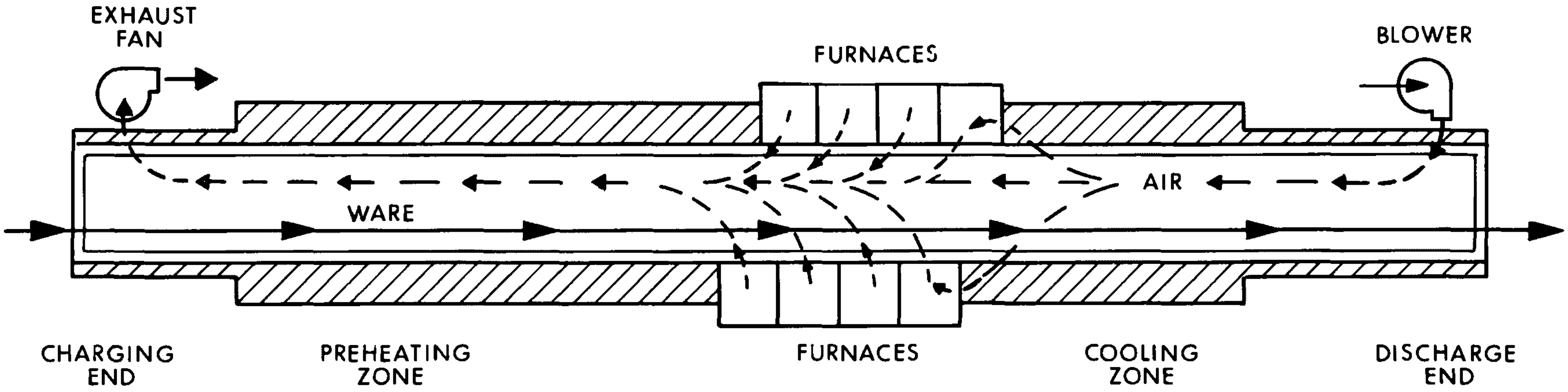


FIGURE 69
PLAN SECTION OF TUNNEL KILN

Marls contain a substantial amount of lime in the form of chalk or limestone. *Loams* contain a good deal of sand which makes them easy to work. *Shales* are very hard materials formed by geologic processes into nearly rock-like masses. *Fire clays* contain a high proportion of minerals with very high decomposition temperatures, such as magnesia, and are used for furnace linings, etc. *Boulder clays* are produced by glacial action and generally contain round stones or boulders. Clays with a low percentage of constituents such as sand or limestone and a high fraction of plastic alumino-silicates are termed *fat clays*.They are usually improved by the addition of other materials such as sand or limestone. Table 89 contains a chemical formulation of some of the alumino-silicate materials which are suitable for brick making.

It can be seen from Table89that the clay minerals themselves are not a source of sulfur dioxide or fluoride emission with the possible exception of hectorite, which contains fluorine. It is impurities in the clay (see Table 90) that are responsible. In addition to these naturally occurring impurities, materials such as sand, ground fired bricks, coal, coke, ashes, sawdust, and water are added to clay to impart useful properties to it.(1)

NATURE OF THE GASEOUS DISCHARGE

Tunnel kilns are basically furnaces in which the water of hydration of the clay minerals is removed by firing. The kiln operates continuously, and has a relatively steady flow of gas and constant heat input. The effluent gas leaving the kiln consists of air from which some of the oxygen has been removed by combustion of fuel along with the carbon dioxide, water vapor, and sulfur dioxide or other contaminants produced by combustion of the fuel. In addition, the water driven off of the brick is contained in the effluent gas. Tunnel kilns can be fired with any of the commonly available fuels such as natural gas, fuel oil, or coal. The composition of the gas leaving the kiln depends but little on the type of fuel used in that the kiln operates at a very high ratio of total air to theoretical combustion air and the composition is altered minimally by the combustion of the fuel. In order to illustrate this, Table 91 lists the products of combustion calculated for a 100 ton/day kiln using clean natural gas and high sulfur coal as fuels. For most purposes, the tunnel kiln effluent can be presumed to consist of air plus water vapor.

NATURE OF THE AIR CONTAMINANTS

Due to the diverse nature of the raw material and its effect on the emission from the kiln, three types of operation will be discussed.

1. Where the clay contains no sulfur or fluorine-containing material

TABLE 89

CHEMICAL FORMULATION OF BRICKMAKING CLAYS

Kaolinite Group	Montmorillonite Group	Micaceous Group	Aluminous Group
Kaolinite $Al_2(Si_2O_5)\ (OH)_4$	Pyrophyllite* $Al_2Si_4O_{10}(OH)_2$	Muscovite* $Al_4K_2(Si_6Al_2)O_{20}(OH)_4$	Gibbsite* $Al\ (OH)_3$
Dickite $Al_2(Si_2O_5)\ (OH)_4$	Montmorillonite $(Al_{1.67}Mg_{0.33})Si_4O_{10}(OH)_2$ $\downarrow$ $Na_{0.33}$	Bravaisite $Al_4K_x(Si_{3\text{-}x}Al_x)O_{20}(OH)_4$	Diaspore* $HalO_2$
Nacrite $Al_2(Si_2O_5)\ (OH)_4$	Beidellite $Al_{2.17}(Al_{0.83}Si_{3.17})O_{10}(OH)_2$ $\downarrow$ $Na_{0.33}$	Brommallite $Al_4Na_x(Si_{8\text{-}x}Al_x)O_{20}(OH)_4$	Boehmite $HAlO_2$
Anauxite $Al_{2\text{-}n}(Si_{2+n}O_5)\ (OH)_4$	Nontronite $(Fe_{2.00})Al_{0.33}Si_{3.62})O_{10}(OH)_2$ $\downarrow$ $Na_{0.33}$	Attapulgite $(Mg_5Si_8)O_{20}(OH)_2 2H_2O$	
Endellite $Al_2(Si_2O_5)\ (OH)_4 2H_2O$	Saponite $Mg_3(Al_{0.33}Si_{3.62})O_{10}(OH)_2$ $\downarrow$ $Na_{0.33}$	Ordovician bentonites	
Halloyste $Al_2(Si_2O_5)\ (OH)_4$	Hectorite $(Mg_{2.67}Li_{0.33})Si_4O_{10}(F,OH)_2$ $\downarrow$ $Na_{0.33}$	(Most of the minerals in this group are not very specific.)	
Allophane, amorphous	Sauconite $Zn_3(Al_{0.33}Si_{3.67})O_{10}(OH)_2$ $\downarrow$ $Na_{0.33}$		

*These minerals are not usually considered among the clay minerals, but when finely ground behave like clays in ceramic processes.

TABLE 90

SOME NATURALLY OCCURRING IMPURITIES

Quartz

Feldspars (orthoclase, plagioclase)

Micas (muscovite and biotite)

Iron minerals (hematite, magnetite, limonite, pyrites, siderite)

Titanium minerals (rutile, anatase)

Limestone (calcite, dolomite)

Magnesite

Gypsum

Garnet

Tourmaline

Fluorspar

Organic matter

TABLE 91

CALCULATED COMPOSITION OF COMBUSTION PRODUCTS FROM 100 TON/DAY TUNNEL KILN

	Gas Fired		Coal Fired	
	SCFM	Mol %	SCFM	Mol %
O_2	1490	16.5	1400	15.6
N_2 + A	6620	73.6	6660	74.0
CO_2	135	1.5	260	2.9
H_2O	745	8.3	660	7.3
SO_2 + HF*	10*	0.1*	20	0.2
Total	9000	100.0	9000	100.0

*HF derived from clay impurities

2. Where the raw material does contain sulfur and fluorine

3. Where the clay contains organic matter such as lignite or sawdust.

In the first case, the contaminants are derived only from the fuel used. Where natural gas is used, there should be no problems. High sulfur fuel oil or coal will produce both SO_2 and flyash emissions. There is a possibility of CO emissions from passing the hot gases over the incoming bricks, but the concentration should be negligible.

In the second case, the fuel will produce contaminants as it does in the first case. Fluorides and additional SO_2 will be emitted from the impurities in the clay. One common fluorine containing impurity is fluorite or fluorspar, CaF_2, which can react as follows:(3)

1. $CaF_2 + 3/2\ SiO_2 = CaSiO_3 + 1/2\ SiF_4$

2. $CaF_2 + 1/2\ CaSiO_3 = 3/2\ CaO + 1/2\ SiF_4$

3. $CaF_2 + H_2O = CaO + 2HF$

4. $CaF_2 + H_2O + SiO_2 = CaSiO_3 + HF$

In addition, silicon tetrafluoride can react with water vapor as follows:(3)

5. $SiF_4 + 2\ H_2O = SiO_2 + 4HF$

The equilibrium constants for these reactions at 1200°C are, respectively:

1. 0.13

2. 1.6×10^{-6}

3. 2.0×10^{-4}

4. 0.36

5. 16.4

It can be seen from the above that essentially all SiF_4 formed in the presence of the water vapor from the combined and free water in the clay should be hydrolyzed to HF.(3) Therefore, the fluorine is emitted in the form of HF rather than SiF_4.

With a fuel containing 15% ash and 2% sulfur, the flue gas of a kiln using 150 lbs of fuel per ton of ware fired and 600% excess air(4) will contain about 0.74 gr/ACF flyash and 125 ppm SO_2.

If the raw material contains 0.1% sulfur and 300 to 500 ppm fluorine which is 30 to 90% volatilized, the flue gas will contain about 290 ppm SO_2 and from 25 to 125 ppm HF. The HF probably hydrolizes to form hydrofluoric acid mist at the flue gas condition.

The third case, involves the generation of air pollutants when organic matter such as sawdust or powdered coal is added to the clay with the objective of burning it out in the kiln and leaving a porous, low density brick. Such bricks have improved insulating qualities as well as being light in weight. In this case, and also when there is a high percentage of naturally occurring organic material such as coal in the clay, there may be a partial volitilization of the organic matter in the kiln followed by condensation and partial oxidation. One result of this sequence is the production of a black organic smoke consisting of very tiny carbon particles. Unlike the sulfur oxides or hydrofluoric acid, the carbonaceous smoke may be decomposed to some extent in the furnace. However, there is likely to be sufficient emission to cause violation of visible smoke ordinances in circumstances where a substantial amount of organic matter is included in the clay. For example, if a clay is blended with sawdust to form a 1% organic matter mixture, the total amount of carbonaceous material present in the clay would be sufficient to produce a grain loading of 0.85 gr/ACF at the kiln discharge. However, only a fraction of the total carbonaceous matter is likely to be vaporized and survive as black particulate matter.

ABATEMENT EQUIPMENT

It is apparent that air pollution abatement equipment must be tailored to the specific contaminants generated from impurities in the clay or in the fuel. These may be divided into:

Gaseous Contaminants	Particulates
SO_2	flyash
HF	smoke

The gaseous contaminants can be removed by either absorption in a solvent or adsorption on a solid material. Of the two, absorption using water as the scrubbing medium is the method accepted in practice. Wet scrubbers are suitable for removal of both gaseous impurities.

Gaseous absorption is carried out in a variety of scrubbing devices, most of which involve counter-current contacting of the gas and liquid. Where gases are absorbed into liquid streams free of solids, fixed beds of packing material are most frequently used. The presence of solids in either the liquid or gas phases tends to cause plugging problems and requires the use of non-plugging scrubbers. These may be co-current Venturi scrubbers, cross-flow packed scrubbers, or a variety of proprietary devices utilizing moving packings or self-cleaning impingement surfaces.

Where collection of particulate matter and absorption are required, Venturi scrubbers, mobile packing devices and self-cleaning scrubbers are necessary. This case was chosen for the specification of a hypothetical kiln in which sulfur-bearing coal is burned and both SO_2 and HF are generated by decomposition of the clay impurities.

HF is readily absorbed in water until the pH becomes quite low. However, fluoride-containing effluent water cannot ordinarily be discharged into natural bodies of water, so it is necessary to add some reagent which will precipitate the fluoride as a solid. Typically lime or limestone is used for this purpose and insoluble CaF_2 is produced. This material is most frequently deposited in a pond in which the scrubber effluent is impounded and from which water is recycled.

Where SO_2 is present in the gas, it may be removed by absorption, but the pH requirement is higher than for HF absorption. For this reason, addition of lime to the scrubber system rather than to the pond may be chosen for a system specification.

The removal of flyash can be accomplished by wet scrubbing, electrostatic precipitation or fabric filtration. However, the flyash problem is relatively limited in scope because of the predominance of gas fired kilns and because of the low ratio of coal to total ventilating air. The flyash collection has been limited, for purposes of this report, to wet scrubbing with the concurrent removal of HF and SO_2. Special circumstances at a given plant might indicate the use of an electrostatic precipitator or fabric collector for flyash collection where no gaseous contaminants are involved.

"Smoke" produced by volatilization of organic material present in the clay or added to modify the properties of the ware presents a somewhat different problem. Here the conventional particulate collection devices such as fabric collectors and precipitators may operate satisfactorily or may be subject to a variety of operating problems because of the nature of the particles. These can vary from droplets of liquid oil to dry, solid carbon particles. Where there is a possibility of caking or of wetting the collecting elements, both filters and precipitators present special design problems. In particular, fabric collectors are prone to "blinding" of the cloth, which restricts the gas volume sharply. This would interfere with or prevent the normal operation of the kiln. Precipitators have difficulty in handling solids with a caking tendency, and are also subject to fire hazards when operating with combustible particulate in oxygen-rich gas streams.

Scrubbers have difficulty collecting particulate "smokes" which are formed by volatilization and carbonization of organic materials. This is due to the small particle size rather than to the hydrophobic nature of the particulate matter, and high pressure drop across a Venturi scrubber contributes toward improved operation. The application of a high energy scrubber for smoke abatement usually requires careful measurement with a pilot unit to determine the pressure drop and horsepower requirement.

Incineration is an acceptable method of abatement for smokes generated by volatilization of organic material in ovens. There are two limiting cases which have different requirements, however. Where the volatile material is vaporized at relatively low temperature and passes through the oven without oxidation, the result is usually a white or blue-white plume similar in appearance to a light steam plume. This material is generally in the vapor phase at temperatures above 500°F and can be oxidized by passing it over a catalyst, or by thermal incineration. Typical operating conditions for catalytic and thermal incinerators on volatile hydrocarbons which tend to produce white smoke are:

	Catalytic	Thermal
Temperature, °F	700	1250
Residence time, sec	0.05	0.5

The second condition involves a partial incineration or oxidation of the organic vapors in the furnace at a high temperature, and frequently in the absence of sufficient oxygen to produce complete combustion. The resultant material is a carbonaceous solid similar to lamp black. The appearance of a plume of this material is gray to black. This material must be treated as a solid in the incineration equipment. Catalytic incineration is not suitable, in that only materials reaching the surface of the catalyst as vapors are subject to the rate-increasing action of the catalyst. Thermal incineration is suitable but requires a much more severe combination of time and temperature to provide time for complete burning of the carbon particles. Reasonable conditions for incineration of the black smoke are in the range of 1400 to 2000° F and 1 to 2 seconds residence time. The smoke produced by brick kilns is relatively low in concentration and is likely to require no more than 1 second residence time at 1500° F.

Because of the possibility that both types of organic emissions can exist in a kiln firing clay to which organic materials have been added, a thermal incinerator was specified for the hypothetical plants covered by the specifications in this section.

Thermal incinerators have a substantial fuel requirement and some form of heat recovery equipment is usually included. In this case, a self-regenerative heat exchanger was prescribed for the incinerator. The choice between this kind of heat recovery and using the heat to preheat furnace makeup air is purely an economic one and will be specific to each application.

SPECIFICATIONS AND COSTS

Because emissions from brick and tile kilns are limited to those cases where impurities in the clay are present, it is difficult to describe a general case which covers all of the possibilities. The alternatives considered in this section are:

1) No air pollution control required

2) Inorganic gaseous pollutants generated by fluorides and sulfur in the raw materials

3) Organic emissions from vegetable matter or oil in the clay

4) Both inorganic and organic impurities.

To cover these possibilities, two specifications were written. The first specifies the installation of a wet scrubbing system for limiting fluoride and SO_2 emissions. This was based on the presumption of a high level of natural fluoride minerals in the clay and emission requirements of the same order of magnitude as those currently imposed by the State of Florida. In addition, sulfur and flyash from combustion of high sulfur coal are included.

The second specification covers the installation of thermal incineration equipment for the removal of carbonaceous smoke produced in the kiln by incomplete burning of sawdust inclusions in the clay.

These specifications are given in Tables 92, 93, 96 and 97. The averages of the quotations submitted in response are given in Tables 94, 95, 98 and 99 and plotted in Figures 70, 71, 73 and 74. The first cost for the scrubber installations varies considerably because these systems are not common and there is no stereotype which can be followed. It might be expected that the costs for commercial installations solicited without a preliminary process design might vary over a wide range.

The thermal incineration system quotations were received from two companies of the IGCI who furnish this type of equipment. Of these, only one quoted the complete turnkey installation, while the other supplied only the cost of the incineration equipment.

There are few operating systems using either incineration or scrubbing equipment. It is unlikely that any single instance exists where both of the problems described are present in the same operation. If there is such a situation, it would be necessary to install the two systems in tandem, and the costs would approach the sum of the individual system costs.

TABLE 92

WET SCRUBBER PROCESS DESCRIPTION
FOR BRICK AND TILE KILN SPECIFICATION

This specification describes the air pollution aspects of a tunnel kiln used alternately for manufacture of common brick and drainage tile. The ware is manufactured from a local clay containing both fluorspar and pyrites, and therefore produces both fluoride and sulfur dioxide emissions. In addition, the kiln is fired with high sulfur coal burned on a moving grate. The scrubber must handle the particulate and sulfur dioxide emissions from the fuel as well as the gaseous emissions from the ware.

SCRUBBER SECTION

The scrubber is to be a medium energy level type, capable of the specified particulate efficiency, and concurrent reduction of SO_2 *and fluorine to the desired levels. The scrubber shall circulate at least 10 gallons of slurry per 1000 ACFM of gas discharge from the scrubber.*

The scrubber is to maintain a recycle of scrubbing liquor to limit the consumption of fresh water. Make-up water to offset evaporation losses shall be added automatically as required. The ID fan shall precede the scrubber so as to avoid corrosion problems relating to wet fluoride and sulfite gases. The fan and ductwork preceding the scrubber may be constructed of carbon steel. The scrubber proper and all of the inter-connecting piping shall be rubber lined, or equal. A rubber lined stack extension shall be provided to raise the discharge point to approximately 50 ft above grade.

INSTALLATION

The scrubbing system is to be located adjacent to a railroad siding which will run between the kiln and the scrubber system. The flue gas must be conducted across the siding, a distance of approximately 30′ at elevation + 25′ with respect to grade, to the inlet of the ID fan. Adequate space is available for all equipment in this area. Soil bearing pressures of 2,000 lb/ft^2 *may be assumed for the area. Equipment is to be located outside and freeze protection must be provided for ambient temperatures down to* $-10^{o}F$*. All utilities are available at a substation adjacent to the scrubber area. The flow control instruments, alarms for high and low liquid levels and motor control stations shall be assembled on a single control panel, located inside the existing kiln control room.*

TABLE 93

WET SCRUBBER OPERATING CONDITIONS FOR BRICK AND TILE KILN SPECIFICATION

Because the absorption of HF is one principal objective of this system, only one efficiency level is specified.

	Small	Large
Capacity, ton/day	100	250
Process weight, ton/day	124.8	312.06
Dry ware	100	250
Water	16.8	42
Sulfur	0.25	0.63
Fluorine	0.25	0.63
Coal	7.5	18.8
Total	124.8	312.06
Kiln discharge gas		
Flow, ACFM	15,000	36,000
Temp., ^{o}F	270	290
Flow, SCFM	11,000	25,500
Flow, DSCFM	10,300	23,900
Moisture content, vol. %	6.0	6.4
Discharge Gas Contaminants		
HF, ppm	350	375
SO_2, ppm	715	770
Flyash, gr/ACF	0.60	0.65
F, lb/hr (as F)	11.5	28.7
SO_2, lb/hr	80.0	200
Flyash, lb/hr	77	195
Scrubber Additions		
Water, GPM total	4.2	9.6
evaporation, GPM	4.0	9.1
entrainment, GPM	0.2	0.5
Scrubber discharge		
Flow, ACFM	12,900	29,600
Temp., ^{o}F	119	120
Flow, SCFM	11,600	27,000
Moisture content, vol %	11.2	11.5
Flow, DSCFM	10,300	23,900
Discharge gas contaminants		
HF, ppm	< 100	< 100
HF, lb/hr	< 3.4	< 8.1
Efficiency required, %	71.5	73.5
SO_2, ppm	270*	290*
SO_2, lb/hr	32*	80*
Efficiency required, %	–	–
particulate, gr/ACF	0.02	0.02
particulate, lb/hr	2.2	5.1
efficiency required, %	97.1	97.3

*NOTE: These values are expected at a scrubber pH of 5.

TABLE 94

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS
FOR BRICK AND TILE KILNS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			15,000	36,000
°F			270	290
SCFM			11,000	25,500
Moisture Content, Vol. %			6.0	6.4
Effluent Dust Loading				
gr/ACF			0.6	0.65
lb/hr			77	195
Cleaned Gas Flow				
ACFM			12,900	29,600
°F			119	120
SCFM			11,600	27,000
Moisture Content, Vol. %			11.2	11.5
Cleaned Gas Dust Loading				
gr/ACF			0.02	0.02
lb/hr			2.2	5.1
Cleaning Efficiency, %			97.1	97,3
(1) Gas Cleaning Device Cost			13,697	22,250
(2) Auxiliaries Cost				
(a) Fan(s)			3,735	8,245
(b) Pump(s)			1,589	2,854
(c) Damper(s)				
(d) Conditioning, Equipment			533	750
(e) Dust Disposal Equipment				
(3) Installation Cost			68,752	81,610
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost			88,306	115,709

TABLE 95

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR BRICK AND TILE KILNS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$6/hr			600	600
Supervisor					
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance				2,520	2,659
Replacement Parts					
Total Replacement Parts				1,007	2,216
Utilities					
Electric Power	$.011/kw-hr			3,894	9,438
Fuel				-	-
Water (Process)	$.25/M gal			722	1,651
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				4,616	11,089
Total Direct Cost				8,743	16,564
Annualized Capital Charges				8,831	11,571
Total Annual Cost				17,574	28,135

FIGURE 70
CAPITAL COSTS FOR WET SCRUBBERS FOR BRICK AND TILE KILNS

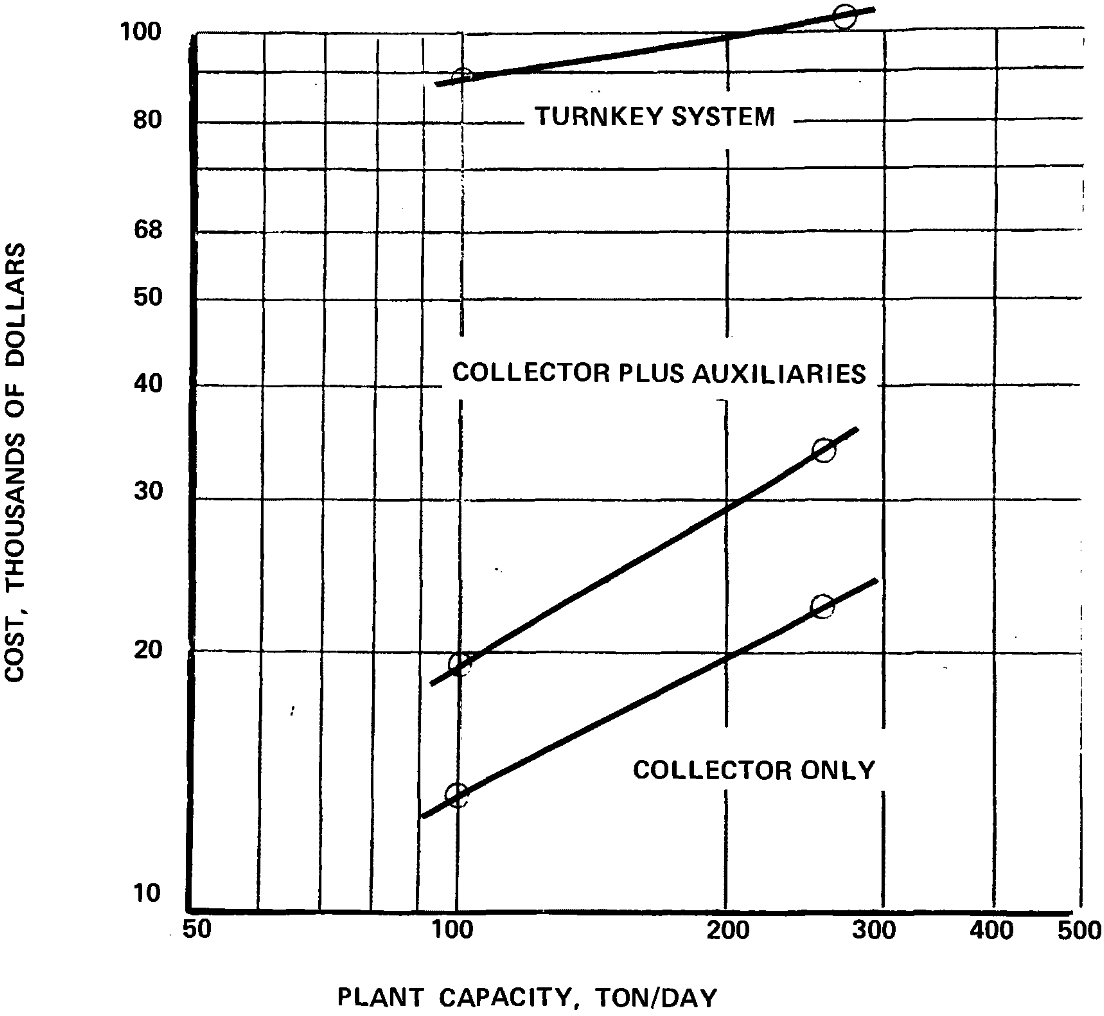


FIGURE 71
ANNUAL COSTS FOR WET SCRUBBERS
FOR BRICK AND TILE KILNS

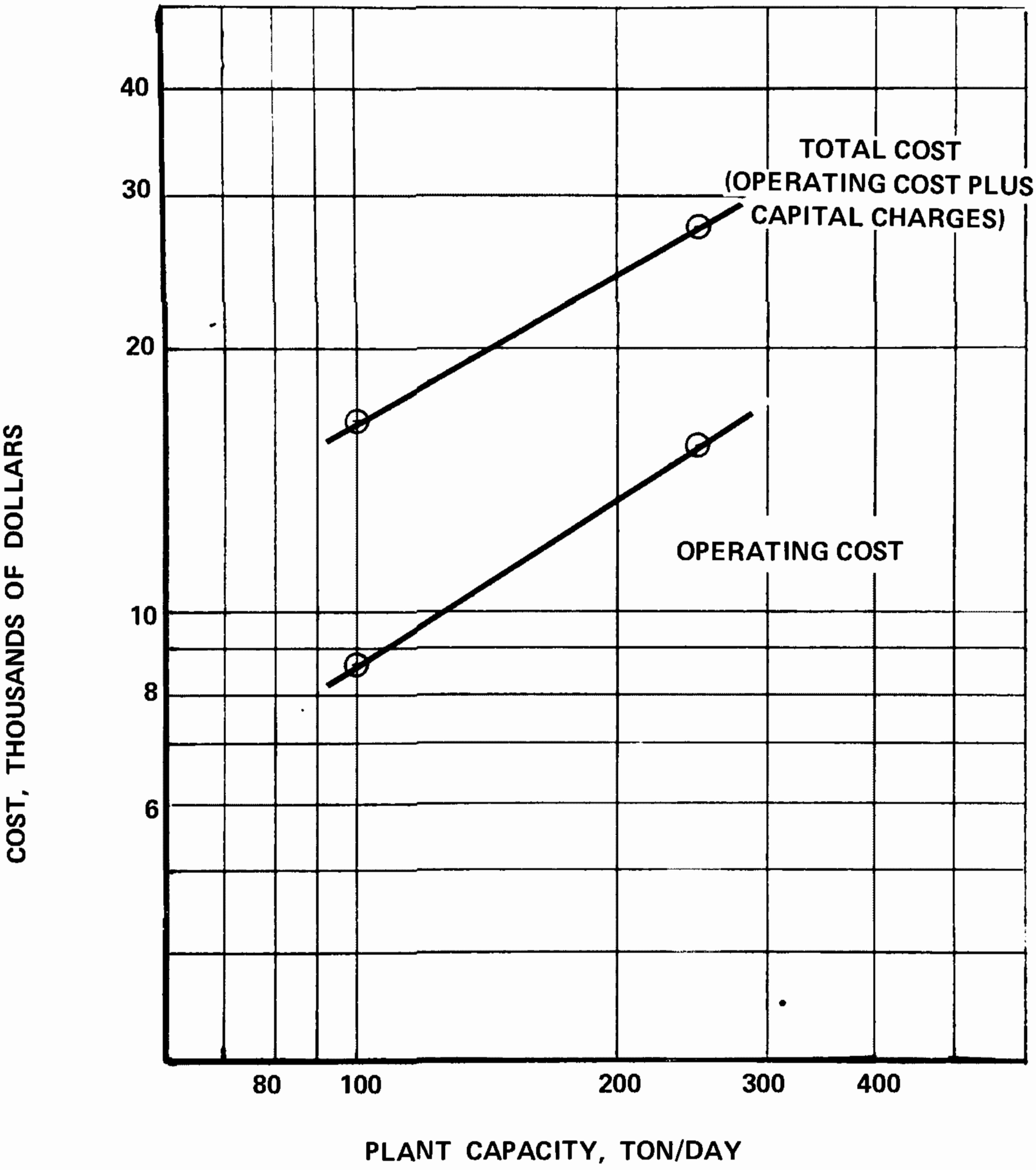


FIGURE 72
CONFIDENCE LIMITS FOR CAPITAL COST OF WET SCRUBBERS ONLY FOR BRICK AND TILE KILNS

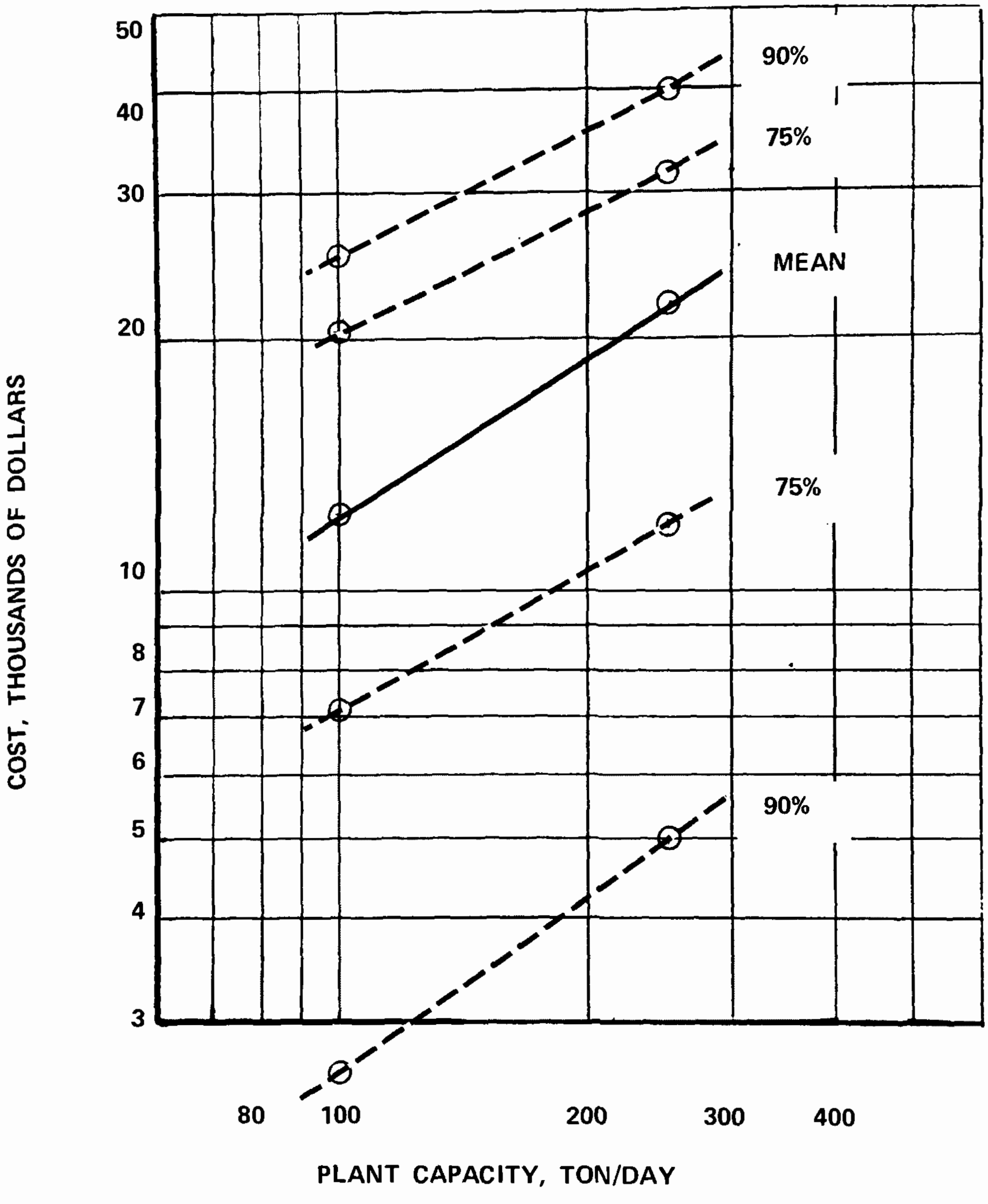


TABLE 96

THERMAL INCINERATOR PROCESS DESCRIPTION FOR BRICK AND TILE KILN SPECIFICATION

This specification describes the requirements for a thermal incinerator for abatement of a gray or black smoke plume produced by the kiln. The smoke plume exists only when organic filler (sawdust) is added to the clay to improve the insulation characteristics of bricks. Other than the emission of this particulate matter, the kiln produces no byproducts which could be construed as air pollutants. Natural gas is the fuel used for firing, and the native clay may be considered free of fluoride, sulfur or any other noxious materials.

The incinerator must be designed to abate the smoke plume from the effluent stream as presently comprised. However, reuse of heat is a prime concern and is to be accomplished by a self regenerative heat exchanger.

The incinerator shall be maintained under a negative pressure by virtue of a fan at the outlet of the heat exchanger on the flue gas side. This fan is to be selected to overcome the pressure drop of the incinerator and both sides of the heat exchanger. This new ID fan is to discharge into a 50 ft stack, which may be constructed of carbon steel.

The incinerator shall be fueled by natural gas. The burner shall be of the 100% secondary air type, utilizing oxygen in the furnace effluent for combustion. The burner shall be equipped with a continuous pilot, and shall be controlled to maintain an outlet temperature no higher than 1500°F. Gas piping flame failure controls, etc. shall be designed to meet F.I.A. safety standards.*

A damper shall be provided to prevent overloading the fan during startup if required.

INSTALLATION

The incineration system is to be located adjacent to a railroad siding which will run between the kiln and the incineration system. The flue gas must be conducted across the siding, a distance of approximately 30′ at elevation + 25′ with respect to grade, to the inlet of the incinerator. Adequate space is available for all equipment in this area. Soil bearing pressures of 2,000 lb/ft^2 may be assumed for the area. Equipment is to be located outside. All utilities are available at a substation adjacent to the area.

For purposes of this proposal, the fan and dampers are to be considered auxiliaries. A complete turnkey proposal including foundations, stack, etc. is requested. Ductwork from present stacks to the incinerator shall be included in the turnkey price.

**Factory Insurance Association*

TABLE 97

THERMAL INCINERATOR OPERATING CONDITIONS
FOR BRICK AND TILE KILN SPECIFICATION

One incinerator should be quoted for each size kiln listed below.

	Small	Large
Kiln capacity, ton/day	100	250
Process weight, ton/day	116.8	292
Dry ware	100.0	250.0
Water	16.8	42.0
Total	116.8	292.0
Kiln discharge conditions		
Gas flow, ACFM	15,000	36,000
Temp, °F	270	290
Gas flow, SCFM	11,000	25,500
Organic content, Btu/SCF	0.5	0.5
Organic content, gr/SCF	0.35	0.3
Organic content, lb/hr	33	79
Incinerator discharge conditions		
Gas flow, SCFM	~11,150	~25,900
Temp, °F	1,500	1,500
Organic content, gr/SCF	0.0039	0.0036
Organic content, lb/hr	.033	.079
Incineration efficiency, %	99.9	99.9
Hot gas discharge from heat exchanger, °F	770	770
Cold gas flow, SCFM	11,000	25,500
Cold gas temp, °F	270	290
Cold gas discharge temp, °F	1,010	1,010
Heat exchanger duty, MM Btu/hr	~ 9.6	~ 22.4

TABLE 98

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR THERMAL INCINERATORS
FOR BRICK AND TILE KILNS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			15,000	36,000
°F			270	290
SCFM			11,000	25,500
Moisture Content, Vol. %			64	64
Effluent Dust Loading				
gr/ACF				
lb/hr Comb.			33	79
Cleaned Gas Flow				
ACFM			24,862	58,115
°F			725	735
SCFM			11,120	25,775
Moisture Content, Vol. %			84	84
Cleaned Gas Dust Loading				
gr/ACF				
lb/hr Comb.			0.033	0.079
Cleaning Efficiency, %			99.9	99.9
(1) Gas Cleaning Device Cost			50,900	89,300
(2) Auxiliaries Cost				
(a) Fan(s)*			12,463	25,177
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost				
(a) Engineering			15,932	20,182
(b) Foundations & Support			10,621	15,122
(c) Ductwork			31,863	40,366
(d) Stack			7,300	10,061
(e) Electrical			5,311	7,060
(f) Piping			3,540	6,707
(g) Insulation			1,770	3,354
(h) Painting			4,200	6,200
(i) Supervision			2,700	3,600
(j) Startup			1,800	2,700
(k) Performance Test			2,500	3,500
(l) Other				
(4) Total Cost			150,900	233,329

* Includes motors, starters, drives

Based on one quote.

TABLE 99

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)	$6/hr			1,500	1,500
Operator					
Supervisor					
Total Operating Labor				1,500	1,500
Maintenance	$6/hr				
Labor				960	960
Materials				40	40
Total Maintenance				1,000	1,000
Replacement Parts					
Total Replacement Parts				300	300
Utilities					
Electric Power				-	-
Fuel	$0.80/MMBTU			44,720	103,200
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				44,720	103,200
Total Direct Cost				47,520	106,000
Annualized Capital Charges				16,700	27,003
Total Annual Cost				64,220	133,003

FIGURE 73
CAPITAL COSTS FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS

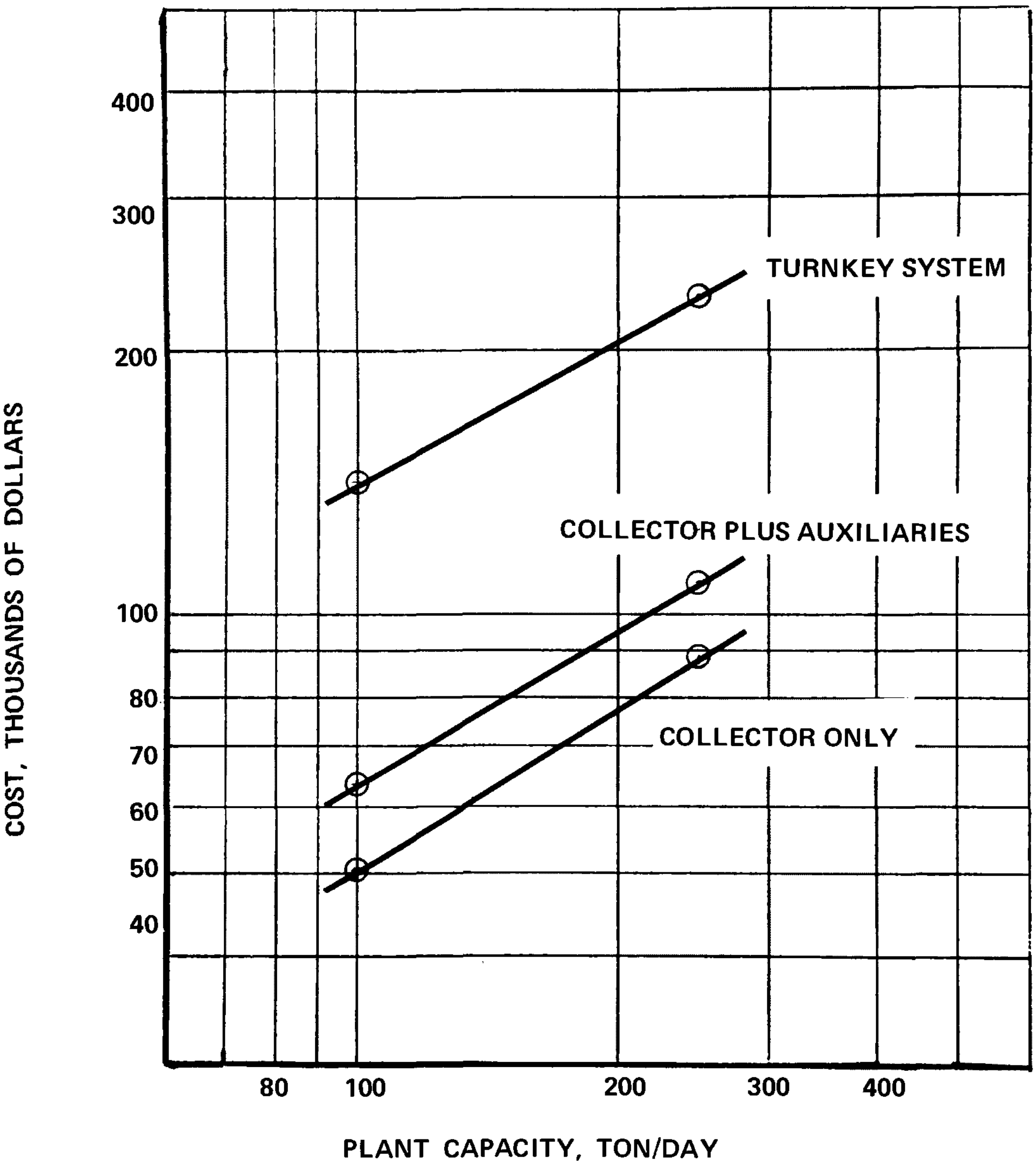
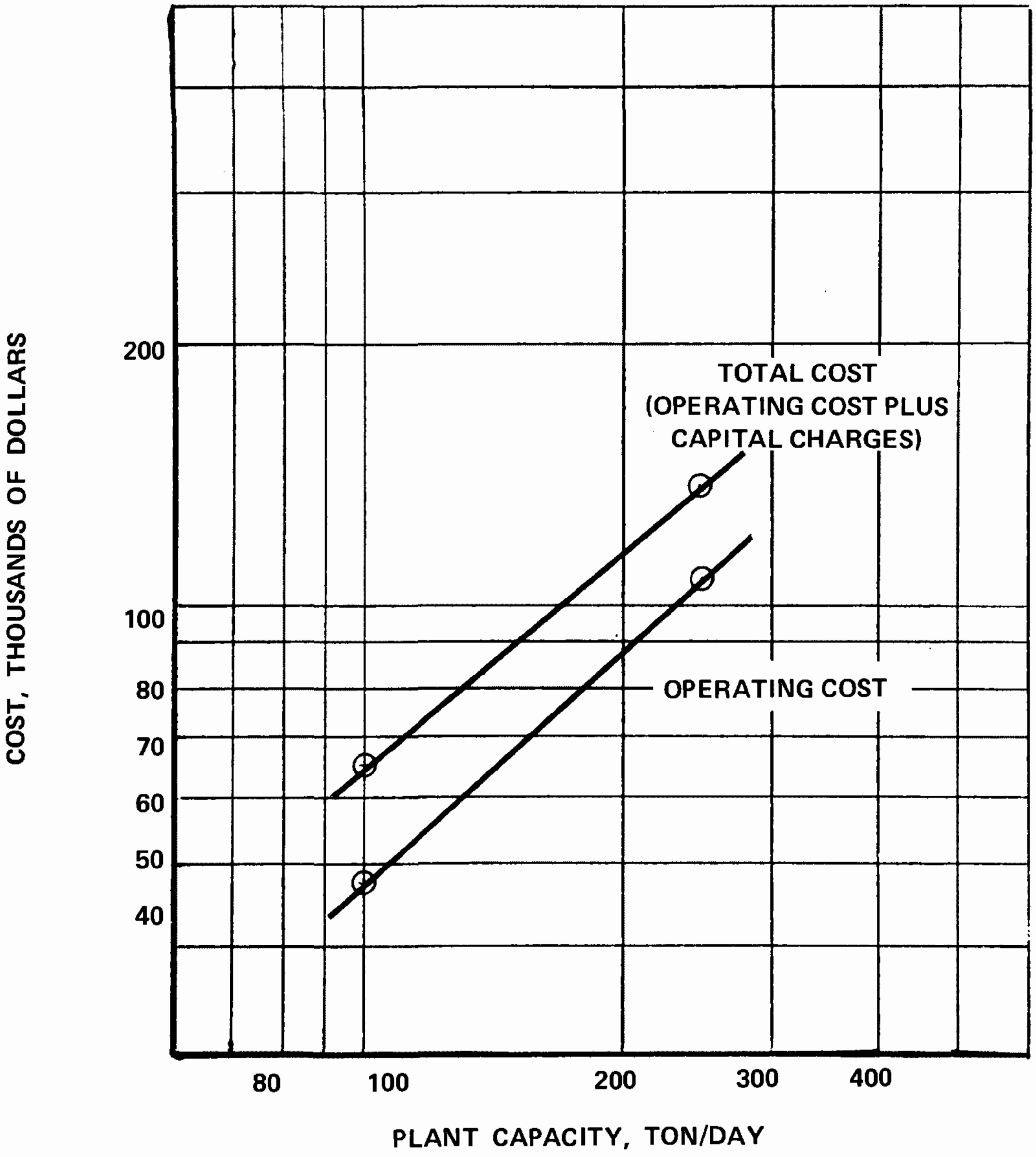


FIGURE 74
ANNUAL COSTS FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS



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COPPER SMELTING

7. COPPER SMELTING

Copper is a widely used metal because of its high thermal and electrical conductivity, and because it is very resistant to corrosion. The latter property is due to the formation of a thin protective layer of basic salts on the surface when it is exposed to the atmosphere.(1) Copper is also widely used as an alloying element in corrosion resistant materials such as brass, bronze, monel metal and cupro-nickel.

Almost all of the industrial uses of copper require the metal in relatively pure, metallic form. Most natural copper deposits in the U.S. occur as sulfides, and this discussion deals primarily with the methods used to obtain pure metal from the natural sulfide ores. Some copper deposits in oxide form and as metallic or "native" copper are found in the U.S., but these are of secondary interest, both as sources of copper and as air pollution sources.

Most of the copper mined in the U.S. is from deposits of:

	Gornite	Cu_5FeS_4
	Chalcopyrite	$CuFeS_2$
and	Enargite	$Cu_3(As, Sb)S_4$.

These minerals are of igneous origin, and are usually distributed in massive rock strata as "porphyry" deposits. These deposits are low in copper content – around 1% or 20 lb/ton Cu by weight – but are readily processed by large scale open-pit ore handling and concentration techniques.(2)

The complex chemistry of the ore materials, the low concentration in the rock or gangue, and the strong affinity of copper for sulfur, all contribute to the complex series of operations necessary to produce metallic copper from ore.

This discussion will describe the smelting process in general, and will cover the most clearly defined processing steps – roasting, reverberatory furnace smelting, and converting – in some detail. The air pollution aspects of roasting furnaces and reverberatory furnaces without sulfuric acid plants for SO_2 control and recovery will be discussed.

THE OVERALL SMELTING PROCESS

Copper almost always occurs in deposits with other metals such as iron, lead, arsenic, tin or mercury. The smelting process must be adapted to the particular ore type and concentration at any given mine. In the U.S., about 94% of the copper ore is processed by a series of operations consisting of mining, concentrating, smelting and refining.(2) These steps can be further subdivided as follows:

- mining
  - drilling
  - blasting
  - loading
  - handling
- concentrating
  - crushing
  - grinding
  - classification
  - flotation
  - dewatering
- smelting
  - roasting
  - reverberatory smelting
  - converting
- refining
  - fire refining
  - electrolytic refining

Although this discussion is aimed primarily at the smelting area, some discussion of the other operations is included for background.

MINING

Most U.S. produced copper comes from large open-pit mines such as those in the Southwest (Arizona, Nevada and Utah) and in Montana. The porphyry deposits are scraped clear of over burden, and blasting operations with ammonium nitrate or other low-cost explosives are used to loosen the ore. Electric shovels, with bucket capacities as large as 15 cubic yards, load trucks of 60 to 85 ton capacity. The ore is hauled to a mill for concentration from 1% or so up to 15 to 30% copper by weight.

CONCENTRATION

Sulfide ores can be separated from the non-copper bearing rock or gangue by a froth flotation process. In order to accomplish this separation, the porphyry must be ground to a powder and the valuable minerals "liberated" from the gangue.

The grinding usually starts in gyratory crushers which reduce the maximum size to the 6 to 9 inch range. These are followed by cone-type crushers which reduce the size to 1 to 2 inches. Wet grinding operations in rod mills and, finally, wet grinding in ball mills are used to produce a nominal 65 to 200 mesh product. The ball mills are generally built with a particle size classifier on the outlet, which separates the ground product into a fraction which is acceptable to the flotation process, and an oversize fraction which is recycled to the mill. Lime is often added to the ore before final grinding if FeS_2 is present.(2)

Flotation is accomplished by introducing air into the water slurry along with chemical agents called "frothers" and "collectors". These materials produce a froth of air bubbles which rise to the top. The copper sulfide minerals attach themselves to the froth bubbles and are carried out the top of the flotation cell, while the gangue sinks to the bottom and is discarded as "tailings".

Many complex procedures are used in flotation processes to upgrade the ore to the optimum concentration by operation of flotation cells in series, by "differential flotation" to separate sulfide salts of other metals such as FeS_2 and MoS_2. Chemicals such as xanthates, dithiophosphates, and dextrin are used as collectors, "activators", "dispersants", etc. in these processes.

The usual product of copper sulfide ore concentration is a washed and dewatered concentrate, containing 15 to 30 wt. % copper, and suitable for smelting.

SMELTING

"Smelting" covers all of the processes necessary to transform copper salts into metallic copper. These processes usually include reverberatory smelting. Figure 75 is a schematic representation of the relationship between these processes.(1)

The steps in the smelting process are aimed at making two types of separations:

1) between the metals and the gangue

2) between copper and the chemically combined contaminants sulfur and iron

The reverberatory furnace accomplishes the main separation between the minerals and gangue which is withdrawn as a molten slag. The ratio of Cu/S/Fe is adjusted in the mineral portion of the melt to produce a "matte" with about

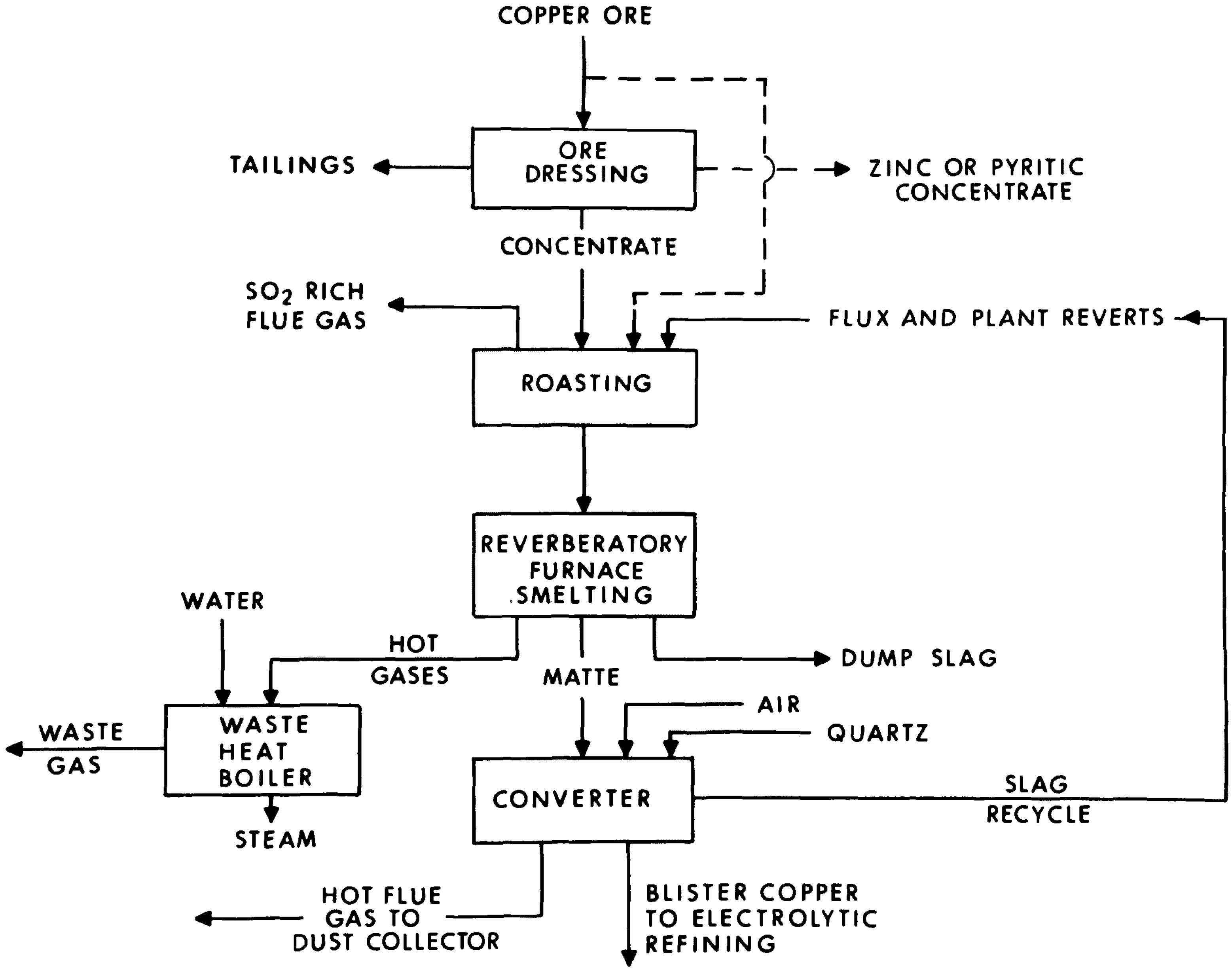

FIGURE 75

SCHEMATIC DIAGRAM OF SMELTING PROCESSES

45% Cu content. This is then taken to the converter where the iron is oxidized and withdrawn as a slag, after which the sulfur is oxidized to SO_2 and discharged as a gas.

Each of the smelting steps is described in more detail in the following paragraphs.

ROASTING

Roasting of dried ore concentrate prior to reverberatory furnace smelting is not as widely practiced now as it was in the past. Over the past 30 years, a trend toward discontinuing roasting and feeding "green" concentrates directly into the reverberatory furnace resulted in shutting down most roasting furnaces. However, there has been a reversal in this trend, and a number of new roasting processes as well as processes of new design have been started up recently(4).

Roasting is basically involved with heating the ore concentrate to a temperature below the melt point in order to drive off some of the sulfur as sulfur dioxide. This is a useful step in adjusting the sulfur content of the concentrate so that the reverberatory furnace product will be optimized. Several other advantages of roasting are:

1) the ore is dried and conditioned so as to minimize handling problems

2) the roaster permits easy arsenic and antimony removal

3) some oxidation of iron and copper improves iron removal in the reverberatory furnace.

ROASTING PROCESS DESCRIPTION

Roasting has been done mainly in multiple hearth roasting furnaces known as Nichols-Herreshoff or MacDougall furnaces, and in fluidized solids devices such as that used in the Fluo Solids Process.* These furnaces contain a series of circular hearths, arranged one above another. The solid ore is moved from the outer edge of the top hearth toward the center by rotating "rabble arms" supported by a central shaft. At the center of the hearth, the ore falls through an opening onto the next hearth down, where it is raked toward the outside. Eight to 12 hearths are provided in conventional roasters. Figure 76 shows a schematic drawing of a multiple hearth roaster.

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*Registered trademark of the Dorr Company

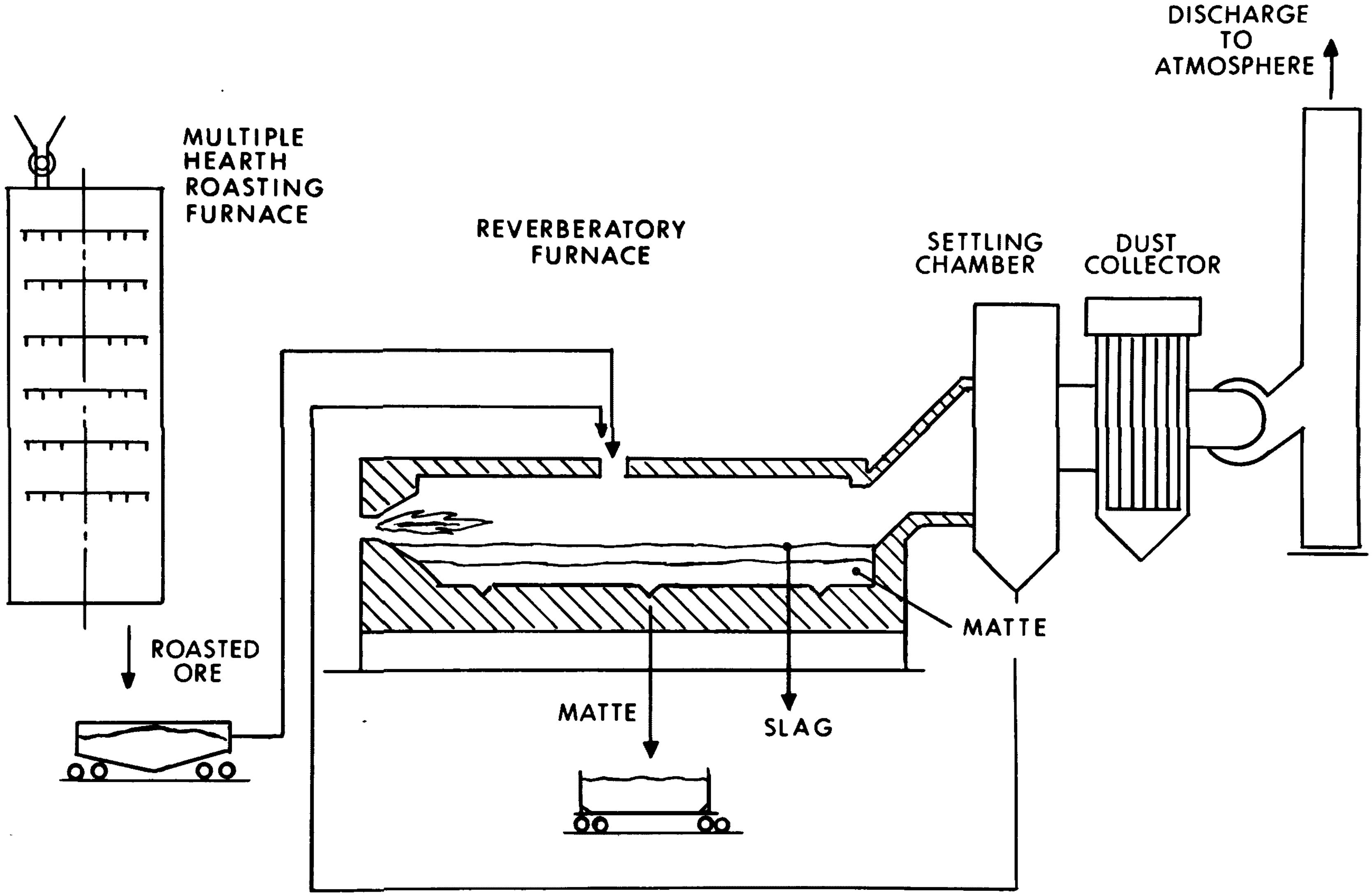


FIGURE 76

MULTIPLE HEARTH ROASTER

These units are fed with cold concentrate and gradually raise the temperature to 1400°F or so. Heat may be supplied by burners installed beneath any hearth level although firing beneath the lowest hearths only is most common. "Autogenous roasts" where the heat requirements are supplied entirely by the heat of oxidation of sulfur to SO_2 can be made at sulfur contents of about 24 wt. % and higher. Even then, heat generated by gas or oil burners is required to bring the roaster up to temperature.

Multiple hearth roasting has been largely discontinued, and the fuel, maintenance and air pollution control costs associated with the operation of these furnaces eliminated. This has been made possible by the improvement of concentration processes, which produce a rich enough green concentrate for charging directly to the reverberatory furnace.

The air pollution problems in reverberatory furnace smelting are increased by the omission of the roasting step because the SO_2 ordinarily discharged from the roaster must be discharged from the reverberatory furnace. The roaster is basically a more efficient heating device, and produces a more concentrated SO_2 product than the reverberatory furnace. A typical roaster operates with flue gas at 400 to 600°F and an SO_2 content of 3 to 10% by volume, whereas the flue gas from a reverberatory furnace is about 2300°F and 1 to 2 volume % SO_2.(1), (4)

Where no SO_2 abatement is practiced, it is obvious that the lower concentrations and higher temperatures produced by the reverberatory furnace result in better dispersion of SO_2 into the atmosphere. However, when minimizing SO_2 emission or recovering the sulfur values is an objective, the advantage lies clearly with the lower temperatures and higher concentrations produced in roasting.

This is the principal reason for the resurgence of interest in roasting. The newer operations in which roasting is being used have tended toward use of a fluidized solids technique such as the Fluo Solids Process (a registered trademark of the Dorr Company). In this process, the concentrate is maintained in a fluidized bed by upflow of heated air. For those concentrates with sufficient sulfur content, the fluidized bed can be operated autogenously with minimum excess air, and SO_2 concentrations of about 15% can be achieved.(5) This provides an excellent feed gas for a contact sulfuric acid plant, and minimizes the cost of SO_2 abatement.

Much development work is proceding in the area of process modification to further reduce emissions of SO_2. This is aimed primarily at recovery of sulfuric acid from gas equivalent to that of the flash roaster, without the subsequent, difficult-to-treat emission from the reverberatory furnace.

NATURE OF GASEOUS DISCHARGE FROM ROASTERS

The gases leaving a roaster consist principally of air which has been modified by oxidation of fuel in the gas or oil-fired burners, followed by oxidation of some of the sulfur in the ore. The combination of these processes can be represented by the equations:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

and

$$Fe_2S + 2O_2 \rightarrow 2FeO + SO_2.$$

The relationship between heat requirement, oxygen content and effluent gas composition can be calculated for any combination of circumstances. The concentration of SO_2 is influenced by the amount of heat required as input to the burners, and by the efficiency of contacting the furnace gases with the charge. SO_2 concentrations somewhat lower than theoretical for the oxygen content are usually obtained.(6)

Some additional oxygen usage for oxidation of arsenic and other impurities can bring about higher ratios of SO_2 to oxygen than indicated by theoretical equations. However, calculations of this sort should produce results accurate enough for sizing pollution control equipment.

Gaseous Contaminants

In addition to these gaseous constituents, there may be enough SO_3 to cause acidic corrosion problems whenever the gas temperature is reduced sufficiently to produce liquid condensate. This probably arises from the following sequence of reactions:

$$Fe_2S + 2O_2 \rightarrow 2FeO + SO_2$$

$$2SO_2 + O_2 \xrightarrow{\text{Catalyst}} 2SO_3$$

Roaster operations take place at a low enough temperature to favor formation of sulfur trioxide, but there is insufficient residence time or available catalyst to convert more than 1 to 3% of the SO_2 to SO_3.(6)

There may also be traces of HCl and HF from the decomposition of halogen bearing minerals such as fluorite or fluorapetite rock, present as gangue in the roaster charge. These are most objectionable because of the severe corrosion problems generated when these acids co-absorb with SO_3 to form halogen contaminated strong acids.

Particulate Contaminant

The roaster gases contain substantial concentrations of dust, produced mechanically by the handling of the concentrate as it is dumped into the roaster, pushed around each hearth and dumped from hearth to hearth. In addition, there is some formation of SO_3 which combines with water vapor at temperatures below about 400°F to form sulfuric acid mist. This mist is of very small particle size, and is more difficult to remove by mechanical means than is the dust.

In order to clean the gas sufficiently for charging to a contact-type sulfuric acid plant, the particulate material must be removed to prevent plugging the catalyst bed, and also to minimize contamination of the product acid. H_2SO_4 mist must be removed to prevent corrosion and plugging in the "front end" of the acid plant. Also any acid mist formed will pass through the converters and absorbers.

The particulate contaminants vary in composition with the specific ore in question. Common constituents are arsenic, antimony, mercury, and lead, which appear as oxides in the roaster effluent. Upper limits(6) for contamination of the gas stream may be estimated on the assumption that all of the contaminants appear in the product acid. These are shown below.

SO_2Content, Vol. % of Dry Gas	7	9
	Solids Content	gr/DSCF
Chlorides as Cl	0.055	0.071
Fluorides as F	0.011	0.014
Arsenic as As_2O_3	0.087	0.11
Lead as Pb	0.087	0.11
Mercury as Hg	0.0011	0.014
Selenium as Se	0.044	0.056
Total Solids	0.44	0.56

GAS CLEANING EQUIPMENT

The treatment of roaster gases for particulate removal is practiced whether or not the gases are processed for the removal of sulfur. However, the high concentration and low gas temperature usually require some form of sulfur dioxide removal before discharge into the atmosphere.

Sulfuric acid plants are capable of bringing about SO_2 removal at efficiencies as high as 99.5%, while manufacturing 98 wt. % sulfuric acid of salable quality.(6) This approach has been used on most roasters now in operation.

The roaster effluent must be treated to remove coarse dust, fine dust, gaseous halogens, SO_3 in particulate and gaseous form, and water vapor before it is acceptable for charge to a contact sulfuric acid plant. One of several possible schemes for treatment is shown in Figure 77.

Coarse dust is most often removed by a large mechanical collector or settling chamber or a combination of the two. The dust is returned to the process – usually by way of the reverberatory furnace – and this collection step is ordinarily treated as a part of the process rather than as a gas cleaning operation. Precipitators may be used instead of the mechanical collector in special cases.

The removal of halogen gases, part of the particulate solids and some of the SO_3 is accomplished in a wet scrubber. This may be located after the precipitator, but it is customary to minimize the dust loading to the precipitator by using the flow scheme shown. The scrubber is ordinarily a "medium-energy" impingement tray type in which jets of gas impinge on wetted baffles.

The scrubber can build up a substantial concentration of sulfuric acid if the scrubbing liquor is recycled. This can cause severe corrosion problems in the scrubbing circuit, even when stainless steel is used throughout, if there is much chloride or fluoride present. In order to avoid this problem, the acid concentration is limited by withdrawing acid and adding fresh water make-up to the system. Acid concentrations from less than 3 wt. % to over 30 wt. % have been used.(6) Concentrations in excess of 10 wt. % have led to corrosion problems in the field.

The precipitator following the scrubber serves mainly to remove sulfuric acid mist and also to do the final cleanup of particulate matter. This is of very small particle size and is not effectively removed by medium-energy scrubbers. The mist precipitator collects the acid mist as a relatively concentrated liquid – up to 60 or 70 wt. %. The precipitator needs no rappers, of course, because the tubes are washed by the acid as it runs down into a collection sump at the bottom. The entire unit must be designed to withstand acidic corrosion. In addition to the mist, some residual dust will, of course, be collected. This material becomes a contaminant in the product, and reduces the desirability of the dilute acid. In some areas it may be salable for pickling or other applications where high strength and purity are not important.

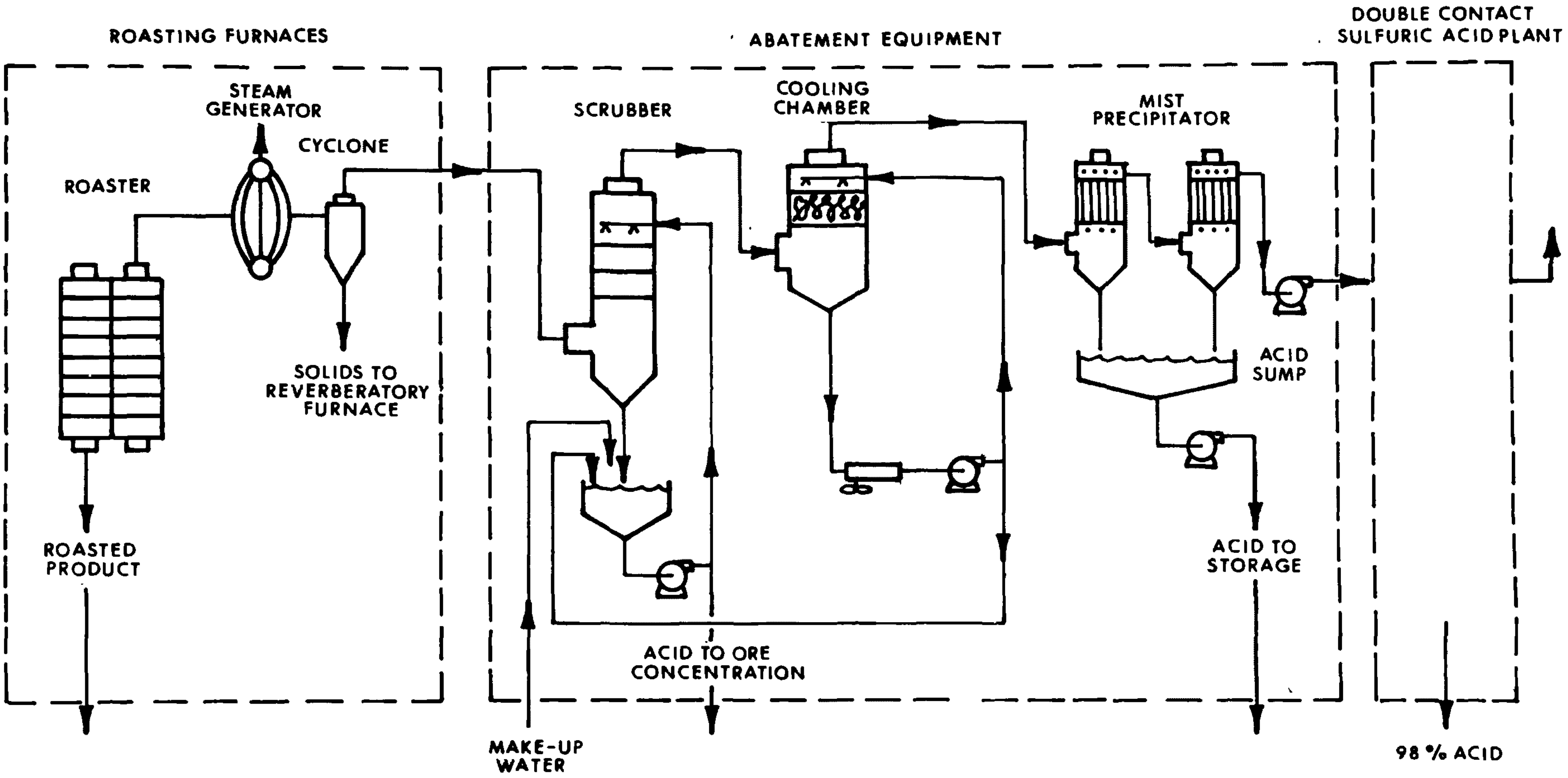


FIGURE 77

SCHEMATIC DRAWING OF ROASTER GAS CLEANING SYSTEM

The precipitator must remove acid mist to a low enough level that it will not be troublesome in the sulfuric acid plant. One stage of precipitation (one electrical field in the direction of gas flow) may be satisfactory but a conservative design will require two fields in order to minimize the effect of an electrical failure.

At elevated temperatures, the ratio of water to SO_2 in the gas stream is likely to be too high to allow the production of concentrated acid. For this reason it is customary to cool the gases. The cooling can be done in the scrubber by evaporation or in a contact cooling chamber located between scrubber and precipitator. The temperature required may be calculated on the basis of the chemistry taking place in the acid plant. For example, to produce 98 wt. % sulfuric acid at 99% efficiency, the combining proportions are:

$$SO_2 + ½O_2 + H_2O \rightarrow H_2SO_4$$

$$64\text{ lb} + 16\text{ lb} + 18\text{ lb} \rightarrow 98\text{ lb}$$

for 100% acid, or

$$64\text{ lb} + 15\text{ lb} + 20\text{ lb} \rightarrow 100\text{ lb}$$

for 98% acid. The ratio of water vapor to reacted acid is (20/64) provided all of the SO_2 is converted to acid. If only 99% of the SO_2 is converted but all of the water is, then the allowable weight ratio of water to acid is reduced to 0.99 x (20/64) = 0.31/1, or a volume ratio of (64/18) x 0.31 = 1.11.

For a gas stream containing 9 volume % on a dry basis, the water content can be 9 x 1.11 = 10 volumes per 100 volumes of dry gas. This corresponds to a saturation temperature of about 110°F at sea level.

REVERBERATORY FURNACE SMELTING

Reverberatory furnace smelting is an essential step in the production of most of the copper mined in the U.S. Either calcine from a roaster or green concentrate is charged to the reverberatory furnace. Molten slag and a molten product called "matte", containing the copper, iron and residual sulfur are produced. The reverberatory furnace accomplishes several functions,(2) which include:

(1) melting the minerals

(2) separation of valuable minerals from the gangue

(3) final adjustment of sulfur content of the matte for charging to the converter

(4) removal of precious metals from the gangue by extraction with the liquid matte.

The basic reverberatory smelting process is shown diagramatically in Figure 76 and Figure 78.

Roasted calcine or green concentrate is added to the reverberatory furnace from cars or belt conveyors located above and to the sides of the furnace. The solid is added at the sides and along the length of the furnace, as shown in Section A-A of Figure78.This forms a trough consisting of a pile of solid charge along either side of the furnace, with molten matte and slag toward the center.

The furnace is heated by gas or oil-fired burners located above the charge at one end and firing toward the other end. Pulverized coal firing is occasionally used. The heat produced by the burner flame is transferred to the molten slag and matte, and to a lesser extent to the solid charge, by convection and by radiation from the hot refractory arch and sidewalls.

As heat is transferred to the cold charge, moisture is released and some sulfur is driven off. At about 1650°F, the cuprous and ferrous sulfides begin to diffuse into one another, and at about 1800°F they melt to form liquid matte. This trickles down through the remaining solid charge and heats it. At the same time, silver, gold, arsenic, antimony, and other metallic impurities are dissolved in the matte.(3)

Matte forms continuously and is tapped at intervals from matte taps at the bottom of the hearth, along the length of the furnace. The slag floats on top and is skimmed through slag tap holes at the flue end of the furnace.

Although many of the operations such as charging, tapping matte and skimming are done intermittently, the process is basically continuous, with relatively stable firing of the burners and production of flue gas.

CHEMISTRY AND PHYSICS OF THE PROCESS

Reverberatory smelting involves a relatively complex set of reactions between copper, sulfur, iron and oxygen; simultaneously complex side reactions involving impurities such as precious metals, arsenic, antimony and other minerals are also going on. The basic Cu—Fe—S—O reactions are relatively

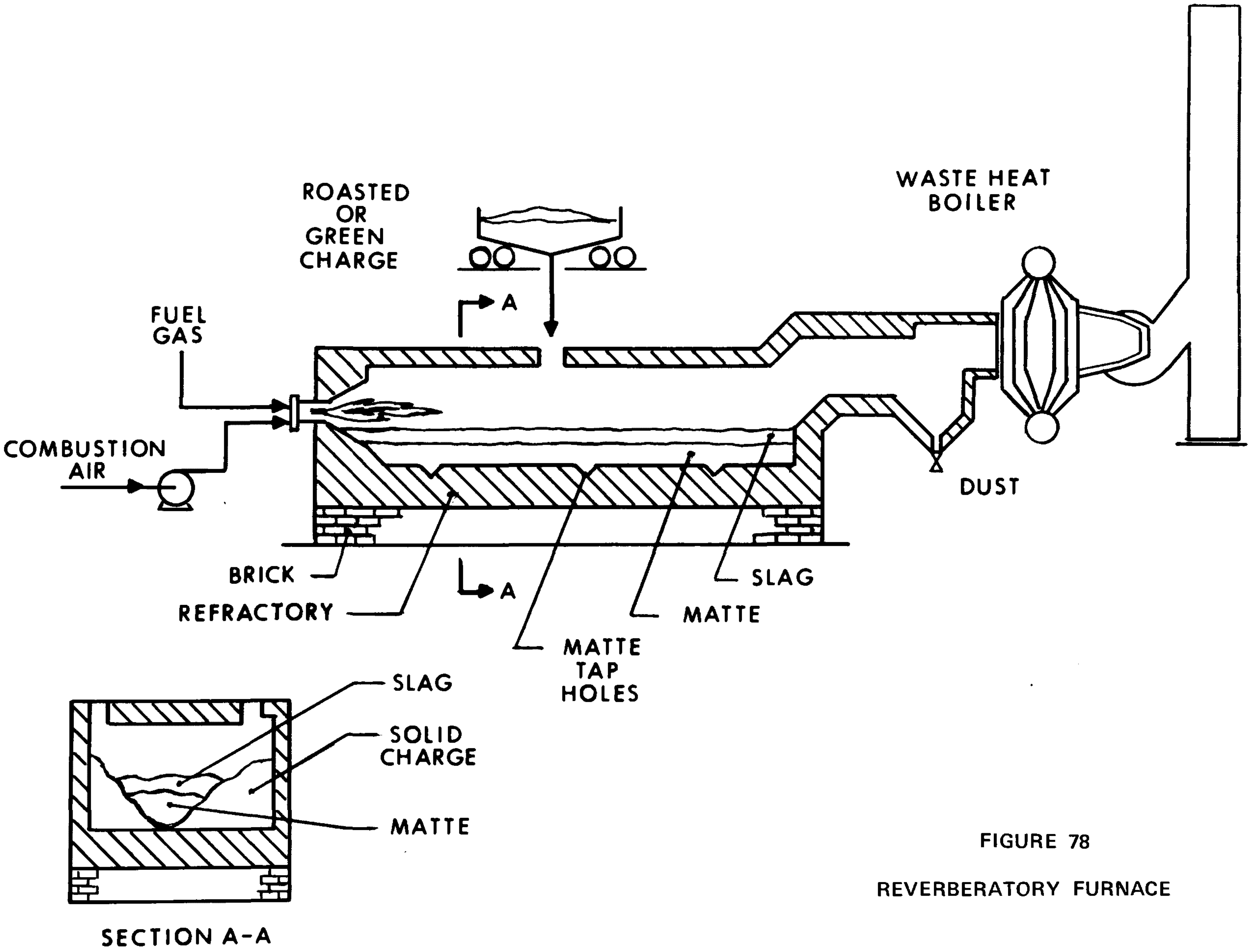


FIGURE 78

REVERBERATORY FURNACE

consistent from one smelter to another, while those involving impurities show great variability.

Ore is ordinarily charged to a reverberatory furnace in the green state, with a copper content of 15 to 30 wt. %.(2)

A green concentrate of chalcopyrite has approximately the following composition(1) of elements:

	Atomic Wt.	Wt. %
Cu	63.57	34.3
Fe	58	31.2
S	64	34.5
		100.0

In order for this to have 30 wt. % copper, it is necessary that diluent material (gangue) to the extent of 0.143 lb per pound of chalcopyrite, or 0.125 lb/lb ore be included.

Now, in the smelting furnace, the copper preferentially attaches itself to sulfur as cuprous sulfide, Cu_2S. Some of the sulfur is driven off as SO_2, and some remains with the iron as FeS. However, the temperature and oxygen content are sufficiently high that part of the iron is oxidized to FeO, and becomes more soluble in the slag than in the matte. The overall reactions might be represented in oversimplified form, as:

$$2CuFeS_2 + 2\frac{1}{2}O_2 \rightarrow Cu_2S + FeS + FeO + 2SO_2$$

This process produces a matte that is substantially free of gangue, and has between 30 and 50% copper content by weight. In order to reach 50% copper, about half of the iron charged, and half of the sulfur charged must be removed by the products of combustion, or with the slag.

Several reactions are important in the removal of iron from the matte without an inordinate amount of copper loss. Ferrous oxide (FeO) combines readily with silica or calcium silicate. For this reason both lime and silica are added to the reverberatory furnace as fluxes. Some magnetite (Fe_3O_4) may be present in the charge as an impurity, or may be formed by the oxidation of ferrous oxide. This dissolves readily in the slag, and tends to cause high solubility of copper in the slag. Magnetite has several other undesirable effects.(2)

GASEOUS EFFLUENT FROM THE PROCESS

The flue gas produced by a reverberatory furnace is relatively rich in CO_2 and water because of combustion of the fuel, and little of the oxygen is used for combustion or replacement of sulfur. Typically, the flue gas contains around 13% CO_2 and only 1½% SO_2.(4) The reactions involved in the generation of the flue gas are summarized below.

Combustion:

$$CH_4 + O_2 + N_2 \rightarrow CO_2 + H_2O + O_2 + N_2$$

oxidation of sulfur, iron:

$$O_2 + CuFeS_2 \rightarrow Cu_2S + FeS + FeO + SO_2.$$

H. Lanier(2) gives the composition limits for reverberatory furnace effluent gases as follows:

	Volume %	
	Minimum	Maximum
O_2	5	6
N_2	72	76
CO_2	10	17
H_2O	4	10
CO	0	0.2
SO_2	1	2

The composition may be derived on a theoretical basis for any given oxygen and SO_2 content in the flue gas by presuming that the only reactions which take place will be:

$$(CH) + 1\tfrac{1}{4}O_2 \rightarrow CO_2 + \tfrac{1}{2}H_2O \qquad \text{(using coal for example)}$$

and

$$\text{Ore} + 2\tfrac{1}{2}O_2 \rightarrow \text{slag} + \text{matte} + 2SO_2.$$

A material balance such as that shown in Table 100 may be prepared. This gas composition falls into the range indicated. However, most reverberatory furnaces are now gas fired, and the combustion products are likely to be much wetter and contain less CO_2. Table 101 illustrates a calculation of flue gas composition for a gas-fired furnace. Fuel oil fired furnaces should fall between these limits. It appears that the fuel composition should have a more

TABLE 100

CALCULATED COMPOSITION OF REVERBERATORY FURNACE FLUE GAS

(from coal burning)

	Mol/100 Mol Air						
	Air	Fuel	Burner Reaction	Combustion Products	Smelting Reaction	Furnace Flue Gas	Vol. %
O_2	20.8	–	–12.6	8.2	–2.0	6.2	6.1
N_2	79.2	–	–	79.2	–	79.2	77.6
CO_2	–	–	+10.0	10.0	–	10.0	9.8
H_2O	–	–	+ 5.0	5.0	–	5.0	4.9
SO_2	–	–	–	–	+1.6	1.6	1.6
(CH)	–	10.0	–10.0	–	–	–	–
	100.0	10.0	– 7.6	102.4	– 0.4	102.0	100.0

TABLE 101

CALCULATED COMPOSITION OF REVERBERATORY FURNACE FLUE GAS

(from gas burning)

Mol/100 Mol Air

	Air	Fuel	Burner Reaction	Combustion Products	Smelting Reaction	Furnace Flue Gas	Vol. %
O_2	20.8	–	–12.2	8.6	–2.1	6.5	6.1
N_2	79.2	–	–	79.2	–	79.2	74.2
CO_2	–	–	+ 6.1	6.1	–	6.1	5.7
H_2O	–	–	+12.2	12.2	–	12.2	11.4
SO_2	–	–	–	–	+1.7	1.7	1.6
CH_4	–	6.1	– 6.1	–	–	–	–
	100	6.1	0.0	106.1	– 0.4	105.7	99.0

pronounced effect on flue gas composition than indicated in the literature.

The rate of flue gas production by a given furnace varies with the type of fuel, the excess air (or oxygen content of the flue gas) and the rate of heat generation.

Typically, a reverberatory furnace may have the following fuel requirements:(2)

coal	275 – 400 lb/ton of charge
oil	0.5 – 1.5 bbl/ton of charge
fuel gas	30 – 80 therm/ton of charge

These values represent heat requirements between about 3 and 8 million BTU/ton of charge. If one presumes gas firing with a flue gas composition as given in Table 2, 105.7 mols of flue gas are produced per 6.1 mols of natural gas. At a value of 5 MMBTU/ton charge and 970 BTU/SCF, the furnace should produce

$$\frac{5{,}000{,}000}{970} \times \frac{105.7}{6.1} = 89{,}000 \text{ SCF/ton charge}$$

or, on the basis of a 30% Cu charge and 45% product, the value of

$$89{,}000 \times \frac{45}{30} = 134{,}000 \text{ SCF/ton matte}$$

should be applicable. Corresponding numbers can be derived for other fuels, oxygen contents, etc.

PARTICULATE CONTAMINANTS

Reverberatory furnaces charge several powdered or granular materials which may become suspended in the flue gas and create a dust emission problem. These are:

1. fresh concentrate or calcine
2. lime
3. silica

The dusts are relatively coarse and are removed to a considerable extent by gravity settling within the furnace, settling within the waste heat boiler, or collection in cyclone collectors. Dusts collected in these locations may contain as much as 25% copper(2) and collection improves the overall process economy.

Fumes, on the other hand, consist mainly of high vapor pressure impurities which have vaporized out of the matte, and recondensed as tiny oxide particles. Arsenic, antimony, lead, and zinc are common fume-forming materials. Sulfur trioxide, formed to the extent of perhaps 1 to 3% of the SO_2 produced, and carbonaceous smoke produced by improper combustion may also be contributors to the fume loading. Also considerable lime may be present.

Fume-like materials settle only to a limited extent, and most of the effort to limit particulate air pollution must be directed toward these materials. For purposes of this discussion, it may be assumed that a typical reverberatory furnace produces a flue gas with about 1½% SO_2 by volume, and that this concentration is too low for economical recovery of the sulfur values as H_2SO_4. The gas discharge from the furnace must be treated to remove the fume-like materials to a suitable degree for discharge into the atmosphere.

POLLUTION CONTROL CONSIDERATIONS

Reverberatory furnaces are ordinarily equipped with steam generators to recover heat from the flue gases. The combination of the waste heat boiler and a tall stack for SO_2 dispersal allows for natural draft ventilation of the furnace when there is no air pollution control equipment.

Installation of an electrostatic precipitator for particulate control may be made without the installation of an induced draft fan. However, any application of scrubbers or filters, and many precipitator applications will require the installation of an induced draft fan to offset the pressure losses in the abatement equipment. The application of induced draft fans allows a higher degree of control of the furnace draft, and provides for minimum outleakage of hot, contaminated flue gases prior to cleaning.

Common practice is to install flue gas cleaning equipment which handles only the gases passing through the steam generator. Dusting, which occurs as concentrate, lime and other solids are added to the furnace, is held to a minimum by the design of the hoppers and conveyors and frequently by the processing of these materials while they are still wet. The charging system is designed to minimize air infiltration into the furnace, and the "closed-in" design also helps minimize dusting problems.

The slag tapping and matte withdrawal produce some fume which is released into the building. This fume is not sufficiently troublesome to require hooding of the matte taps, slag taps, launders or ladles.

The dust collected from the copper reverberatory furnace flue has a definite economic value. The dust consists of copper concentrate, fluxes and partially smelted materials. Ordinarily, the collected material may be returned directly to the reverberatory furnace for resmelting. Very fine dusts may require sintering before re-addition to the furnace. Some furnaces produce particulate materials too rich in arsenic, antimony or other impurities to be returned to the furnace without chemical treatment.

There may be a significant difference in composition between the coarse dust — produced by mechanical action in the furnace — and the fine fume which is generated by vaporization of such volatile metals as antimony and zinc. The coarse material may contain as much as 25% copper by weight, and be suitable for direct addition to the furnace, whereas the fume is likely to be low in copper content, and have a high fraction of objectional volatile metals. It is customary to make a crude separation between these two by providing large "balloon flues" which serve as settling chambers for the coarse dust, and minimize the "catch" in the final gas cleaning device.

APPLICABLE EQUIPMENT TYPES

Electrostatic precipitators were originally developed in the 1890's to solve the fume problem produced by copper smelters. These devices have many advantages when processing hot gases at high flow rates. These include:

1. minimal gas moving equipment
2. low operating cost
3. freedom from corrosion problems
4. ability to capture fine fume particles
5. production of a dry solid.

Wet scrubbers have been used for fume collection on reverberatory furnaces. Although they require a substantial pressure drop — with the attendant operating cost — to produce satisfactory performance, they offer some advantages. These include:

1. production of a wet slurry (which is advantageous if wet chemical operations follow)

2. the scrubber does not require careful control of gas temperature or humidity, as does the precipitator

3. first cost is relatively low.

Offsetting these advantages are three disadvantages.

1. When used for cooling purposes, scrubbers exhibit high water consumption.
2. Corrosion and maintenance costs can be high.
3. Scrubbers produce steam plumes.

For the purposes of this study, both approaches have been included in the specifications and cost comparisons.

SPECIFICATIONS AND COSTS

The copper roasting furnace gas cleaning system as described in the specifications in Table 102 differs from all the other applications covered by this study, in that it covers only a part of the air pollution abatement system. The complete system is comprised of the gas cleaning equipment described and a sulfuric acid manufacturing plant for the removal of SO_2 from the gas stream. The gas cleaning equipment serves to clean the gas sufficiently to keep the sulfuric acid plant catalyst clean and to produce the proper temperature and humidity to yield the desired acid strength. The system specified describes a multiple hearth roaster, but should be applicable to fluidized bed roasters at similar SO_2 levels.

This portion of the system is included in the study to procure costs for the precleaning equipment to add to costs for sulfuric acid plants already assembled by the EPA.

The equipment described serves to remove entrained dust in an impingement scrubber; then the moisture content of the gas stream is reduced by direct contact cooling so the acid produced will not contain too much water diluent. Finally the sulfuric acid mist present in the gas stream must be removed at near 100% efficiency to prevent "front-end" corrosion in the acid plant and damage to the catalyst bed.

It is customary for the entire train to be quoted by the precipitator manufacturer, as though the scrubber and cooler were auxiliaries to the precipitator. In this case, the quotations were prepared for the complete train installed as a system.

The precipitator for this application is of the vertical tubular variety, quite different in design from the more conventional plate-type precipitators used in dry applications. In particular, when two or more independent fields are specified, as is the case here, it is necessary to provide two separate housings, or in effect, two separate precipitators. Two housings, connected by lead ductwork were quoted for both efficiency levels. For plate-type precipitators, a single casing can house two or more fields.

It should be noted that a single efficiency level was specified for this section. This efficiency was chosen to protect the sulfuric acid plant and has no relationship to the level of pollution abatement.

Copper reverberatory furnaces produce an effluent contaminated with particulate matter and SO_2. Because of the low SO_2 concentration, the economics of SO_2 removal are very unattractive; it is not customary to equip reverberatory furnaces with sulfuric acid plants. Particulate collection by either electrostatic precipitator or wet scrubber is common, however.

In this section, specifications are written for precipitators (Tables 106 and 107) and alternatively for wet scrubbers (Tables 110 and 111). The capital costs submitted in response to these specifications are given in Table 108 for the precipitators and 112 for the scrubbers. These costs are plotted in Figures 81 and 83. It is apparent that the first costs for the precipitators are higher than those for scrubbers regardless of size or efficiency level. However, when operating costs, listed in Tables 109 and 113 and plotted in Figures 82 and 84, are taken into account, the positions are reversed.

The costs submitted by the member companies correspond to new or "grass roots" construction, in which none of the problems of backfitting to an existing process exist. The same equipment, installed in an old plant, might cost considerably more because of the greater complexity of ductwork, plot restrictions, etc.

TABLE 102

COMBINED GAS CLEANING SYSTEM

PROCESS DESCRIPTION FOR COPPER ROASTING FURNACE SPECIFICATION

The gas cleaning system is to serve a group of Herreschoff multiple hearth roasters which reduce the sulfur content of a chalcopyrite ore concentrate from 32 wt. % sulfur to 20 wt. % sulfur. The furnaces are equipped with a waste heat boiler which reduces the flue gas temperature to 400°F, followed by mechanical dust collectors which effectively remove dust particles 20 μ and larger. The coarse dust is conveyed to the reverberatory furnace for smelting.

The specification covers two plant sizes. The "small" plant consists of three, one hundred ton/day Herreschoff 10-hearth roasters operated in parallel. The equipment must be capable of satisfactory performance at the design flow rates specified, and with one furnace out of service. The "large" plant consists of four, two hundred ton/day furnaces.

The mechanical dust collector outlet will be located at elevation +40 ft relative to grade. The air pollution abatement system will begin at this point and will include all of the equipment, auxiliaries, etc., thru the discharge from the cooling tower. The gases will be piped into a new sulfuric acid plant by others. The major equipment items include:

1. *A scrubbing tower*
2. *A cooling tower*
3. *An electrostatic mist precipitator*

Each piece of equipment is described in the following paragraphs, and in the table of operating conditions. The ductwork run from the mechanical collector outlet to the scrubber inlet is of minimum length, and may be constructed of 316L stainless steel.

Scrubber

A single impingement type (or other suitable non-plugging) scrubber is to be supplied. The scrubber is to remove particulate materials and soluble fluoride and chlorides each at approximately 95% efficiency. Recirculated liquor is to be maintained at approximately 3 wt. % sulfuric acid. Net liquid is to be discharged into the ore concentration unit, from which it will be recycled into the reverberatory furnace.

The scrubber is to be constructed of type 316L stainless steel or Alloy 20 throughout. The scrubber is to be equipped with a recycle pump suction tank with automatic make-up water control. Net solids-bearing effluent from the recycle pump discharge is to be maintained by a density control instrument. Pumps, piping, etc. shall be either type 316L stainless steel or rubber-lined carbon steel. FRP piping may also be used.

The scrubber is to be equipped with emergency flush water connections, so that the interior may be washed down with fresh water in the event of recycle pump or general electric power failure.

Cooling Chamber

The effluent from the scrubber shall pass through a cooling tower designed to reduce the gas temperature from 140°F to approximately 105°F, and to accomplish an equivalent reduction in moisture content. The cooling tower shall be constructed of 304L stainless steel. Ceramic saddles or other acid resistant packing material is suitable for this service.

The cooling chamber shall produce an effluent with less than 1 gr/DSCF entrained water.

The cooling chamber shall be complete with fin-tube air cooler operating between 125°F and 95°F. Provision shall be made to hold the normal circulating water inventory of the system plus the accumulation of condensate over a 4 hour period. Condensate shall be discharged into the scrubbing section on automatic control. Pumps shall be acid resistant construction (either 316L stainless steel or rubber lined carbon steel). All concrete, metal and other wetted parts shall be able to withstand contact with dilute sulfuric acid of 1/2 of 1 wt.% concentration.

Precipitator

The electrostatic mist precipitator is to be designed for wet acid service. The precipitator is to collect substantially all of the sulfuric acid mist in the cooler effluent. At least two fields must be provided in the direction of gas flow in order to minimize the effect of an electrical failure. Interconnecting ductwork shall be lead or lead-lined.

Construction is to be acid resistant throughout. Acid concentrations up to 10 wt. % sulfuric acid must be acceptable at normal operating temperature. The precipitator shall be equipped with a sump capable of retaining acid mist accumulation for 8 hours.

The precipitator shall be equipped with an electrical interlock system such that no personnel access to any high voltage equipment can be made without first de-energizing and grounding all primary circuits. Test ports shall be provided for sampling inlet and discharge gases, and these shall not be located so as to permit accidental contact with high voltage equipment.

Installation

The contractor shall assume, for the preparation of his installation bid, that there are no serious space limitations,. and that adequacy of soil bearing pressures have been determined by tests. No unusual physical limitations or access restrictions exist in the area. As this equipment discharges into the sulfuric acid plant, no stack is required.

TABLE 103

COMBINED GAS CLEANING SYSTEM OPERATING CONDITIONS FOR COPPER ROASTING FURNACE SPECIFICATION

	Small	*Large*
Furnace feed rate, ton/day	*395*	*1,080*
Furnace product ton/day	*300*	*800*
Process weight, ton/hr	*16.8*	*45*
Effluent from furnace		
Flow, ACFM	*24,200*	*64,000*
Temp., °F	*500*	*500*
Gas Composition, vol. %		
$N_2 + A$	*79.1*	*79.1*
O_2	*3.4*	*3.4*
H_2O	*8.9*	*8.9*
CO_2	*0.4*	*0.4*
SO_2	*8.2*	*8.2*
	100.0	*100.0*
Flow, SCFM	*13,250*	*35,000*
Flow, DSCFM	*12,120*	*32,000*
Solids loading, lb/hr	*2,060*	*5,500*
Solids loading, gr/ACF	*10*	*10*
SO_3 *loading, lb/hr*	*300*	*825*
SO_3 *loading, gr/ACF*	*1.5*	*1.5*
Outlet from scrubber		
Flow DSCFM	*12,120*	*32,000*
Temp., °F	*140*	*140*
Moisture content, vol. %	*19.5*	*19.5*
Flow, ACFM	*16,800*	*45,000*
Dust loading, lb/hr	*100*	*275*
Dust loading, gr/DSCF	*0.1*	*0.1*
Efficiency, %	*95*	*95*
Gas to cooling chamber		
Flow, ACFM	*16,800*	*45,000*
Temp., °F	*140*	*140*
Moisture, vol. %	*19.5*	*19.5*
Flow, DSCFM	*12,120*	*32,000*
Gas from cooling chamber		
Flow, ACFM	*14,350*	*37,900*
Temp., °F	*105*	*105*
Moisture, vol. %	*9.1*	*9.1*
Flow, DSCFM	*12,120*	*32,000*

Gas from precipitator		
Dust loading, lb/hr	*0.05*	*0.137*
Dust loading, gr/DSCF	*0.005*	*0.005*
Dust loading, gr/ACF	*0.004*	*0.004*
Dust removal efficiency, %	*99.95*	*99.95*
H_2SO_4 *mist loading, lb/hr*	*0.72*	*2.0*
H_2SO_4 *mist loading, gr/ACF*	*0.06*	*0.06*
H_2SO_4 *mist removal efficiency, %*	*99.75*	*99.75*

TABLE 104
ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR COMBINED GAS CLEANING SYSTEM
FOR COPPER ROASTING FURNACE

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			24,200	64,000
°F			500	500
SCFM			13,250	35,000
Moisture Content, Vol. %			8.9	8.9
Effluent				
gr/ACF Solids			10	10
gr/ACF Mist			2,060	5,500
Cleaned Gas Flow				
ACFM			14,350	37,900
°F			105	105
SCFM (Dry)			12,120	32,000
Moisture Content, Vol. %			9.1	9.1
Cleaned Gas				
gr/ACF Solids			0.06	0.06
gr/ACF, Mist			0.72	2.0
Cleaning Efficiency, % Solids			99.75	99.75
Mist				
(1) Gas Cleaning Device Cost			183,670	401,040
(2) Auxiliaries Cost (a) Fan(s) (b) Pump(s) (c) Damper(s) (d) Conditioning, Equipment (e) Dust Disposal Equipment			51,600	93,550
(3) Installation Cost (a) Engineering (b) Foundations & Support (c) Ductwork (d) Stack (e) Electrical (f) Piping (g) Insulation (h) Painting (i) Supervision (j) Startup (k) Performance Test (l) Other			94,390	163,705
(4) Total Cost			329,660	658,295

TABLE 105
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR COMBINED GAS CLEANING SYSTEM
FOR COPPER ROASTING FURNACE

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator				-	-
Supervisor					
Total Operating Labor					
Maintenance					
Labor	$6/hr			780	780
Materials					
Total Maintenance				780	780
Replacement Parts					
Total Replacement Parts				1,750	2,450
Utilities					
Electric Power	$.011/kw-hr			10,697	22,493
Fuel				-	-
Water (Process)	$.25/M gal			4,379	11,096
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				15,076	33,589
Total Direct Cost				17,606	36,819
Annualized Capital Charges				32,966	65,830
Total Annual Cost				50,572	102,649

FIGURE 79
CAPITAL COSTS FOR COMBINED GAS CLEANING SYSTEM FOR ROASTING FURNACES

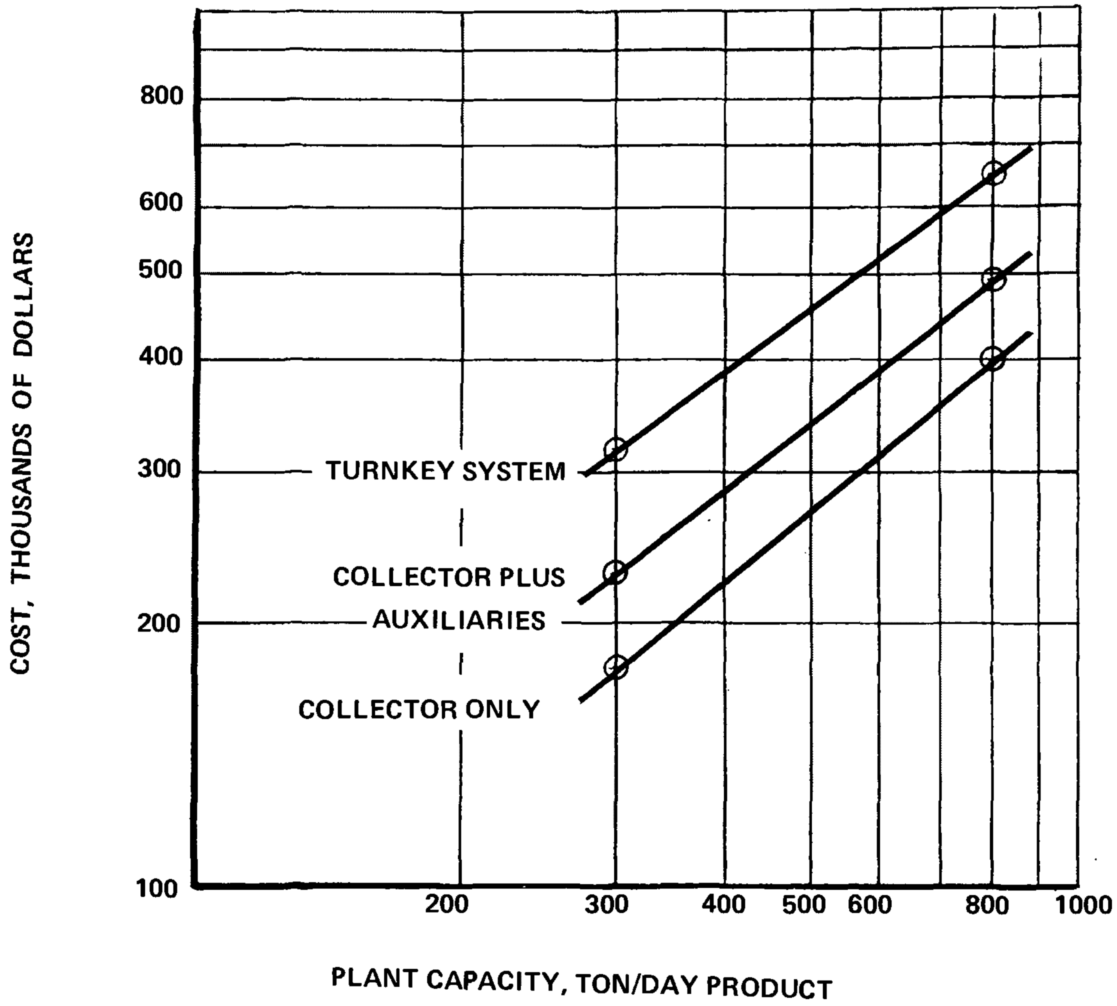


FIGURE 80
ANNUAL COSTS FOR COMBINED GAS CLEANING SYSTEM FOR ROASTING FURNACE

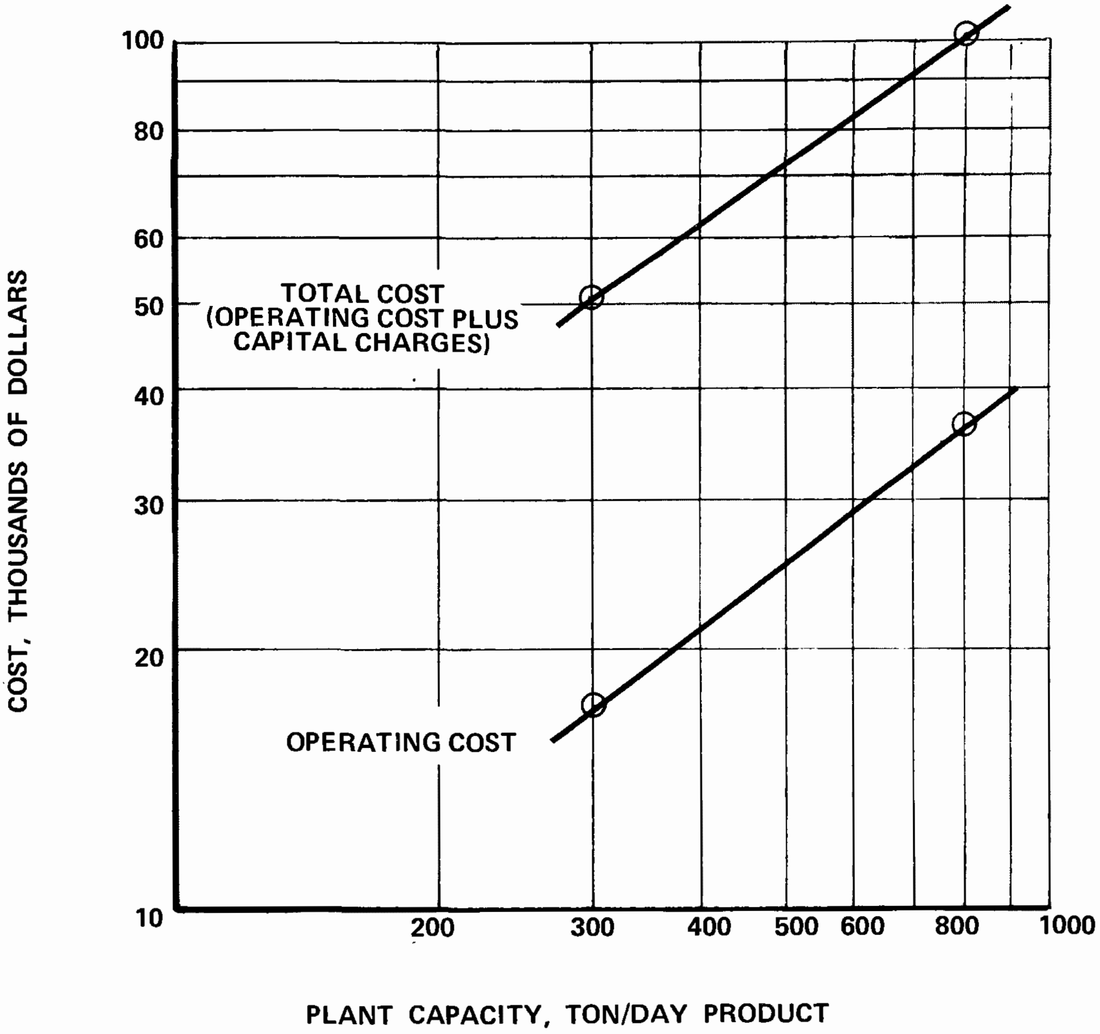


TABLE 106

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR COPPER REVERBERATORY FURNACE SPECIFICATION

The precipitator is to serve a pair of reverberatory furnaces in each case. Two sizes and two efficiency levels are specified. These should be considered as completely independent specifications and four separate quotations should be prepared.

In each case, the reverberatory furnaces process green concentrate plus several recycled materials such as flue dust and precipitate from other operations. The furnaces are equipped with a waste heat steam generator and a mechanical dust collector which effectively removes all particulate material larger than 20 μ in diameter. The flue duct is carried outside the smelting building wall at elevation +40 ft relative to grade. The precipitator, ID fan and stack are to be installed in an area without encumberances adjacent to the building at this point.

The precipitator is to remove the particulate matter to the degree specified during normal, sustained operation.

Provisions must be made for collecting and storing within the hoppers the dust generated during an 8 hour period. Hoppers shall be equipped with screw conveyors for continuously removing the dust for discharge onto a closed belt conveyor for return to the concentration plant, or shipment to a refining plant.

A single precipitator casing shall be supplied. Sectionalization of the precipitator shall be sufficient to allow operation at greater than 90% efficiency with any one section out of service. In each case it shall be assumed that a 100 foot stack will be provided as a part of the furnace contract, and that the precipitator contractor must tie into this duct.

TABLE 107

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR COPPER REVERBERATORY FURNACE SPECIFICATION

Four separate quotations should be prepared for the following conditions:

	Small	Large
Product (matte) production, ton/day (total for both furnaces)	400	1,000
Charge Materials, ton/day		
Green Concentrate (30% Cu, dry basis)	560	1,400
Copper Precipitate	20	50
Fluxes	60	150
Flue Dust	6	15
Converter Slag	220	550
	886	2,165
Gas Fuel Fired, SCFM	3,000	7,500
Process Weight, ton/hr	37	92.5
Effluent from Steam Generator		
Pressure, inches w.c.	–6	–6
Flow, SCFM	52,000	130,000
Temp., °F	600	600
Flow, ACFM	104,000	260,000
Composition, Mol %		
N_2 + A	77.6	77.6
O_2	6.1	6.1
CO_2	9.8	9.8
H_2O	4.9	4.9
SO_2	1.6	1.6
	100.0	100.0
Solids loading, lb/hr	2,700	6,800
Solids loading, gr/ACF	3.0	3.0
Case 1 – Medium Efficiency		
Outlet loading, lb/hr	40	40
Outlet loading, gr/ACF	0.045	0.018
Efficiency, Wt. %	98.5	99.4
Case 2 – High Efficiency		
Outlet loading, lb/hr	13.4	33.4
Outlet loading, gr/ACF	0.015	0.015
Efficiency, Wt. %	99.5	99.5

TABLE 108
ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	104,000	260,000	104,000	260,000
°F	600	600	600	600
SCFM	52,000	130,000	52,000	130,000
Moisture Content, Vol. %	4.9	4.9	4.9	4.9
Effluent Dust Loading				
gr/ACF	3.0	3.0	3.0	3.0
lb/hr	2,700	6,800	2,700	6,800
Cleaned Gas Flow				
ACFM	104,000	260,000	104,000	260,000
°F	600	600	600	600
SCFM	52,000	130,000	52,000	130,000
Moisture Content, Vol. %	4.9	4.9	4.9	4.9
Cleaned Gas Dust Loading				
gr/ACF	.045	.018	.015	.015
lb/hr	40	40	13.4	33.4
Cleaning Efficiency, %	98.5	99.4	99.5	99.5
(1) Gas Cleaning Device Cost	175,510	395,895	221,037	401,312
(2) Auxiliaries Cost (a) Fan(s) (b) Pump(s) (c) Damper(s) (d) Conditioning, Equipment (e) Dust Disposal Equipment	52,470	91,712	55,633	93,810
(3) Installation Cost (a) Engineering (b) Foundations & Support (c) Ductwork (d) Stack (e) Electrical (f) Piping (g) Insulation (h) Painting (i) Supervision (j) Startup (k) Performance Test (l) Other	206,887	385,206	269,923	409,587
(4) Total Cost	434,867	872,813	546,593	904,709

TABLE 109

ANNUAL OPERATING COST DATA

(COSTS IN $/YEAR)

FOR ELECTROSTATIC PRECIPITATORS

FOR COPPER REVERBERATORY FURNACES

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$6/hr	1,050	1,050	1,050	1,050
Supervisor	$8/hr	105	105	105	105
Total Operating Labor		1,155	1,155	1,155	1,155
Maintenance					
Labor	$6/hr	575	575	575	575
Materials		500	500	500	500
Total Maintenance		1,075	1,075	1,075	1,075
Replacement Parts					
Total Replacement Parts		4,250	7,500	5,250	7,500
Utilities					
Electric Power	$.011/kw-hr	3,443	6,831	3,443	6,831
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		3,443	6,831	3,443	6,831
Total Direct Cost		9,923	16,561	10,923	16,561
Annualized Capital Charges		43,487	87,281	54,659	90,461
Total Annual Cost		53,410	103,842	65,582	107,022

FIGURE 81
CAPITAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES

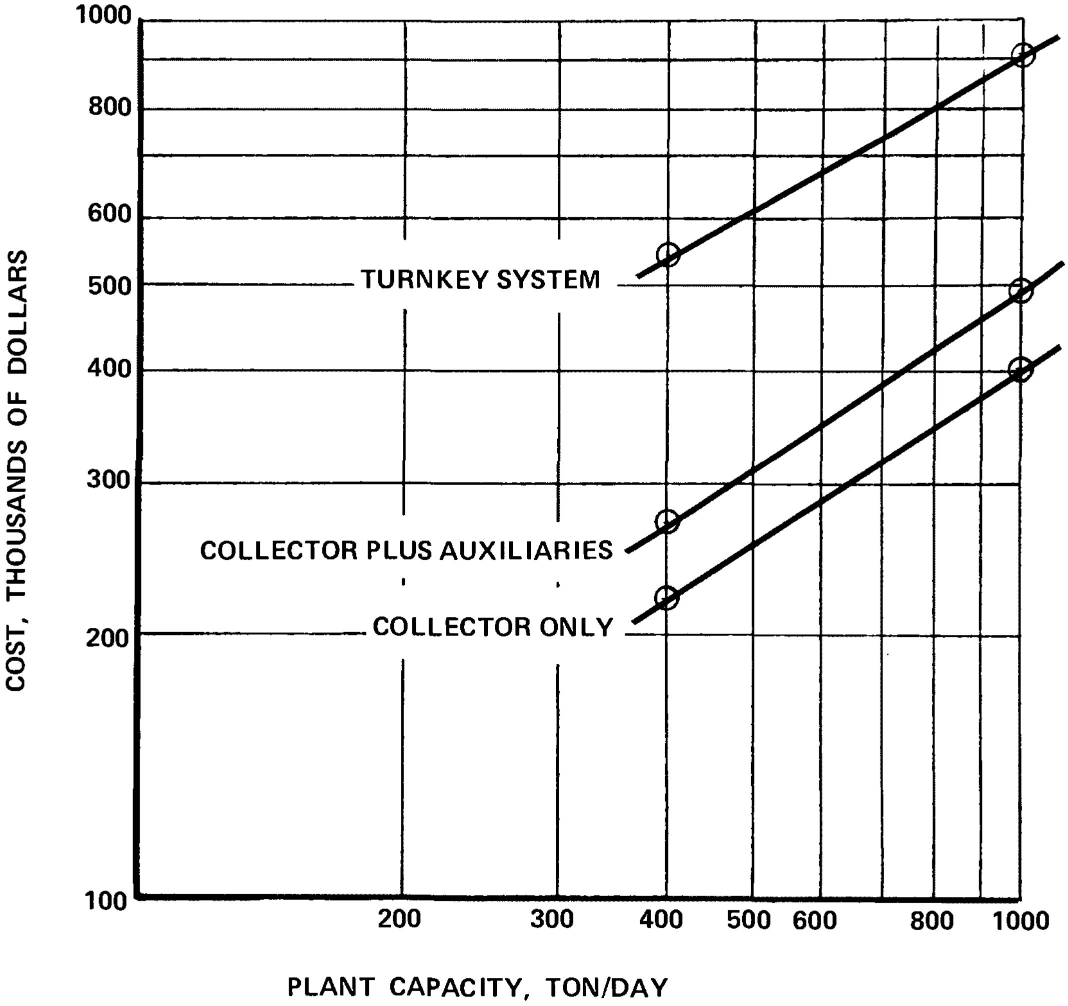


FIGURE 82
ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES

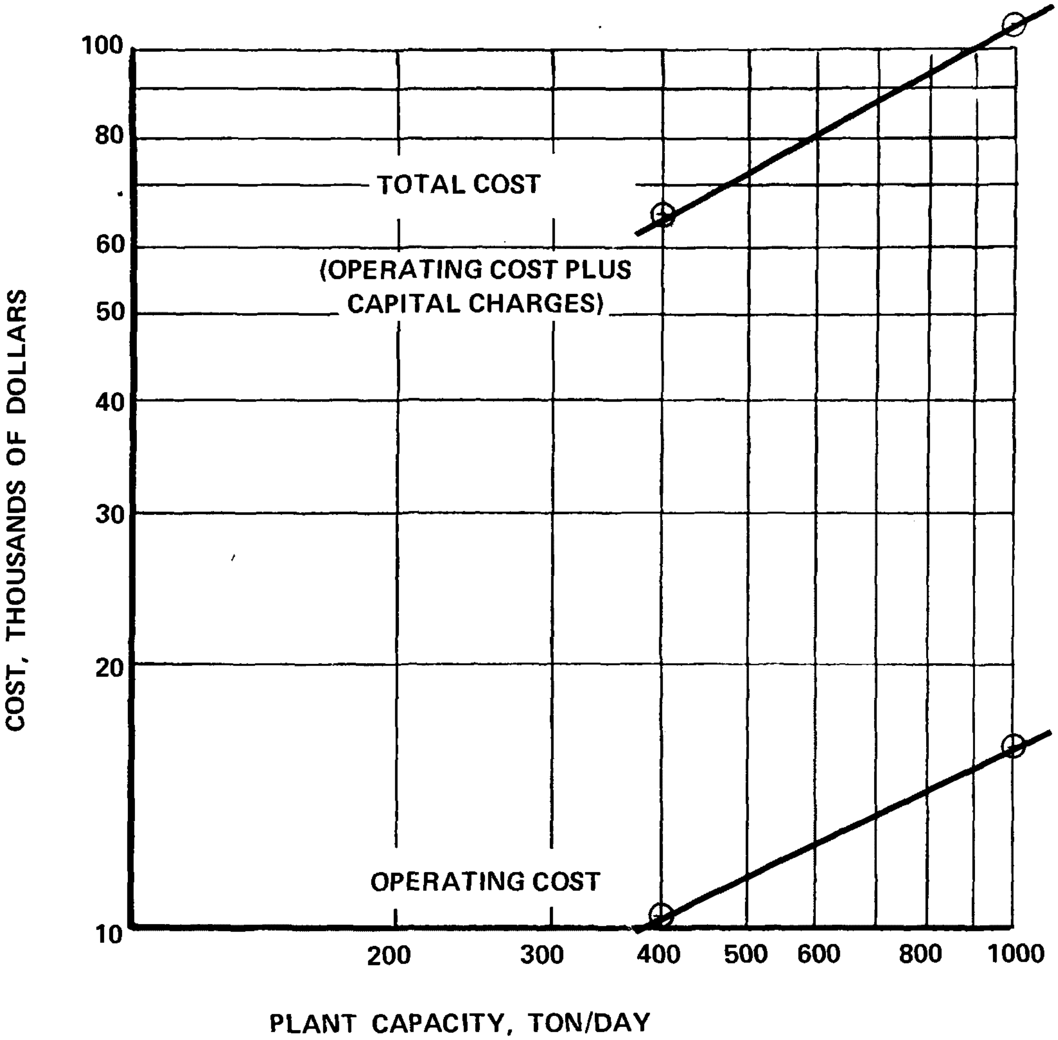


TABLE 110

WET SCRUBBER PROCESS DESCRIPTION FOR COPPER REVERBERATORY FURNACE SPECIFICATION

The scrubber system is to serve a pair of reverberatory furnaces in each case. Two sizes and two efficiency levels are specified. These should be considered as completely independent specifications and four separate quotations should be prepared.

In each case, the reverberatory furnaces process green concentrate plus several recycled materials such as dust and precipitate from other operations. The furnaces are equipped with a waste heat steam generator and a mechanical dust collector which effectively removes all particulate matter larger than 20 μ in diameter. The flue duct is carried outside the smelting building wall at an elevation +40 ft relative to grade. The scrubber, ID fan and stack are to be installed outside in an area without encumberances adjacent to the building at this point. The settling and filtering equipment to provide for a completely closed water system must also be located in an area adjacent to the smelting building, about 100 ft away from the flue duct exit.

The scrubber is to remove the particulate matter to the degree specified, and provide the recovered fines as a semi-dry solid containing no more than 40% moisture by weight. This material is to be returned by conveyor to the concentration plant. The vendor is to furnish the following items:

(1) Scrubber

(2) Reheat burner

(3) Fan

(4) Settling pond or clarifier

(5) Filter

(6) Necessary ductwork, piping, pumps, controls, etc.

(7) 200 ft stack for SO_2 dispersion

All of the wetted equipment shall be constructed of type 316L stainless steel, rubber, or other acid resistant materials. Installation and freeze protection suitable for -20°F operation shall be provided as required. The scrubber -- fan combination shall be capable of operation without exceeding the specified discharge weight at gas flows as low as 50% of the design rates specified. Adequate controls are to be provided to maintain a constant 0.5 inches w.c. draft at the steam generator inlet with gas flows between 50 and 110% of the normal flow specified.

A natural gas reheat burner to reheat the scrubber effluent approximately 100°F shall be provided to protect the fan, ductwork and stack from corrosion, and to provide for steam plume dissipation.

TABLE 111

WET SCRUBBER OPERATING CONDITIONS

FOR COPPER REVERBERATORY FURNACE SPECIFICATION

Four separate quotations should be prepared for the following conditions.

	Small	*Large*
Product (matte) production, ton/day (total for both furnaces)	*400*	*1,000*
Charge Materials, ton/day		
Green Concentrate	*560*	*1,400*
Copper Precipitate	*20*	*50*
Fluxes	*60*	*150*
Flue Dust	*6*	*15*
Converter Slag	*220*	*550*
	886	*2,165*
Gas fuel fired, SCFM	*3,000*	*7,500*
Process weight, ton/hr	*37*	*92.5*
Effluent from Steam Generator		
Pressure, inches w.c.	*−6*	*−6*
Flow, DSCFM	*49,500*	*124,000*
Temp., °F	*600*	*600*
Flow, ACFM	*104,000*	*260,000*
Composition, Mol %		
$N_2 + A$	*77.6*	*77.6*
O_2	*6.1*	*6.1*
CO_2	*9.8*	*9.8*
H_2O	*4.9*	*4.9*
SO_2	*1.6*	*1.6*
	100.0	*100.0*
Effluent from Scrubber		
*Pressure, psia**	*13.7*	*13.7*
Flow, DSCFM	*49,500*	*124,000*
Temp., °F	*137*	*137*
Flow, ACFM	*75,000*	*187,000*
Moisture, Vol. %	*20*	*20*
SO_2*, Vol. %*	*1.35*	*1.35*
Reheat Burner		
Duty, MM BTU/hr	*7.5*	*18.5*
Gas usage, SCFM	*124*	*310*
Air Usage, SCFM	*1,240*	*3,100*
Effluent from Fan		
Pressure, psia	*14.7*	*14.7*
Flow, DSCFM	*50,740*	*127,400*
Temp., °F	*250*	*250*
Flow, ACFM	*85,000*	*213,000*
Moisture, Vol. %	*23.5*	*23.5*
SO_2*, Vol. %*	*1.3*	*1.3*

**Vendor should specify actual scrubber inlet pressure and pressure drop required.*

	Small	*Large*
Particulate Loading to Scrubber		
lb/hr	*2,700*	*6,800*
gr/DSCF	*6.35*	*6.35*
gr/ACF	*3.00*	*3.00*
	Case 1 — Medium Efficiency	
Outlet loading, lb/hr	*40*	*40*
Outlet loading, gr/DSCF at fan discharge	*0.092*	*0.037*
Outlet loading, gr/ACF at fan discharge	*0.055*	*0.022*
Efficiency, wt %	*98.5*	*99.4*
	Case 2 — High Efficiency	
Outlet loading, lb/hr	*11.0*	*28.4*
gr/DSCF at fan discharge	*0.025*	*0.025*
gr/ACF at fan discharge	*0.015*	*0.015*
gr/DSCF at scrubber outlet	*0.026*	*0.026*
gr/ACF at scrubber outlet	*0.017*	*0.017*
Efficiency, wt %	*99.6*	*99.6*

TABLE 112

ESTIMATED CAPITAL COST DATA

(COSTS IN DOLLARS)
FOR WET SCRUBBERS FOR
COPPER REVERBERATORY FURNACES

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	104,000	260,000	104,000	260,000
°F	600	600	600	600
SCFM - Dry	49,500	124,000	49,500	124,000
Moisture Content, Vol. %	4.9	4.9	4.9	4.9
Effluent Dust Loading				
gr/ACF	3	3	3	3
lb/hr	2,700	6,800	2,700	6,800
Cleaned Gas Flow				
ACFM	85,000	213,000	85,000	213,000
°F	250	250	250	250
SCFM	50,740	127,400	50,740	127,400
Moisture Content, Vol. %	23.5	23.5	23.5	23.5
Cleaned Gas Dust Loading				
gr/ACF	0.055	0.022	0.015	0.015
lb/hr	40	40	11.0	28.4
Cleaning Efficiency, %	98.5	99.4	99.6	99.6
(1) Gas Cleaning Device Cost	38,750	68,000	38,750	68,000
(2) Auxiliaries Cost				
(a) Fan(s) & Motors	50,000	150,000	71,000	200,000
(b) Pump(s)	2,400	8,000	2,400	8,000
(c) Damper(s)	4,000	7,500	4,000	7,500
(d) Conditioning, Equipment	28,500	51,000	28,500	51,000
(e) Dust Disposal Equipment	32,500	73,000	32,500	73,000
(3) Installation Cost	50,000	85,000	63,000	104,000
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost	206,150	442,500	240,150	511,500

Based on one quote.

TABLE 113
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR
COPPER REVERBERATORY FURNACES

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator		-	-	-	-
Supervisor					
Total Operating Labor					
Maintenance					
Labor		-	-	-	-
Materials					
Total Maintenance					
Replacement Parts		-	-	-	-
Total Replacement Parts					
Utilities					
Electric Power	$.011/kw-Hr	59,400	89,100	198,000	244,200
Fuel	$ 0.80/MMBTU	40,400	99,200	40,400	99,200
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		99,800	188,300	238,400	343,400
Total Direct Cost		99,800	188,300	238,400	343,400
Annualized Capital Charges		20,615	44,250	24,015	51,150
Total Annual Cost		120,415	232,550	262,415	394,550

Based on one quote.

FIGURE 83
CAPITAL COSTS FOR WET SCRUBBERS FOR COPPER REVERBERATORY FURNACES
(HIGH EFFICIENCY)

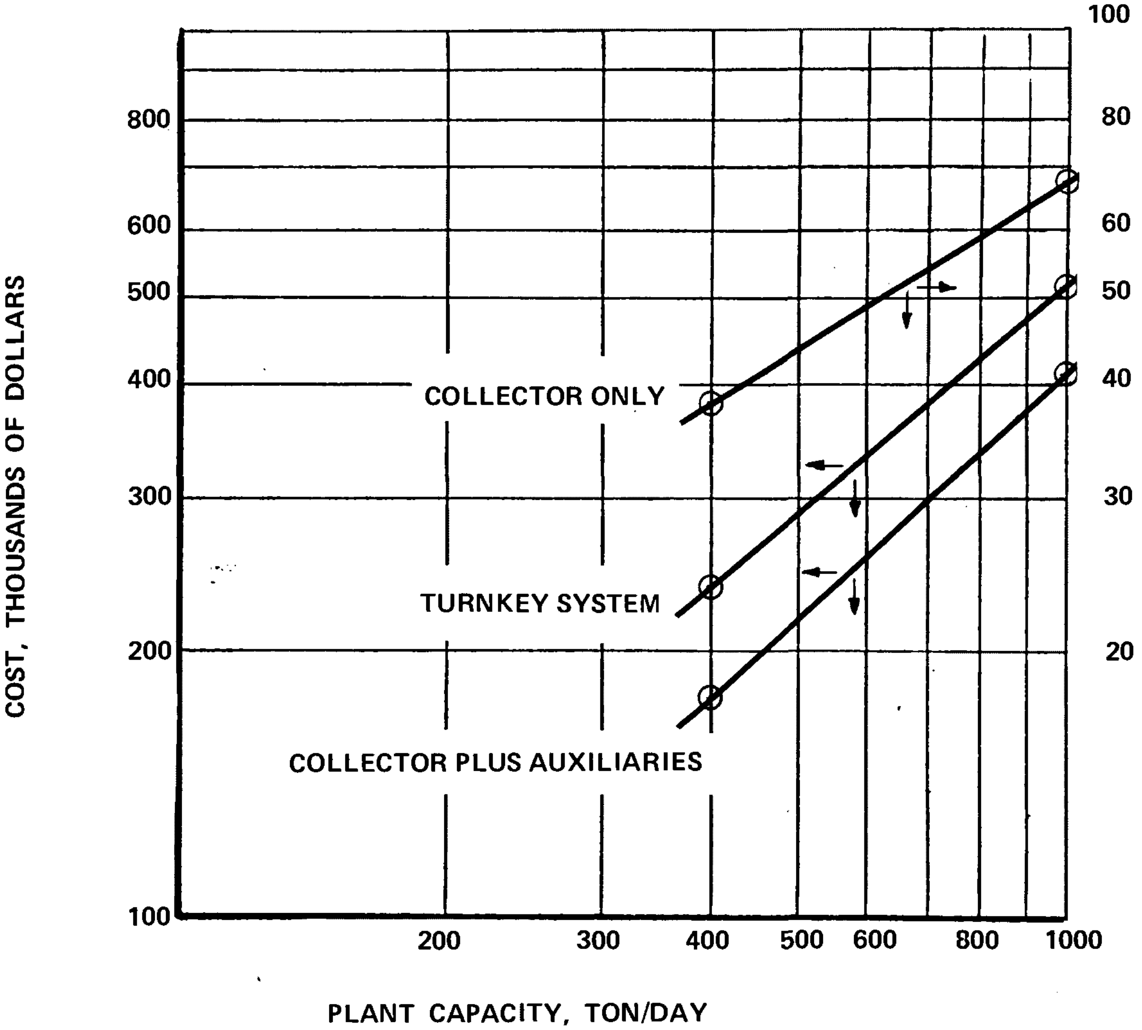
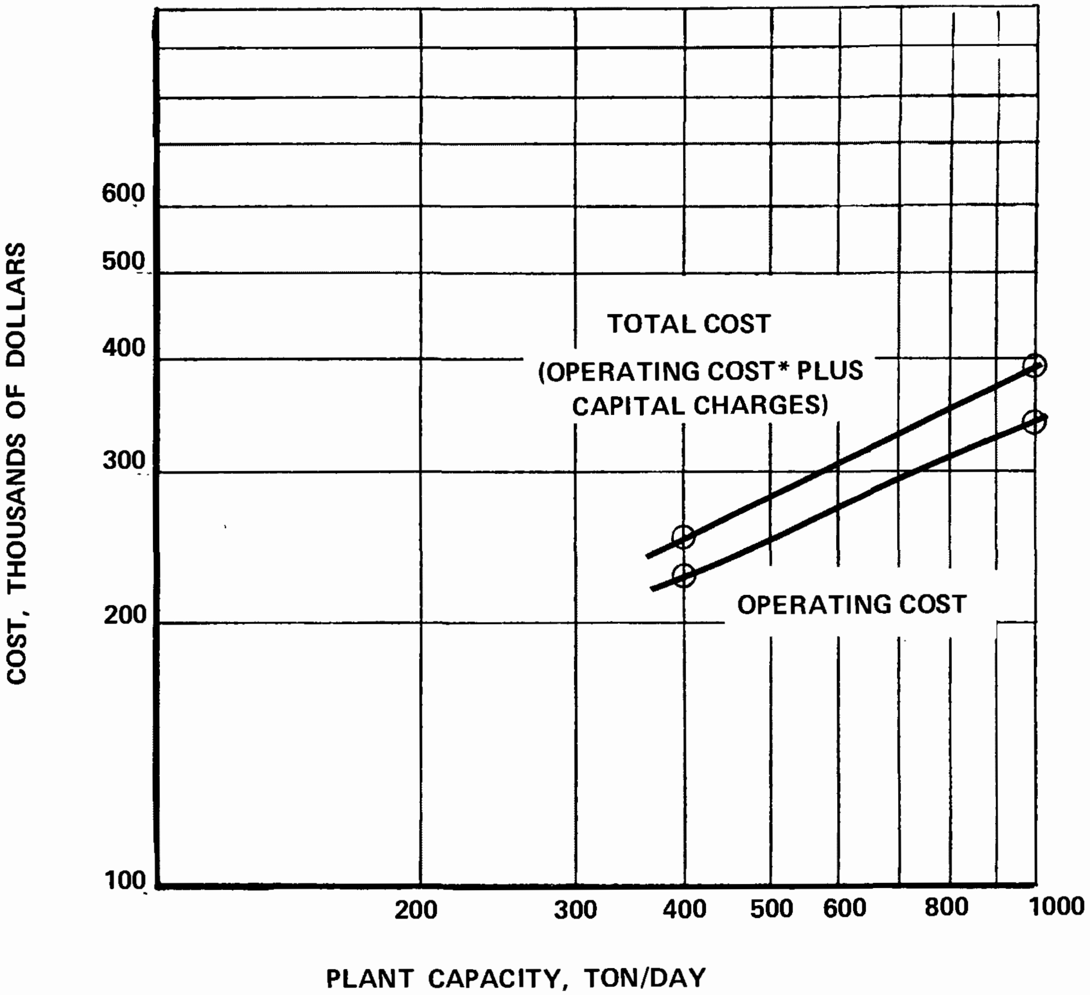


FIGURE 84
ANNUAL COSTS FOR WET SCRUBBERS COPPER REVERBERATORY FURNACES (HIGH EFFICIENCY)



*This does not include operating labor, maintenance labor or repair parts costs.

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BARK BOILERS

8. KRAFT MILL BARK BOILERS

Bark is a byproduct waste of the Kraft mill and ever since the first log was cut for the production of wood chips or lumber, disposal of this waste has been a problem. Bark is one of the most difficult fuels to burn. It normally has a moisture content of 50% or greater and a heating value of only 7600 to 9600 BTU/lb on a dry basis, depending on wood type. It contains a significant amount of sand, ash and other non-combustible materials, and it is difficult to prepare, handle and properly distribute. Because of its high moisture content it requires more time and higher temperatures for combustion than conventional fuels. On a dry basis, bark has a volatile content approaching 80 percent by weight.

The application of modern bark boilers in the Kraft mill is one of the most economical refuse or byproduct disposal methods in industry. The major breakthrough came in the mid-40's with the development of the spreader stoker which offered a much more efficient method of burning than the earlier "Dutch-oven" type furnaces. A modern bark boiler, in conjunction with the other heat and chemical recovery units, can supply all the steam requirements of the mill.

PROCESS DESCRIPTION

While this narrative will concentrate on the bark boiler and related firing and handling equipment, it will also consider the influence of the wood yard area and the dust collection and ash handling equipment. On this basis, the bark handling system in a paper mill can be divided into:

1. Bark handling in wood yard

2. Bark boilers

3. Dust collection

Figure 85 gives a schematic representation of the bark flow in the above areas.

The quality of the bark is partially determined before it arrives at the wood yard and its ash content and moisture content initially depend on handling technique and location. Dry-handled logs, grown in areas of sandy soil such as the east and southeast coast and the state of Michigan, have ash contents which range from 3 to 7 percent.(1) Logs that have been transported over water, flume handled, or hydraulically debarked, in general, have lower ash contents.

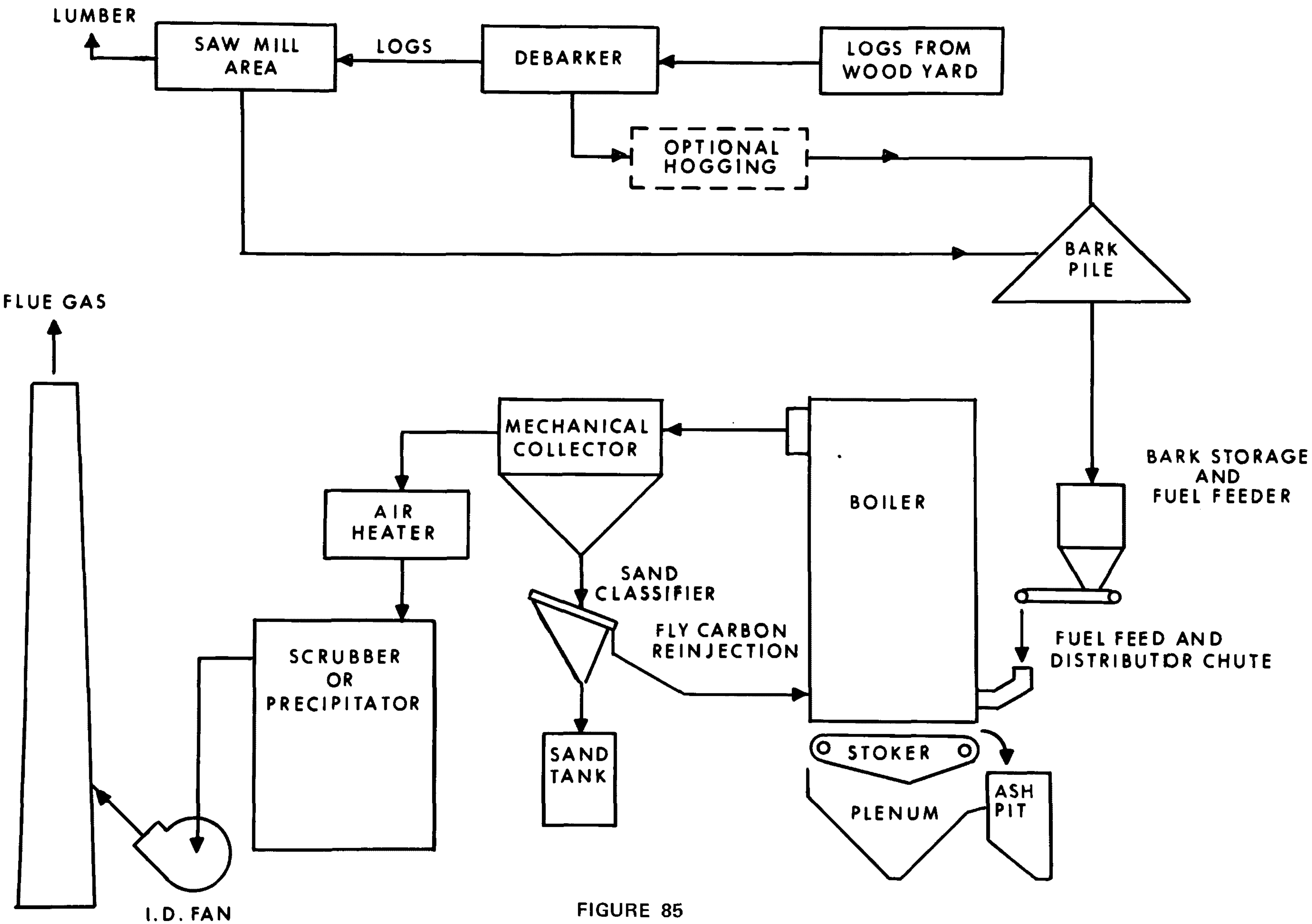


FIGURE 85

BARK FLOW DIAGRAM

This is due to the washing effect which removes most of the sand and dirt, causing the ash content to drop to the range of 1/2 to 2%. Also, hardwood barks have an ash content about twice that of softwood barks which have received the same processing.

The first processing step takes place in the wood yard and consists of continuous and automatic debarking of the logs to be used by the Kraft process or for lumber. The debarking is accomplished in a variety of methods which utilize natural or mechanical friction. In the most commonly used method, logs are fed into the upper end of a rotating drum and debarking results from the abrasion of one log upon another. Hydraulic debarkers are also used and employ high pressure water jets against the logs in such a way as to break up and remove the bark. Typical moisture content of bark and wood for different types of handling is given in Figure 86(1).

The second processing step, which also takes place in the wood yard, is bark hogging. This consists of feeding the various sizes of bark from the debarking operation through a disintegrator or "hog" to produce a uniform size bark chip. Bark hogging adds to the cost of processing, and is not always employed. In some mills the bark from the debarker is screened and only the oversized is hogged. In general, however, most new plants do use hogged bark, since it can be handled more easily and fired more efficiently. Boiler operation is also more reliable and the burning equipment maintenance is reduced.

Typical bark sizes for different types of firing are shown below.(2)

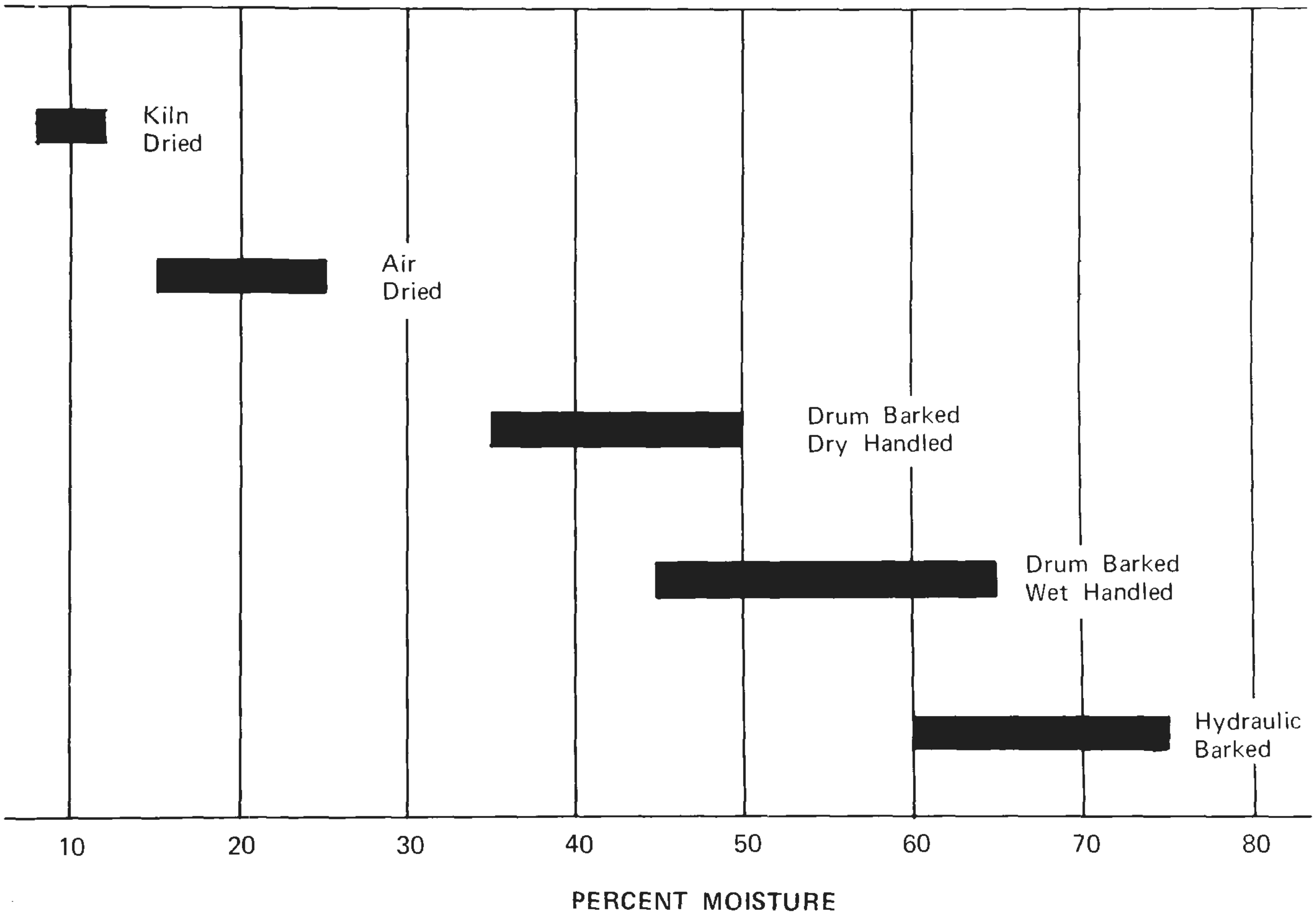
	% Retained on Screen		
Screen	Unhogged Bark	Hogged Bark	
Size, in.	Stoker-Fired	Stoker-Fired	Suspension-Fired
4 x 4	0	–	–
2 x 2	5	0	–
3/4 x 3/4	–	–	0
1/4 x 1/4	–	50 minimum	50 maximum

After hogging, the bark is conveyed to a surge bin or storage facility sized to allow for one to two hours of boiler firing at maximum capacity. In some cases, for economic considerations, the bark is conveyed directly to the boiler without surge capacity but this makes boiler control much more difficult and tends to result in less efficient operation.

Conveying, distributing and proportioning of the bark to the boiler feeding device are the final operations prior to burning. It is of importance to good

FIGURE 86

MOISTURE CONTENT OF BARK AND WOOD



boiler control and a difficult and troublesome operation. A well operating conveyor system should insure a continuous non-pulsating feed and uniformly proportion the fuel to each of the boiler chutes. A variety of devices are in use which include belt conveyors, pneumatic conveyors and vibrating conveyors.

Final distribution of the bark is accomplished from the individual boiler chutes with either a pneumatic or mechanical distributor. The mechanical distributor consists of a rotating cylinder with arms that throw the bark over the furnace grates. Pneumatic distribution is accomplished with an air swept spout distributor which employs a rotary air damper to alternately increase and decrease both the air quantity and pressure several cycles per minute. Both types of distributors can satisfactorily burn hogged bark, but some mechanical distributors have a tendency to become plugged on stringy or unhogged bark. For hogged bark, the distributors can be placed about three feet above the boiler grate while for unhogged bark they must be elevated to about 12 ft to assure good distribution.(1) This results in less residence time for portions of the bark and a decrease in boiler efficiency.

In general, bark boilers can be divided into two ranges of size, less than 150,000 lb/hr of steam and 150,000 to 800,000 lb/hr of steam. For the larger size boilers, there are three main types of burning equipment: stoker (traveling grate or water cooled sloping grate), suspension firing, and cyclone firing. For the smaller size furnaces a greater variety of stoker grates are used such as dump grates, water-cooled pinhole grates, stationary air-cooled grates and vibrating grates. Pile burning is also used in the smaller size boilers.

Within a given size range, the type of burner equipment used is also affected by the size, moisture and ash content of the bark, and the type and requirements for auxiliary fuel, if any.

The general effect of bark moisture on boiler efficiency is shown in Figure 87.

Bark with a moisture content between 55 and 65% is normally pile burned in a refractory-lined furnace. In this type of burning the major burning area supplies enough heat for evaporation of moisture from the surrounding bark so that the overall combustion is self-sustaining without the need of auxiliary fuel. Stokers generally are limited to a bark with a maximum moisture content of 55%. To burn a higher moisture bark, auxiliary fuel may have to be supplied.

Of the three major types of firing equipment, cyclone furnaces have the least application for bark burning. They are limited to a maximum bark input of 30% of the total fuel value and require a finely hogged bark, 100% through 3/4 inch mesh, for proper burning. They also require, as the primary fuel, a lower

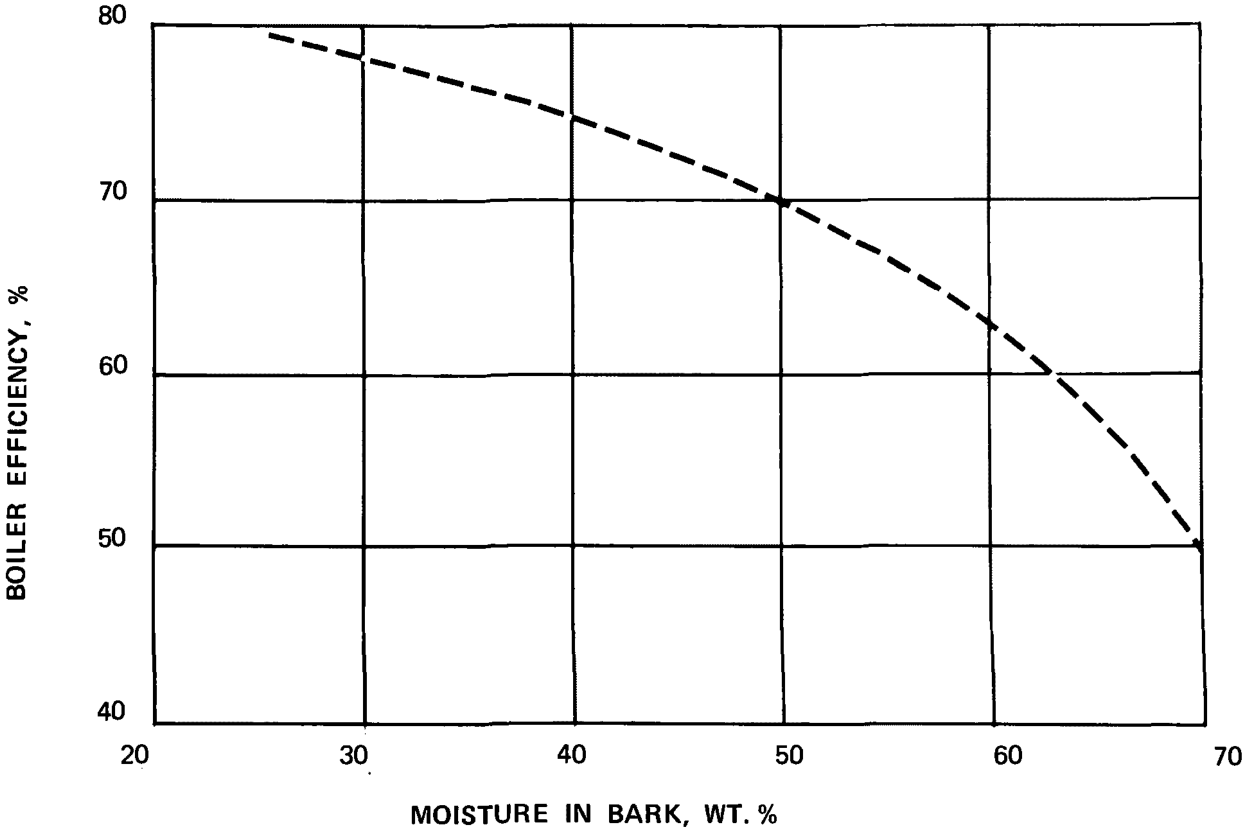


FIGURE 87

THE EFFECT OF BARK MOISTURE ON BOILER EFFICIENCY ash fusion coal to provide a slag coating around the cyclone and insure proper burning of the bark. From an air pollution control standpoint, this type of furnace can be considered as a coal-fired boiler for equipment design purposes.

Another type of boiler that, as yet, has had limited application, is the suspension-fired boiler which is similar to a pulverized coal fired boiler. This type of boiler requires finely hogged bark to assure that the bark will burn in suspension. Most boilers also employ a small dump grate to burn the large bark particles which do not burn in suspension and might otherwise fall into the dust hoppers only partially burned. The bark is conveyed to the boiler with either hot or cold air. Most of these units have a maximum heat input from bark ranging between 30 and 50% and require supplementary fuel. Gas or oil are the auxiliary fuels normally used, but coal can also be used when provided for in the design. From an overall cost standpoint, suspension-fired boilers are not as economical as stoker-fired units until the bark percentage of total fuel drops below 30 percent. They are not a dominant factor in bark boilers and the associated air pollution problems.

Most bark boilers have spreader stoker firing equipment and burn the bark on the grate in a thin layer. The most popular type of stoker is the traveling grate stoker. It is ideally suited for areas with high ash content bark, since it provides for continuous ash discharge. It can also better compensate for bad bark distribution than can a dump grate stoker. Because of this, it requires less grate area and results in a smaller physical size boiler. Fixed position, water-cooled, pin hole grate stokers are also used. They are used primarily for burning bark with a low ash and sand content. They are available in a sloped grate or manual rakeout type, although the manual rakeout type is limited to the smaller size and used only with low ash and sand bark. The sloped grate boiler has the advantage of no moving parts. The flow of fuel and ash over the grates is controlled by steam jets and the ash is discharged to the ash hoppers. The major problem with the water-cooled grate stoker is fusion of the fuel ash over the grate. Even distribution of the bark over the stoker is a must to prevent formation of small bark piles and high grate temperatures. The air temperature to the boilers is also normally limited to around 450°F.

NATURE OF GASEOUS DISCHARGE

The discharge from a bark boiler consists of gaseous products of combustion containing particulate bark char, and sand. Unlike most other stacks in a Kraft mill, there are no significant gaseous air pollutants emitted, and, unlike most coal-fired boilers, there is not an SO_2 problem, since there is little or no sulfur in the bark. In general, the composition of boiler exhaust gas will be typical of the exhaust composition of most coal-fired power boilers. It will have a higher moisture content and lower ash content which will vary widely depending on the type of bark fired.

The quantity of the gaseous exhaust depends primarily, of course, on the size of the boiler. For a given sized boiler firing 100% bark (no auxiliary fuel), the quantity varies with boiler efficiency, bark moisture content, bark sand and ash content, ash reinjection requirements, and excess air requirements. A 1,000 ton/day unbleached Kraft mill processing only unbarked pine would produce about 560 tons of bark per day or 12% of the total 4,600 tons of logs handled each day. Assuming a moisture content of 45%, an ash content of 1-1/2%, an excess air requirement of 20%, and a heating value on a dry basis of 9,000 BTU/lb, the exhaust gas composition and volume would be as shown in Table 114,

PARTICULATE CONTAMINANTS

The particulate carried in the boiler exhaust gas consists of two separate and distinguishable materials: sand and bark char or flyash. These two particulate materials have quite different physical properties and can be expected to behave differently in the carrier gas and air pollution abatement equipment. There is a strong incentive to recover each of these materials for reasons other than air pollution control.

The bark flyash, unlike most flyash, is primarily unburned carbon and, with collection and reinjection, can increase boiler efficiencies from 1 to 4%. Its physical properties are also quite different from normal flyash. It has a low specific gravity, 0.15 to 0.5, and a large surface area to particle mass ratio.(3) It is very fragile and difficult to sample and analyze. A typical size distribution curve is given in Figure 88. Because of its irregular shape, as compared to most typical solid spherical particulate, its reaction to gas stream turbulence and changes in direction is more pronounced.

The sand particulate, on the other hand, is more representative of normal solid spherical particulate. It is finely divided and highly abrasive and can cause serious boiler erosion problems. Because of this problem, velocities through bark boilers and economizers handling sandy flyash are limited to help prevent tube erosion. Single pass boilers are used almost exclusively. Separation of sand from the char, if reinjection is being used, is also required to help minimize boiler and particulate collection equipment damage due to sand erosion.

The dust loading of boiler exhaust gases varies over a wide range. Table 115A Summary of Tests on Bark Boiler Collectors, shows loading from 0.5 to 4.0

FIGURE 88

PARTICLE SIZE DISTRIBUTIONS OF BARK BOILER FLYASH

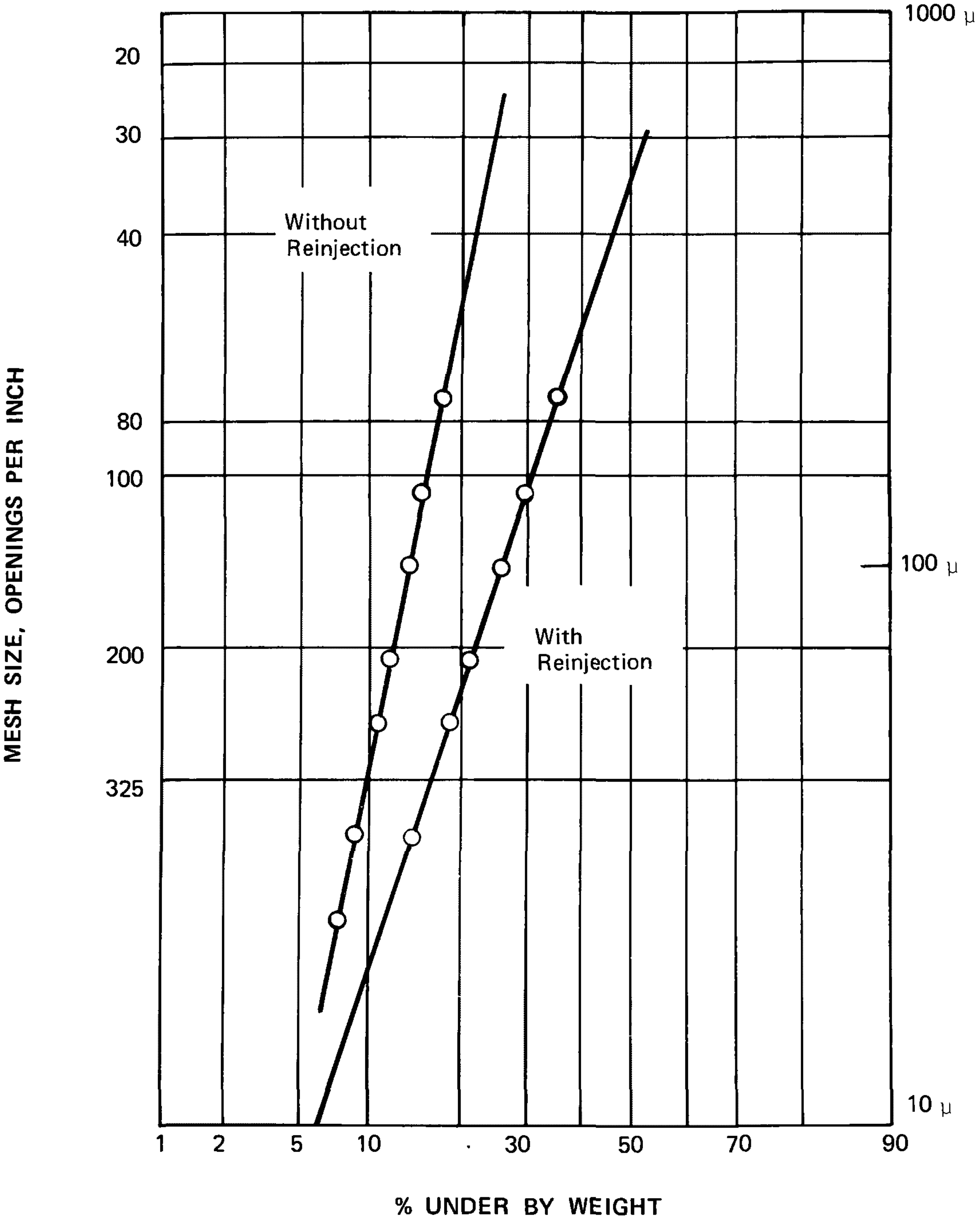


TABLE 114

EXHAUST GAS COMPOSITION

Gas Flow, SCFM	54,900
Temperature, ° F	400
Gas Flow, ACFM	91,000
Estimated Composition, Mol. %	
N_2	68.4
CO_2	11.5
O_2	3.0
H_2O	17.1
Total	100.0
Dust Loading	
Lb/Day	16,200
Lb/10^3 lb of Gas	2.73
Lb/10^6 BTU	2.91
Gr/SCFM	1.43

TABLE 115

SUMMARY OF TESTS ON BARK BOILER TUBULAR COLLECTORS(6)

	Louisiana	Tennessee	Florida No. 1	Florida No. 2	South Carolina	Alabama
Number of tubes	204	285	384	384	344	340
Design, ft^3/min	152,530	215,000	230,000	230,000	293,000	297,542
Design temperature, °F	500	725	450	240	679	725
Design draft loss, in. water gage	2.73	2.5	2.5	2.5	3.0	3.0
Type of fuel	Bark & Gas	Bark, Gas, and Oil	Bark & Oil[a]	Bark & Oil[b]	Bark & Oil	Bark & Gas
Rated steam load, lb/hr	150,000	300,000	300,000	300,000	300,000	300,000
Bark	150,000	340,000	. . .	. . .	. . .	. . .
Bark and auxiliary fuel	165,000	. .	. . .	. . .	. . .	. . .
Auxiliary fuel	200,000	. . .	. . .	. . .	. . .	.
Steam load, lb/hr	150,000	270,000	300,000	268,000	300,000	300,000
Actual oper. temp., °F	460	738	420	410	455-425	640
Actual oper. draft loss, in. water gage	. . .	. . .	3.0	2.5	3.5	2.0
10^6 Btu/hr fired	228	408	457	407	457	457
Max. rated lb/hr of bark	54,700	60,000	. .	. .	. . .	. . .
Volume						
ACFM, inlet	150,190	267,181	222,713	188,510	241,618	279,000
SCFM, inlet	85,323	119,911	134,000	114,800	139,500	133,613
Dust loading						
Inlet, lb/day	60.120	93.432	13.940	20.799	47.902	77.592
Outlet, lb/day	4.096	7.464	1.056	1.455	3.509	5.718
Inlet, lb/10^3 lb gas	6.797	7.566	1.029	1.804	3.376	5.92
Outlet, lb/10^3 lb gas	0.497	0.606	0.0707	0.1052	0.2658	0.513
Inlet, lb/10^6 Btu	10.98	9.54	1.29	2.13	4.36	7.07
Outlet, lb/10^6 Btu	0.75	0.76	0.0965	0.149	0.317	0.52
Grain loading, grains/std. ft^3/min						
Inlet	3.426	3.788	0.5056	0.8805	1.6688	2.8055
Outlet	0.242	0.3027	0.0343	0.05286	0.13018	0.2345
Efficiency of collection, %	93.19	92.19	93.36	94.12	92.25	91.64

[a] 35% Bark hardwood; 65% oil.

[b] 79% Bark pine; 21% oil.

gr/SCFM.(3) The loading increases exponentially as the boiler load increases, due primarily to increased char production. Sand loading also increases, but to a lesser degree, since it is directly related to bark feed rate and sand content of the bark feed. Due to the large increase in char production, the size also increases. Reinjection of collected ash also significantly increases the dust loading. This is graphically illustrated in Figures 89 and 90.

Since the objective of the reinjection is to reburn the collected char, the increase in dust loading is due primarily to an increased sand load. This, in turn, decreases the particle size distribution due to the finer particles that are developed by attrition. This effect is illustrated in Figure 88.

POLLUTION CONTROL CONSIDERATIONS

It has been estimated (NAPCA Contract CPA 22-69-104) that pulp mill bark boilers emitted a total of 82,000 tons of particulate annually after application of existing air pollution control techniques. At present, most bark boilers are equipped with multi-cyclone mechanical collectors. Collection efficiencies for this type of control range from 85 to 95 percent.

At present, bark boiler emissions are more affected by the various process operations than they are by the application of air pollution control equipment. Boiler design, auxiliary equipment design, bark handling techniques and equipment operation all have a significant effect. The most predominant effect by far, however, is the type and amount of flyash reinjection.

The primary purpose of a reinjection system is to assist in the disposal of the bark char without affecting boiler reliability or stack particulate emissions. As shown on Figures 89 and 90 it is not possible to eliminate this solid waste disposal problem without increasing the air pollution emissions. The net effect, however, is a decrease in total waste. Reinjection also has the advantage of increasing boiler efficiency. It can raise it as much as 4% on a boiler firing 100% bark.(1)

The disadvantage to reinjection, especially when firing bark with a high sand content, is high dust loading in the boiler gases, which results in increased boiler tube wear and higher stack emissions. This can be compensated for by the use of sand separators or decantation type dust collectors. In a decantation type collector, the fine particles are separated from the larger bark fly carbon. The bark fly carbon is reinjected to the boiler and the fines are reinjected to the ash pit. The more common method of sand-char separation is accomplished with a screening device. The most common devices are rotary drum screens,

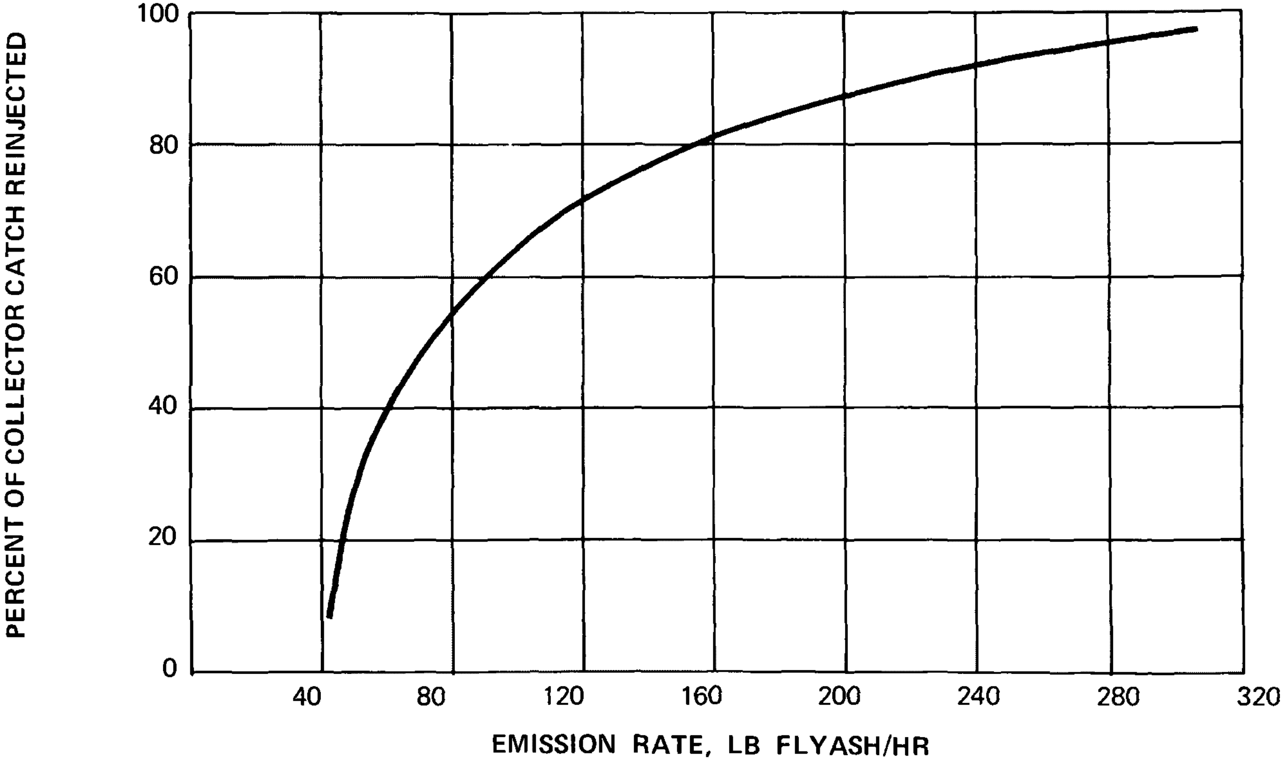


FIGURE 89

DUST LOADING OF BOILER EXHAUST GASES

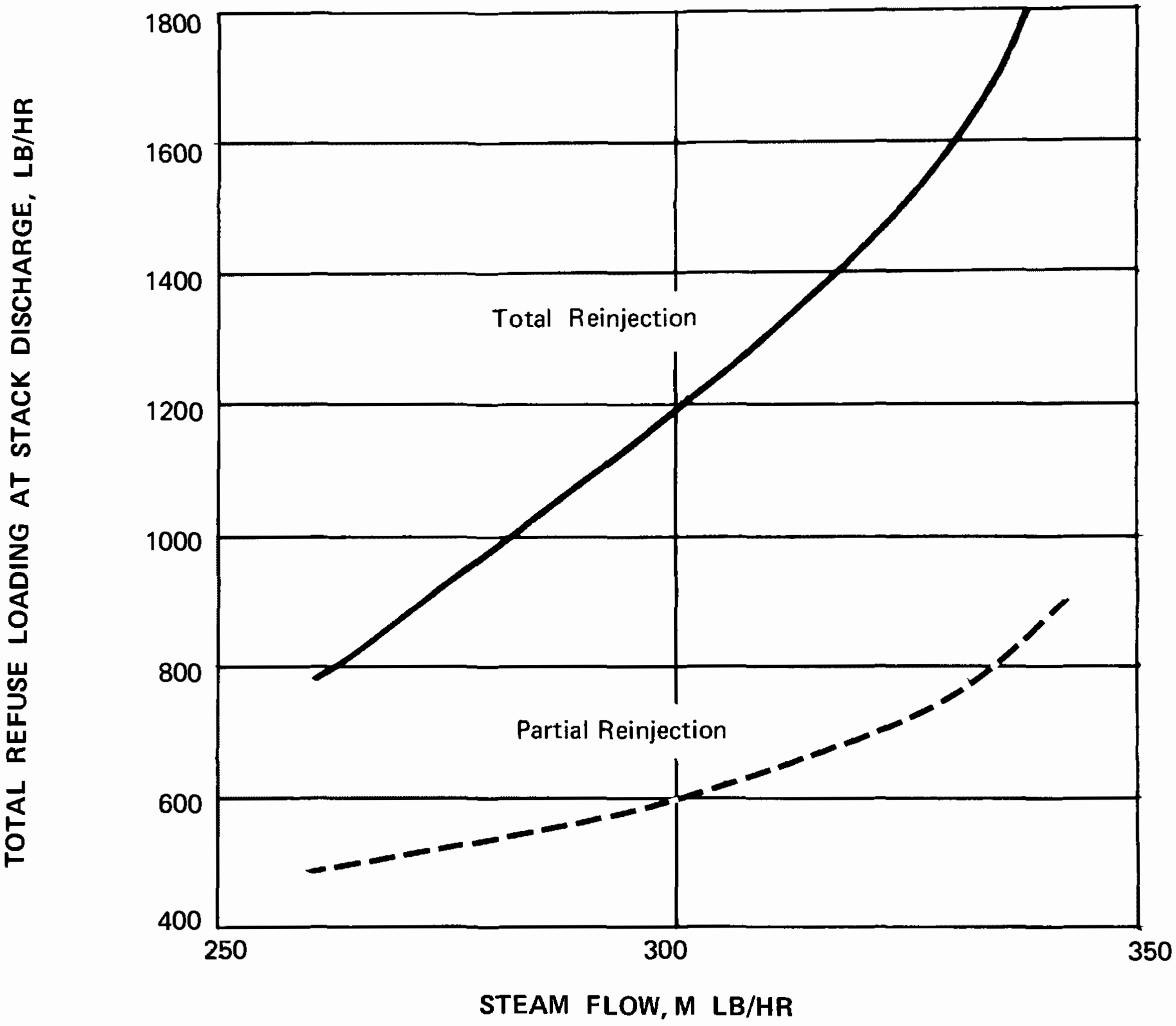


FIGURE 90

TOTAL REFUSE EMISSION RATES

sloped vibrating screens and horizontal vibrating conveyors. The amount of separation of sand and char varies primarily with the screen mesh size used. It is possible on a 30 mesh screen to produce a sand containing no char.(3) It is also possible to remove all the char from stack emission by reinjection if the boiler is using a high efficiency collector which is in good operating condition. Operation in this fashion leads to the maximum rate of stack emission, and the mechanical collector becomes a piece of process equipment rather than a piece of air pollution control equipment.

The ideal approach to air pollution control for bark boilers is operation in the fashion just described, with the addition of a more efficient piece of air pollution control equipment on the mechanical collector outlet gases. It may be possible, depending on the sand and dirt content of the bark, to eliminate the need for sand-char screening prior to 100% reinjections.

The pollution control requirements used in this study limit the emission rates from boilers as outlined below:

SIZE	SMALL	LARGE
Steam Rate, lb/hr	100,000	300,000
Bark Feed, lb/hr	21,000	63,000
Exhaust Volume, ACFM	74,000	222,500
Medium Efficiency		
lb/hr	16.79	40
gr/ACFM	0.038	0.021
High Efficiency		
gr/ACFM	0.040	0.040

As can be seen from the above listing, the medium efficiency requirement is more stringent than the high efficiency or clear stack requirement, and in both cases, they are more stringent than any of the mechanical collector outlet grain loadings outlined in Table 115.

Wet Scrubbers

Wet scrubbers are easily capable of providing the collection efficiency required by the process weight limitation, or of producing a clear stack. There are no requirements for absorption of gaseous pollutants and the particulate should be easily collectable with a low pressure drop Venturi scrubber. Based on the particle size distribution presented in Figure 4 and assuming 100% reinjection, a Venturi pressure drop between 6 and 10 inches w.c. should be adequate. There is no sulfur in the bark fuel and most boilers use natural gas as the auxiliary fuel. Corrosion problems in these cases will be minimal, and discharge of the scrubbing water to the sewer system without neutralization should be permissible. The particulate should be removed first, of course, in either a settling pond, mechanical settler or drum-type filter. This is required to limit water consumption and to minimize water pollution problems. If sulfur bearing auxiliary fuels such as fuel oil or coal are used, it will probably be necessary to add an alkaline material to neutralize the sulfurous acid (H_2SO_3) formed to minimize corrosion and discharge of acidic water to the system sewer. Collection of SO_2 may be required if a high sulfur auxiliary fuel is used.

Reheating of flue gases may be required to limit the steam plume formed where wet scrubbers discharge into the atmosphere.

Electrostatic Precipitation

Electrostatic precipitators have been successfully employed to obtain high particulate removal efficiencies on bark boiler flue gas. Because of their high minimum capital cost, they tend to be non-competitive on small boilers. In many cases, the boiler sizes will be large enough to make a precipitator installation economical. However, the optimum performance is obtained while collecting dust within a narrow band of electrical resistivity. On a bark boiler using 100% reinjection, the resistivity of the remaining sand and flyash is likely to be quite high. This can be compensated for in the precipitator design, but leads to an abnormally large precipitator or requires the addition of chemical conditioning agents. Both of these substantially increase the capital and operating costs of the precipitator. Precipitators will likely find limited use in this application.

Fabric Filters

Fabric filters could also be applied to this problem. The disadvantages involved in their use cannot be justified by the air pollution control requirements for this process. The disadvantages are:

1. Danger of boiler shutdown due to loss of bags from high boiler outlet temperatures and extraordinary operating cost for bag replacement and lost production.

2. Danger of boiler shutdown due to blinding of bags from condensation at low boiler outlet temperature.

3. High operating cost for bag replacements under normal operating conditions.

The air pollution control requirements can be adequately and more safely satisfied by either a wet scrubber or electrostatic precipitator.

SPECIFICATIONS AND COSTS

Bark boiler gas cleaning specifications for both electrostatic precipitators (Tables 116 and 117) and wet scrubbers (Tables 120 and 121) are given in this section. In both cases, the specifications are written for 100% reinjection of the mechanical collector catch.

Because the ash is relatively coarse, the LA-process weight case requires a higher gas cleaning efficiency than does the "high efficiency" case. For this reason, a single level, expected to produce a clear, or nearly clear, stack discharge was specified. It should be noted that historical "clear stack" emission levels may have been based on <100% reinjection.

The costs submitted show a first cost advantage for wet scrubbers, even though a relatively elaborate gas reheating system was included in the specification. These costs are given in Tables 118 and 122. When operating costs are taken into account, they are nearly equivalent. These are given in Tables 119 and 123. Plots of the capital and operating cost data are given in Figures 91, 92, 93 and 94.

TABLE 116

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR KRAFT MILL BARK BOILER SPECIFICATION

A single electrostatic precipitator is to treat the flue gas from a conventional spreader stoker fired boiler. The boiler is equipped with a mechanical collector which serves as the initial collection device for the bark char and sand. 100 percent of the collected bark char is reinjected to the boiler after screening on a 30 mesh sloped vibrating screen. Thirty percent of the initial ash content of the bark is removed in the screening operation while the other 70 percent eventually escapes from the mechanical collector with the outlet gases. The mechanical collector and sand classifying and handling equipment are not to be supplied by the vendor.

The exhaust gas will be brought from the existing mechanical collector to a point 20 feet outside the building and 60 feet above grade. The precipitator will be located at grade in area at the termination of the duct work and the area is free of space limitation. Duct work is also to be supplied to an existing ID fan which is connected to an existing 150 ft stack.

The precipitator is to continuously reduce the particulate content of the flue gas leaving the bark boiler to the levels specified. A minimum of two fields in the direction of gas flow must be provided to reduce the effect of an electrical failure.

The precipitator must be equipped with hoppers capable of retaining the dust collected over 24 hours of normal operation. During normal operation the hoppers will be emptied by a screw conveyor discharging into a dust bin, with a 15 ft elevation above grade to allow for truck loading. The storage bin will be located adjacent to the precipitator and will be sized for seven days storage capacity. Automatic voltage control shall be provided to maximize operating efficiency. Rappers shall be adjustable both as to intensity and rapping period. The precipitator shall be equipped with a safety interlock system which prevents access to the precipitator internals unless the electrical circuitry is disconnected and grounded.

A model study for precipitator gas distribution will be required. The precipitator dust handling equipment and auxiliaries are also to be included in the vendors proposal.

TABLE 117

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR BARK BOILER SPECIFICATION

Two sizes of electrostatic precipitators are to be quoted for one efficiency level. Vendors' quotation should consist of two separate and independent quotations.

	Small	*Large*
Rated steam load, lb/hr	*100,000*	*300,000*
Process weight bark feed, lb/hr wet	*21,000*	*63,000*
Moisture content, wt. %	*45*	*45*
Ash content, wt. %	*1.5*	*1.5*
Excess air rate, %	*20*	*20*
Gas to mechanical collector		
Flow, SCFM	*45,000*	*135,000*
Flow, ACFM	*74,000*	*222,000*
Temp., °F	*400*	*400*
% moisture	*17.1*	*17.1*
Inlet loading, lb/hr	*1,600*	*4,800*
Outlet loading, lb/hr	*400*	*1,200*
Collector efficiency	*75*	*75*
Gas to electrostatic precipitator		
Flow, ACFM	*74,000*	*222,000*
Temp., °F	*400*	*400*
% moisture	*15*	*15*
Inlet loading, lb/hr	*400*	*1,200*
Size distribution		
<10 μ	*10*	*10*
<100 μ	*35*	*35*
	Case 1 — Medium or High Efficiency	
Outlet loading, lb/hr	*16.79*	*40*
Outlet loading, gr/ACF	*.0265*	*0.0211*
Efficiency, wt. %	*95.9*	*96.8*

**Based on 100% reinjection of collected char from mechanical collector.*

TABLE 118

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR ELECTROSTATIC PRECIPITATORS
FOR BARK BOILERS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			74,000	222,000
°F			400	400
SCFM			45,000	135,000
Moisture Content, Vol. %			15	15
Effluent Dust Loading				
gr/ACF			0.63	0.63
lb/hr			400	1,200
Cleaned Gas Flow				
ACFM			74,000	222,000
°F			400	400
SCFM			45,000	135,000
Moisture Content, Vol. %			15	15
Cleaned Gas Dust Loading				
gr/ACF			.0265	.0211
lb/hr			16.79	40
Cleaning Efficiency, %			95.9	96.8
(1) Gas Cleaning Device Cost			114,500	262,260
(2) Auxiliaries Cost				
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment			50,090	97,390
(3) Installation Cost				
(a) Engineering			Included	Included
(b) Foundations & Support			22,630	65,160
(c) Ductwork			23,420	33,540
(d) Stack			Existing	Existing
(e) Electrical			5,680	11,740
(f) Piping			-	-
(g) Insulation			30,610	59,360
(h) Painting			1,500	3,750
(i) Supervision			13,120	31,250
(j) Startup			2,380	4,620
(k) Performance Test			5,250	8,750
(l) Other (Model Study)			21,250	21,250
(4) Total Cost			290,430	599,070

Data based upon one quote.

TABLE 119

ANNUAL OPERATING COST DATA

(COSTS IN $/YEAR)

FOR ELECTROSTATIC PRECIPITATORS

FOR BARK BOILERS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor				--	--
Maintenance					
Labor					
Materials					
Total Maintenance				480	480
Replacement Parts					
Total Replacement Parts				$500	$1,000
Utilities					
Electric Power	$.011/kw-hr			2,629	7,190
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities					
Total Direct Cost				3,609	8,670
Annualized Capital Charges				29,043	59,907
Total Annual Cost				32,652	68,577

Data based upon one quote.

FIGURE 91
CAPITAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR BARK BOILERS

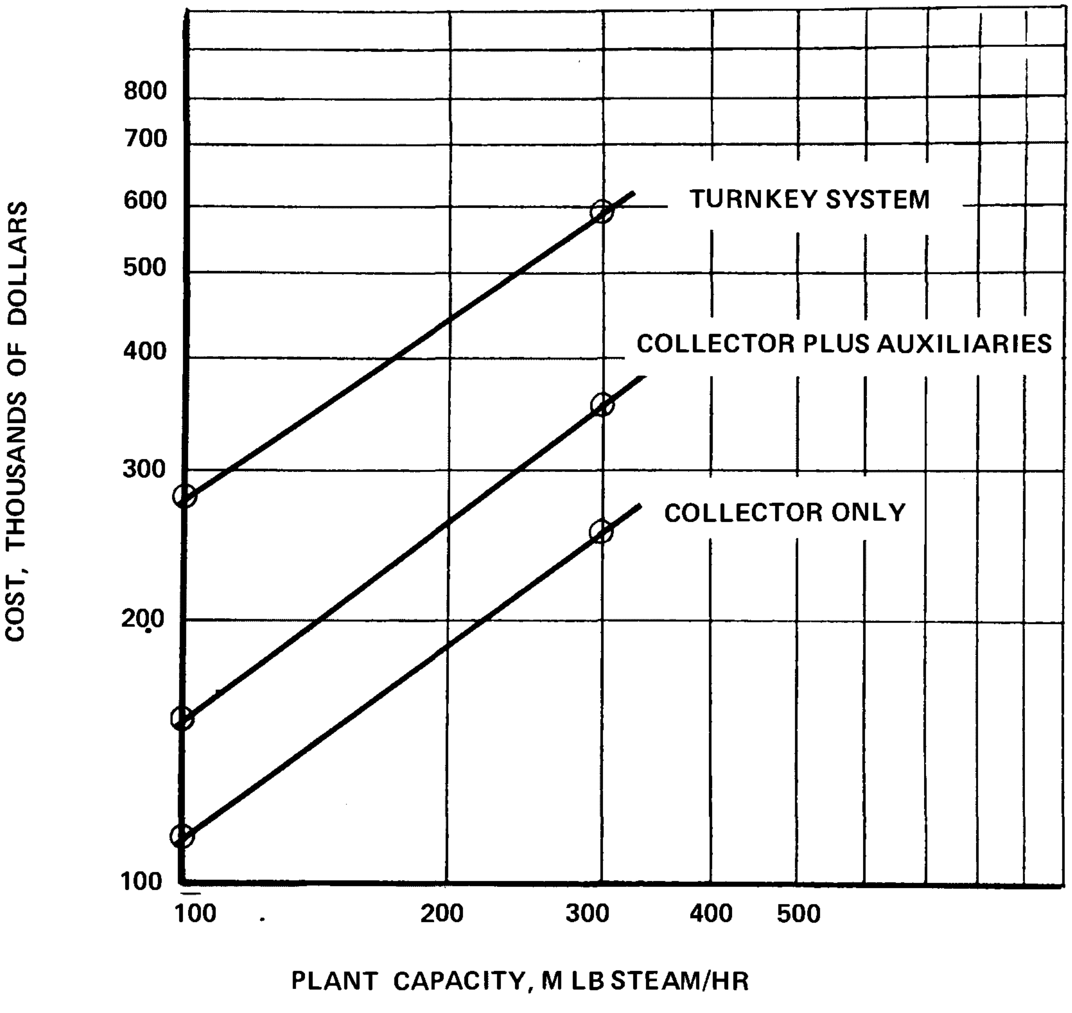


FIGURE 92

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR BARK BOILERS

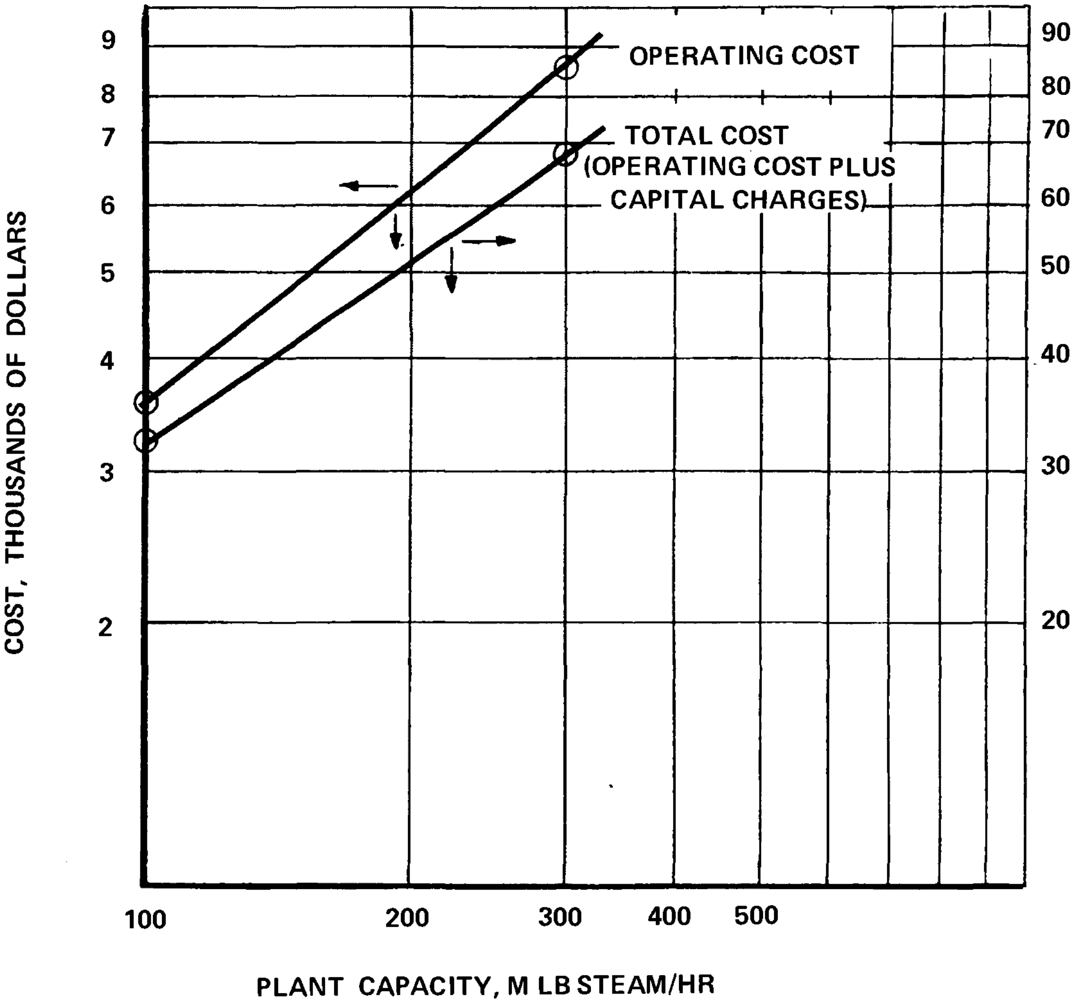


TABLE 120

WET SCRUBBER PROCESS DESCRIPTION FOR KRAFT MILL BARK BOILER SPECIFICATION

A single wet scrubber is to treat the flue gas from a conventional spreader stoker fired boiler. The boiler is equipped with a mechanical collector which serves as the initial collection device for the bark char and sand. 100 percent of the collected bark char is reinjected to the boiler after screening on a 30 mesh sloped vibrating screen. Thirty percent of the initial ash content of the bark is removed in the screening operation, while the other 70 percent eventually escapes from the mechanical collector with the outlet gases. The mechanical collector and sand classifying and handling equipment are not to be supplied by the vendor.

The exhaust gas will be brought from the existing mechanical collector to an existing ID fan located outside the building at grade. The scrubber will be located in the adjoining area which is free of space limitations. The scrubber is to be located in series with and between the existing ID fan and an existing 150 ft stack. The existing fan and stack are connected by a 25 ft straight run of duct work. This existing straight run is to serve as the scrubbing system bypass and the vendor shall furnish and install the required bypass damper.

The scrubbing system shall contain 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 scrubber Venturi is to be constructed of type 304 stainless steel. The de-entrainment separator may be type 304 stainless steel or rubber lined carbon steel. The de-entrainment device shall be a cone-bottom center drained vessel to avoid the collection of particulate. It shall have adequate capacity to serve as the surge tank for the recirculation system. Liquor effluent shall be piped from the bottom of the separator to the recirculation pump. Discharge from the recirculation pump is to be 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 5 wt. % solids. Fresh water is to be added to the system at the separator on level control. External piping is to be constructed of carbon steel. Control valve seat and trim are to be stainless steel alloy.

The vendor is also to supply the following auxiliary equipment:

(1) Pumps – Rubber lined carbon steel or equivalent. Packing glands of slurry pumps to be flushed with fresh water.

(2) Fan – Induced draft with flow control damper. Carbon steel construction. Fan to be sized to overcome scrubbing system pressure drop only. Existing fan will supply static pressure for existing duct work and stack.

(3) Connecting Ductwork and External Piping – Ductwork to be constructed of carbon steel except where condensation may occur where 304 stainless steel construction will be required.

(4) Controls

(5) Reheat Exchanger – Exchanger to be sized to reheat scrubber effluent 100°F. Design to be vertical shell and plain tube type with dirty gas up or down flow on the tube side. Materials of construction to be carbon steel except where condensation may occur.

TABLE 121

WET SCRUBBER OPERATING CONDITIONS FOR BARK BOILER SPECIFICATION

Two sizes of wet scrubbers are to be quoted for one efficiency level. Vendors' quotation should consist of two separate and independent quotations.

	Small	*Large*
Rated steam load, lb/hr	*100,000*	*300,000*
Process weight bark feed, lb/hr wet	*21,000*	*63,000*
Moisture content, wt. %	*45*	*45*
Ash content, wt. %	*1.5*	*1.5*
Excess air rate, %	*20*	*20*
Gas to mechanical collector		
Flow, SCFM	*45,000*	*135,000*
Flow, ACFM	*74,000*	*222,000*
Temperature, °F	*400*	*400*
Moisture, vol. %	*17.1*	*17.1*
Inlet loading, lb/hr	*1,600*	*4,800*
Outlet loading, lb/hr	*400*	*1,200*
Collector efficiency, %	*75*	*75*
Gas to wet scrubber		
Inlet temp. to reheater tube side, °F	*400*	*400*
Inlet temp. to scrubber, °F	*290*	*290*
Inlet flow to scrubber, ACFM	*65,400*	*196,200*
Inlet load, lb/hr	*400*	*1,200*
Size distribution		
% <10 μ	*10*	*10*
% <100 μ	*35*	*35*
Scrubber outlet, °F	*143*	*143*
Scrubber outlet, ACFM	*55,300*	*165,900*
Reheater outlet temp., °F	*243*	*243*
Reheater outlet flow, ACFM	*64,500*	*193,500*
Reheater tube area, ft^2	*7,720*	*23,160*

Case 1 – Medium or High Efficiency

Outlet loading, lb/hr	*16.79*	*40*
Outlet loading, gr/ACF	*.0304*	*.0241*
Efficiency, wt. %	*95.9*	*96.8*

TABLE 122

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS
FOR BARK BOILERS

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			65,400	196,200
°F			290	290
SCFM			45,000	135,000
Moisture Content, Vol. %			17.1	17.1
Effluent Dust Loading				
gr/ACF			0.71	0.71
lb/hr			400	1,200
Cleaned Gas Flow (from reheater)				
ACFM			64,500	193,500
°F			243	243
SCFM			47,500	143,000
Moisture Content, Vol. %			21.5	21.5
Cleaned Gas Dust Loading				
gr/ACF			0.0304	0.0241
lb/hr			16.79	40
Cleaning Efficiency, %			95.9	96.8
(1) Gas Cleaning Device Cost			31,399	92,781
(2) Auxiliaries Cost			39,463	81,521
(a) Fan(s)				
(b) Pump(s)				
(c) Damper(s)				
(d) Conditioning, Equipment				
(e) Dust Disposal Equipment				
(3) Installation Cost			114,126	280,230
(a) Engineering				
(b) Foundations & Support				
(c) Ductwork				
(d) Stack				
(e) Electrical				
(f) Piping				
(g) Insulation				
(h) Painting				
(i) Supervision				
(j) Startup				
(k) Performance Test				
(l) Other				
(4) Total Cost			184,988	454,532

TABLE 123

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR BARK BOILERS

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$6/hr			1,200	1,200
Supervisor				-	-
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance				5,200	12,483
Replacement Parts					
Total Replacement Parts				6,200	13,843
Utilities					
Electric Power	$.011/kw-hr			24,387	84,568
Fuel				-	-
Water (Process)	$.25/M gal			5,450	14,925
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				29,837	99,493
Total Direct Cost				42,437	127,019
Annualized Capital Charges				18,499	45,453
Total Annual Cost				60,936	172,472

FIGURE 93
CAPITAL COSTS FOR WET SCRUBBERS FOR BARK BOILERS

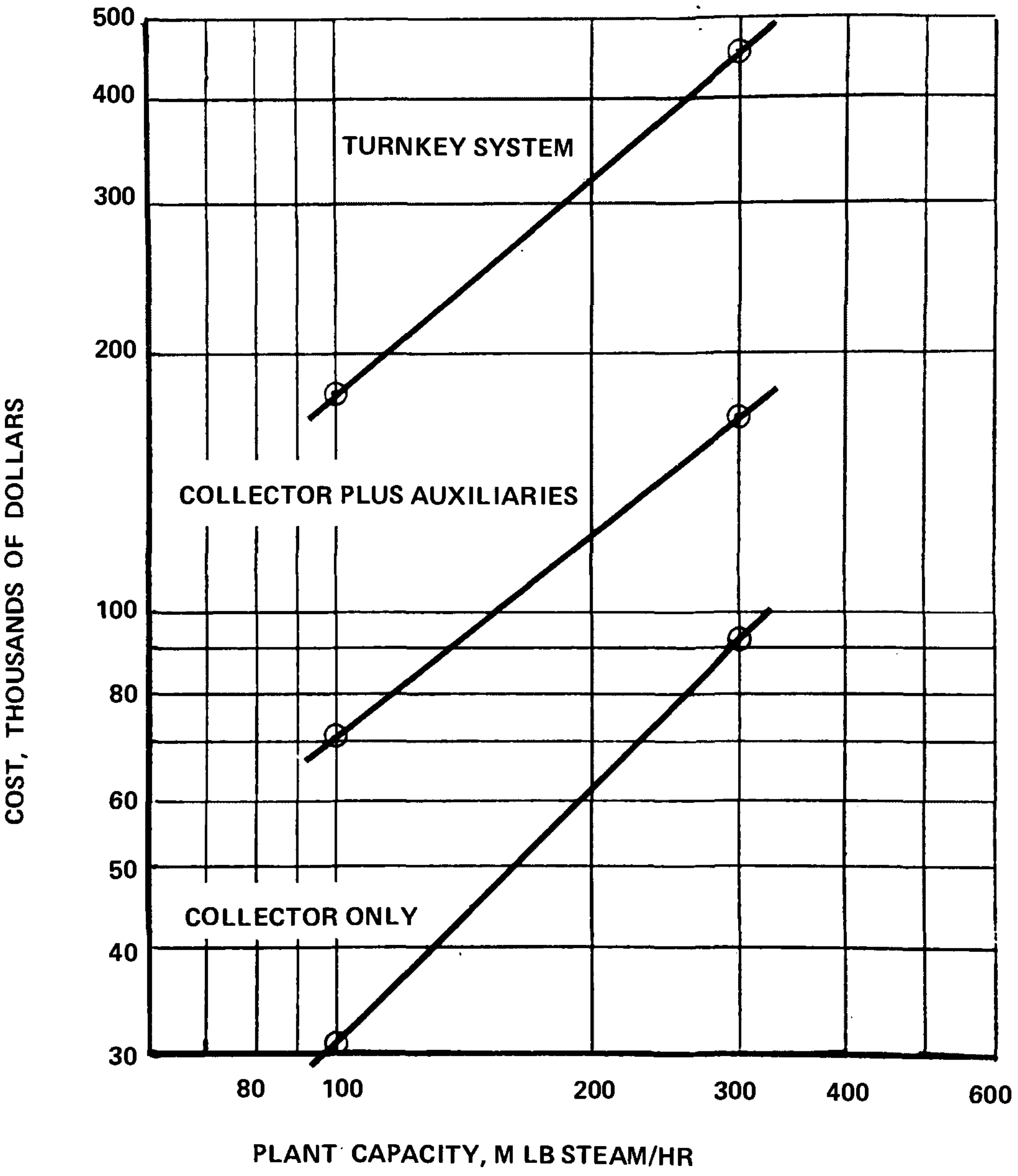


FIGURE 94
ANNUAL COSTS FOR WET SCRUBBERS FOR BARK BOILERS

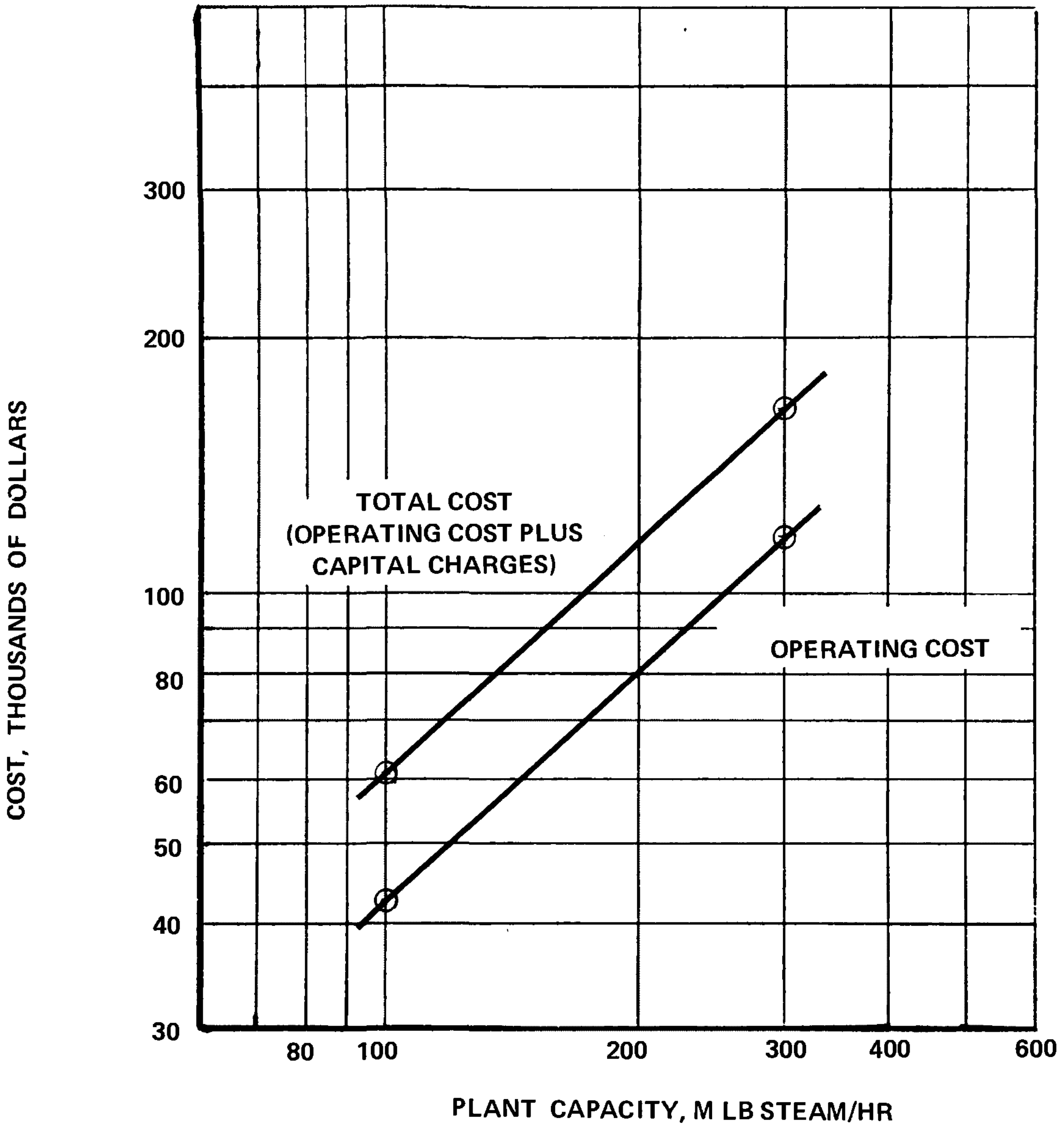
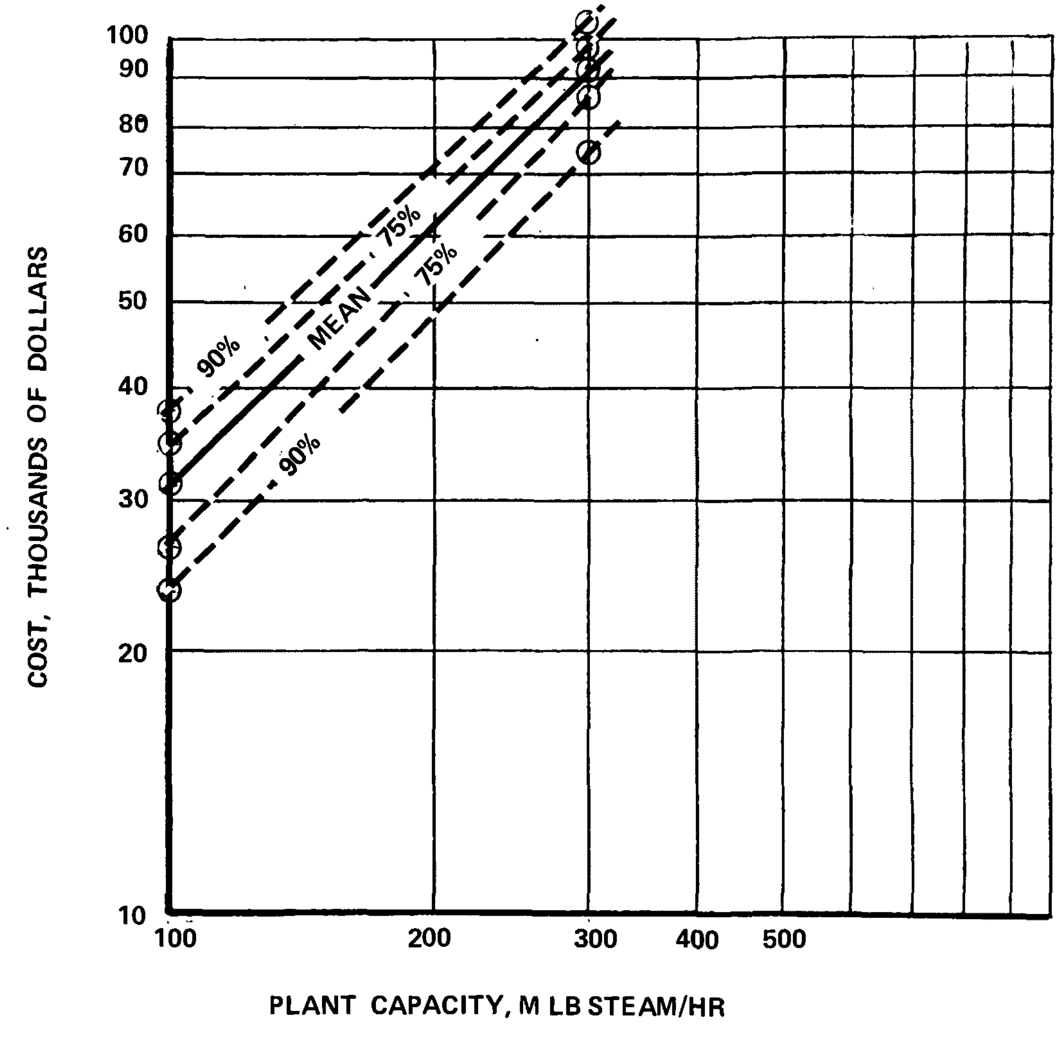


FIGURE 95

CONFIDENCE LIMITS FOR CAPITAL COST OF WET SCRUBBERS ONLY FOR BARK BOILERS



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FERROALLOYS

9. FERROSILICON AND FERROCHROME

Ferroalloy is a generic name for the alloys of iron with materials such as silicon, chromium, manganese, and phosphorus. The nonferrous portion of these alloys can vary from 5 to 90%. They are used primarily as alloying agents and deoxidants in iron and steel production.

Most ferroalloys made in the USA are produced in two kinds of equipment – blast furnaces and electric furnaces. Blast furnace operations can be used to produce *Spiegeleisen**, ferromanganese, ferrosilicon, and ferrophosphorus. These products are made at a lower cost, but are limited to alloys containing a high carbon level and a low percentage of nonferrous metal. Electric furnaces are required to produce low carbon alloys and high nonferrous metal content alloys. For example, ferrosilicon from a blast furnace is limited – primarily by the limited temperature level available – to a maximum of about 17% silicon.(1) A typical carbon content for this product is 1.5 wt. %. Electric furnaces can produce ferrosilicon with a silicon content in excess of 85% and a carbon level less than 0.15%. Typical ferroalloy compositions are shown in Table 124.

Since the vast majority of domestic ferroalloy production is done by electric furnaces, this narrative will deal with this type of processing exclusively and will concentrate upon ferrosilicon and ferrochrome production.

The electric furnaces used for ferroalloy production are different from those used for iron and steel melting. The majority of the energy expended is used to perform a chemical reaction rather than to supply heat for melting. In most cases the electrodes are buried in the charge rather than suspended above. A typical ferroalloy furnace is illustrated in Figure 96. The power supplied is generally three phase and there are, consequently, three or six electrodes. The furnaces range in size from a few hundred to 50,000 kw(1) and exhibit a requirement of 1 to 6 kwh/lb of alloy produced.(2)

The furnaces are fed continuously at the top and tapped at the bottom in small batches relative to the furnace size at one to two hour intervals. The furnace charge consists of iron ore, nonferrous metal ore, reducing agent, and fluxes. The reducing agent may be coke, coal, coke fines, wood chips, or ferrosilicon alloys. As the reactions proceed, the products sink to the bottom of the furnace. Gaseous reaction products rise to the top of the furnace and, if combustible, burn. The unreacted charge remains at the top. The tops of the electrodes are submerged about halfway into the mix to allow mass transfer to occur between the reaction gases and the descending charge.

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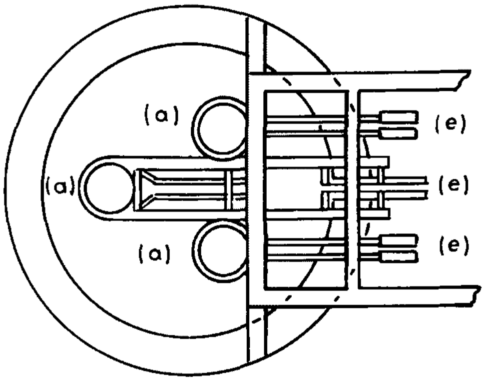
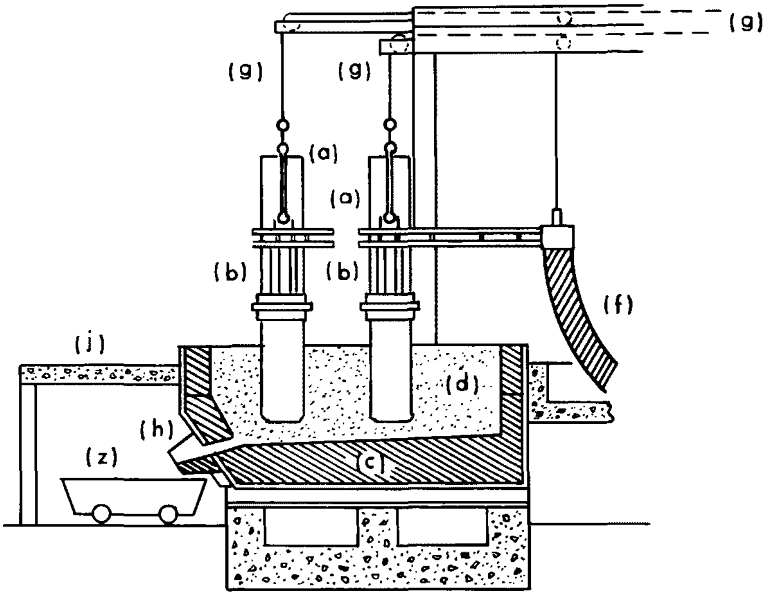
*Spiegeleisen is the name for low manganese content ferromanganese.



PLAN



SECTION

(a)	ELECTRODES.	(f)	FLEXIBLE CONNECTORS.
(b)	ELECTRODE HOLDERS	(g)	CABLES TO COUNTERBALANCES.
(c)	CARBON HEARTH	(h)	TAP HOLE
(d)	CHARGE	(j)	PLATFORM
(e)	BUS BARS	(z)	CAR

FIGURE 96

ELECTRIC FURNACE FOR FERROALLOY PRODUCTION

TABLE 124

COMPOSITIONS OF TYPICAL FERROALLOYS

ALLOY TYPE	C	Mn	P	S	Si	V	Cr	Ti	Al
Ferromanganese (Std.)	7.5*	80	0.35*	0.05*	1.25*				
Ferromanganese (L.C.)	0.1-0.75	83	0.35	0.05	1.25				
Ferrosilicon	0.15*		0.05*	0.04*	50				
Ferrochromium (H.C.)	6				3*		73		
Ferrochromium (L.C.)	0.03-2.0				1.5*		73		
Ferrovanadium	3.5*		0.25*	0.40*	13*	35			1.5*
Silicomanganese		65			20				
Ferrotitanium	4				2.5			20	1.5
Spiegeleisen	6.5*	17	0.25*	0.05*	1.0-4.0				
Silvery Iron	1.5*		0.15*	0.06*	17				

*Maximum

FERROCHROME

Ferrochrome is produced by the direct reduction of chromium spinels often incorrectly called chromite. Chromite is a compound with the formula $FeO \cdot Cr_2O_3$ and containing 67.8% Cr_2O_3. The ores commonly used contain $\leq$ 62% Cr_2O_3 and have a molar ratio of Cr/Fe greater than 2/1.(3) The product of the reduction done in an electric furnace will be 65 to 70% chrome.(4) The carbon content will vary depending upon the process by which it was made.

Ferrochrome is sold on the market in grades delineated by carbon content. High carbon ferrochrome is used for low alloy steels needing the addition of both chrome and carbon. Intermediate carbon levels are used for stainless steels. Low carbon ferrochrome is used for austenitic stainless steels where excess carbon will cause $Cr_{23}C_6$ precipitation at grain boundaries.(4)

High carbon ferrochrome is made by a multi-stage reduction of the chromite ore by carbon. Either coke or anthracite may be used as the source of carbon. The major reactions involved are:(3)

1. $7\,Cr_2O_3 + 27C \rightleftarrows 2\,Cr_7C_3 + 21\,CO$
2. $FeO + C \rightleftarrows Fe + CO$
3. The Cr_7C_3 is dissolved by Fe to yield $(CrFe)_7C_3$

The theoretical carbon content is 8.7%. It is usually lower in practice due to the presence of impurities. If the raw ore contains Al_2O_3, MgO, or SiO_2, a little additional decarburization takes place during production. The high carbon ferrochrome can be reduced to an intermediate carbon level by oxygen lancing in the ladle after tapping.

Low carbon ferrochrome is made by the reduction of high carbon ferrochrome. The most common reducing agent is silicon. The processes used are multi-step involving more than one furnace as well as reaction vessels. A diagram of one such process is shown in Figure 97. Chromite ore, silica, and coke are charged to a submerged arc furnace using Soderberg electrodes. The product is a high carbon ferrosiliconchrome from the following reaction:(4)

$$Cr_2O_3 \cdot FeO + SiO_2 + 6C \rightleftarrows Cr_2FeSi + 6CO$$

This product is tapped into a silica lined ladle and from there sent to the second reaction vessel.

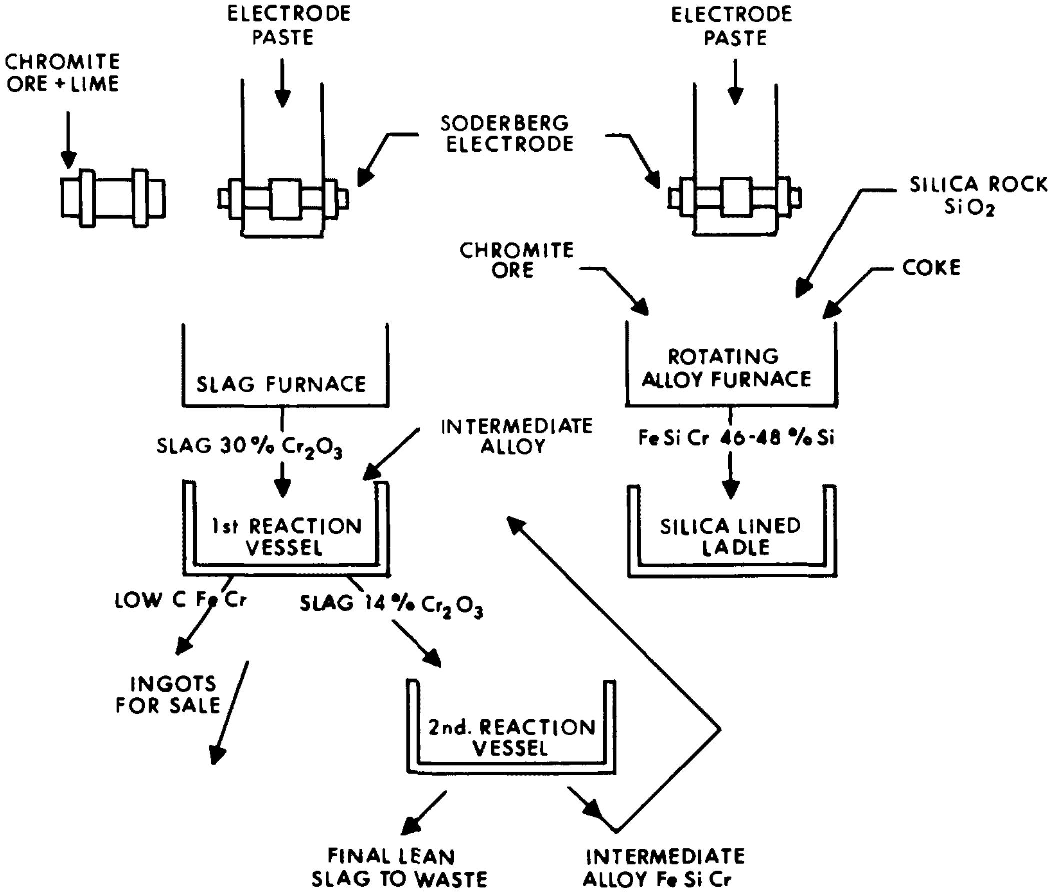


FIGURE 97

PROCESS DIAGRAM FOR LOW CARBON FERROCHROME PRODUCTION

Other chromite ore is mixed with quicklime, preheated and sent to an open arc furnace using Soderberg electrodes. This furnace produces a 30% Cr_2O_3 slag which is tapped to the first reaction vessel. In the first reaction vessel the slag reacts with intermediate ferrosiliconchrome alloy from the second reaction vessel to yield low carbon ferrochrome and 14% Cr_2O_3 slag. The low carbon ferrochrome is cast into ingots for sale. The 14% Cr_2O_3 slag is sent to the second reaction vessel where it reacts with high carbon ferrosiliconchrome from the alloy furnace to form intermediate ferrosiliconchrome alloy and final lean slag which is sent to waste.

Both furnaces in this process generally operate with 40 inch diameter Soderberg electrodes and range from 8000 to 12,000 KVA. The process consumes 11,500 kwh/ton chrome and produces an alloy whose carbon level is as low as 0.015 wt. %. In addition to the carbon, a typical product analysis is:(4)

Cr – 68 to 76 wt. %
S – 0.01 wt. %
P – 0.02 wt. %
As – 0.001 wt. %
Mn – 0.45 wt. %
Ni – 0.45 wt. %
Si – 0.75 wt. %

A second process for low carbon ferrochrome is shown in Figure 98 High carbon ferrochrome is briquetted with an oxidant and dried. The bricks are then heated to 1370°C at a programmed rate to yield a porous product which has the same shape as the briquettes. A typical analysis is:

C – 0.008 wt. %
Si – 1.10 wt. %
Cr – 69.5 wt. %

FERROSILICON

Ferrosilicon is produced in the United States in both blast furnaces and electric furnaces. The blast furnaces are similar to but not identical with those used for steel. They can produce only alloys with low silicon content because of temperature limitations. Higher quality alloys must be made in electric furnaces. These furnaces operate with their electrodes buried in the charge and use the majority of the energy developed to force the combination of iron and carbon with the silica. The raw materials charged to the furnace include a silica source, an iron source, and a reducing agent. Commonly used silica sources are

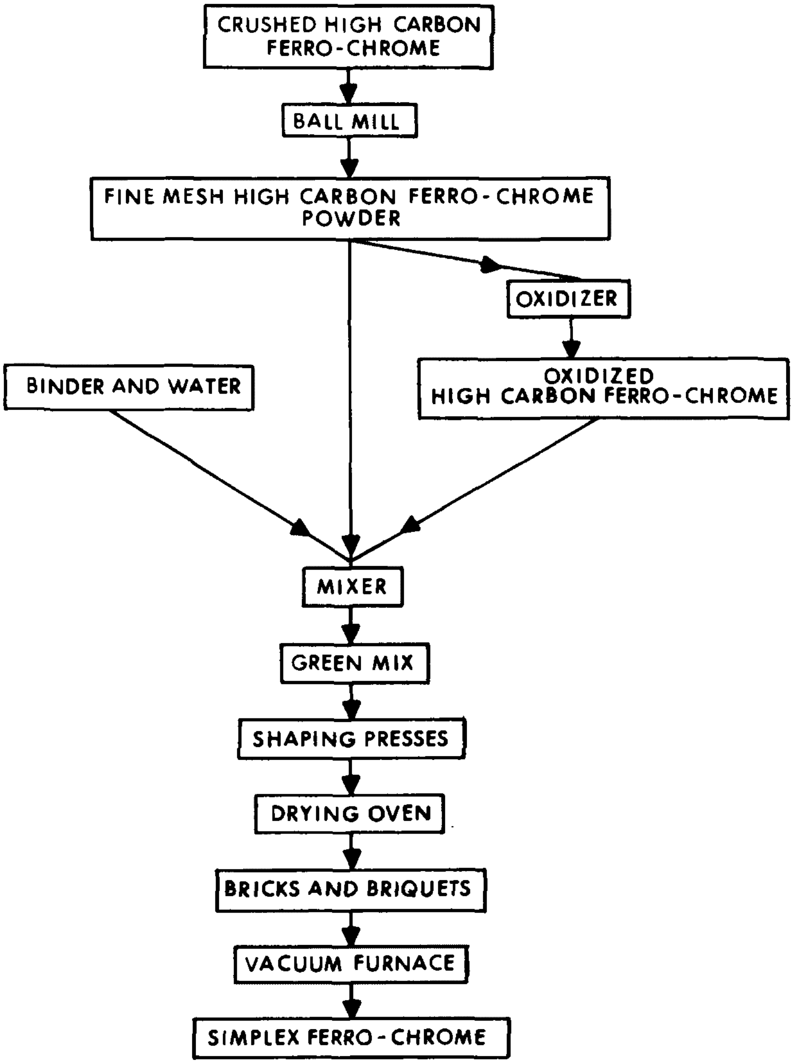


FIGURE 98

PROCESS DIAGRAM FOR LOW CARBON FERROCHROME PRODUCTION quartz, quartzites, chalcedony, sandstone, and sand. Commonly used reducing agents are coke, coal, and charcoal. Steel scrap and iron ore provide iron for the reaction. The net reactions which occur are:

$$SiO_2 + 2C = Si + 2CO$$

$$Fe_2O_3 + 3C = 2Fe + 3CO$$

Temperatures up to 2000°C are used. The actual reactions which occur are complex multi-step ones which net out to the simple relationships shown above. As examples:(3)

$$SiO_2 + 3C = SiC + 2CO$$

$$2SiC + SiO_2 = 3Si + 2CO$$

and

$$SiO_{2(l)} + SI_{(l)} = 2SiO_{(g)}$$

$$2SiO_{(g)} + 2C_{(s)} = 2Si_{(l)} + 2CO_{(g)}$$

Ferrosilicon is produced in a one step process and consumes 1 to 6 kwh per pound of alloy produced.(2)

NATURE OF THE GASEOUS DISCHARGE

The gaseous effluent is different for each of the three types of electric furnaces used in the domestic production of ferrosilicon and ferrochrome. The furnace types are:

Submerged Arc Open Hood Furnace

Submerged Arc Closed Hood Furnace

Open Arc Furnace.

The open arc furnace is used only in low carbon ferrochrome production. The other two types are used in all of the other cases.

CLOSED HOOD

The emission from a closed hood furnace is principally carbon monoxide resulting from the reduction of metallic oxides by the carbon reducing agent. The weight of carbon monoxide given off can exceed the weight of the ferroalloy produced. As an example, the weight balance for a hypothetical batch of 45% silicon content ferrosilicon is presented in Table 125. The numbers in the table are based upon an assumed production rate of 2 tons/hr of alloy. Raw materials assumed were quartzite as the silica source, coke as the reducing agent, steel shavings as the iron source, and Soderberg electrodes.

The calculated emission of carbon monoxide is 2.12 tons/hr compared to the alloy production rate of 2.00 tons/hr.

OPEN HOOD

Emissions from an open hood furnace are quite different because the carbon monoxide which is evolved burns at the top of the furnace as it comes into contact with air being drawn into the hood. This combustion produces a large volume of high temperature gas in the hood going to the abatement equipment. The actual volume of gas depends upon the amount of air induced into the collection system. A specific comparison of gas volumes and temperatures for closed and open furnaces producing 50% ferrosilicon is presented in Table 126. The comparison in the table shows a factor of 26 between the two furnace types. Factors as high as fifty have been reported. Gas is not produced at a steady rate. The amount of variation depends upon operation of the furnace and the hooding system. Variations in flow can be as much as 40%.

Furnaces used in the production of low carbon ferrochrome produce a much lower rate of gaseous discharge because the products of the reduction reactions are not gaseous. A hypothetical weight balance for the production of low carbon ferrochrome is given in Table 127. Notice that the reducing agent utilized is ferrosiliconchrome rather than carbon. The reaction products of the reduction process leave the furnace as slag rather than as carbon monoxide. Those gaseous products which do occur result from impurities in the chromium ore charged to the process.

NATURE OF THE PARTICULATE EMISSION

Operation of ferroalloy furnaces produces particulate emissions at three principal points:

1. The top of the furnace carried out with the reaction gases or hot air stream

TABLE 125

WEIGHT BALANCE FOR PRODUCTION OF 45% FERROSILICON

Production Rate Basis: 2 tons/hr of alloy

Input, tons/hr		Output, tons/hr*	
Quartzite	2.02	Ferrosilicon	2.00
Coke	1.18	Slag	0.06
Steel Shavings	1.15	Gas	2.33
Electrode Mass	0.04		
	4.39		4.39

Major Components of Gas Emission

	Wt %
CO	91.2
SiO	1.6
H_2	0.5
H_2O	2.0
Si	1.0
Volatile**	3.7
	100.0

* Averaged over operating cycle

**Volatile matter from coke, steel shavings, and electrodes

TABLE 126

COMPARISON OF GAS FLOWS FROM OPEN AND CLOSED HOOD 50MW SUBMERGED ARC FURNACES MAKING 50% FERROSILICON

	Closed Hood	Open Hood
Flow, ACFM	20,000	310,000
Temperature, °F	1,100	460
Flow, SCFM	6,600	175,000

TABLE 127

WEIGHT BALANCE FOR PRODUCTION OF LOW CARBON FERROCHROME

Production Rate Basis: 2 tons/hr of alloy

Input, tons/hr		Output, tons/hr*	
Chromium Ore	3.51	Ferrochromium	2.00
Ferrosilicon chromium	1.45	Slag	6.51
Lime	3.72	Gas	0.35
Oxygen from air**	0.18		
	8.86		8.86

Major Components of Gas Emission

	Wt %
CO_2	99.6
P_2O_5	0.4
	100.0

* Averaged over operating cycle

**For oxidation of the silicon

2. The furnace tapholes. Since most furnaces are tapped cyclically rather than continuously, this source is active only about 15% of the time

3. The ladle after tapping, which is also a non-continuous source of particulate.

The particulate emitted is small in size and is composed of the oxides of the metals being produced and used in the process. Some examples are given in Table 128. Agglomeration of the particles can make the effective particle size to the collector much larger than that indicated in the table. Grain loadings have been reported in the range of 5 to 30 gr/SCF for closed hood systems and 0.1 to 2 gr/SCF for open hood systems.(5)

POLLUTION CONTROL EQUIPMENT

Three types of pollution control equipment have been used to control the emissions from ferroalloy furnaces; high energy scrubbers, electrostatic precipitators, and fabric filters.

The only type of scrubber which is applicable to the control of ferroalloy furnaces is the high energy Venturi. This limitation results from the small size of the particulate emitted which requires a high pressure drop for collection. Venturi scrubbers have been successfully employed at collection efficiencies in excess of 98%. Recirculation of the scrubbing water keeps the net water usage at a low level. The Venturi also has the ability to handle the sudden temperature surges common in ferroalloy furnace operation.

There are several drawbacks to their use, however. The high pressure drop causes high energy consumption and power cost. Operating costs are further increased by the requirement of disposal of the sludge produced.

Fabric collectors have also been successfully employed on ferroalloy furnace emissions. Each of these applications has involved a pressure type filter with the fan on the dirty gas side to aid in maintenance of the baghouse. They produce no visible plume and can handle the small sized particulate at a lower energy input than scrubbers. The high temperature of the gas emitted is a problem, however. Filters in this service usually employ high temperature rated bags, such as fiberglass, but can use synthetics if sufficient gas cooling is provided.

TABLE 128

PROPERTIES OF PARTICULATE EMISSIONS FROM FERROALLOY FURNACES

Alloy Type	50% FeSi	H.C. FeCr	Chrome Ore-Lime Melt
Furnace Hood Type	Open	Covered	Open
Particle Size, μ			
Maximum	0.75	1.0	0.50
Range of most particles	0.05-0.3	0.1-0.4	0.05-0.2
Chemical Analysis, wt %			
SiO_2	63-88	20.96	10.86
FeO		10.92	7.48
MgO		15.41	7.43
CaO		–	15.06
MnO		2.84	–
Al_2O_3		7.12	4.88
Cr_2O_3		29.27	14.69
Na_2O		–	1.70
LOI		–	13.86

The filter system must include a gas cooler to protect the bags. Usually a mechanical collector is used to prevent large burning particles which have been ejected from the furnace from reaching the bags and burning holes in them. The type of dust being collected has a marked effect on the pressure drop encountered.

Electrostatic precipitators operate at the lowest pressure drop of the three alternatives. They produce no visible plume and can handle high temperatures more easily than baghouses. Ferroalloy particulate emissions, however, have resistivities which are too high for good precipitator operation.(5) Either operation at high temperature, where the resistivity is acceptable, or conditioning, to alter the resistivity, is required to achieve acceptable performance. Either alternative increases the cost of collection.

SPECIFICATIONS AND COSTS

Specifications have been written for a furnace producing ferrosilicon and for one producing ferrochrome. In each case, the furnace chosen was an open hood submerged-arc type. This type was selected because it is the one used in the majority of industrial applications. Table 129 shows the number and types of furnaces used in the U.S.(2) About 75% of the furnaces used in this country are open hood submerged arc types.

The sizes of the ferrosilicon furnaces selected for the specification were 10 mw and 40 mw. This corresponds to a production rate of 2 tons/hr and 8 tons/hr of 50% ferrosilicon. The ferrochrome furnace sizes selected were 8 mw and 30 mw which produce 1.9 tons/hr and 7.1 tons/hr of high-carbon ferrochrome containing 70% chromium. For each of the four furnaces, specifications were written for a scrubber, a fabric collector, and an electrostatic precipitator.

The exhaust gas volumes used in the specifications were based upon published data for open hood submerged-arc furnaces.(5) Exhaust gases for the 50% ferrosilicon cases were based upon a gas generation of 130 to 140 SCFM/mw and a dilution factor in the hood of 27. Gases for the ferrochrome cases were based upon a gas generation of 80 to 90 SCFM/mw and the same hood dilution factor as for ferrosilicon.

There were no quotations received in response to the precipitator specification. One supplier reported no industrial experience in this application and, as it is a difficult application, could supply no cost estimates. A second supplier cited extensive pilot plant data which demonstrated that conventional precipitator design was not applicable and that the modifications necessary prevented precipitators from being competitive. As a result, this supplier will not quote dry precipitators for ferroalloy applications. The combination of a low energy scrubber followed by a wet precipitator offers an attractive alternative.

Responses to the scrubber specification were varied. All suppliers commented that the pressure drops required to achieve the specified performance levels were high. The quotations from one of the suppliers were based on equipment which, in some cases, could not achieve the cleaning efficiency specified. The supplier quoted equipment for the maximum performance level he could supply. The specified cleaning efficiency was quoted only for the ferrochrome furnace scrubbers designed for the LA Process Weight efficiency. The other supplier who quoted scrubber systems for these applications stated that pilot plant pressure drop determinations would have to be made before the systems could be guaranteed. The cost shown for scrubbing systems, therefore, must be classified as representing undemonstrated technology.

Scrubbing systems were quoted including gas cooling towers. One of the suppliers commented that savings could be effected by the elimination of gas cooling with only minor increases in the capital and operating cost of fans and motors. Capital cost savings would average about 3% for the small furnaces and 5% for the large furnaces. Total annual operating costs would also be lower.

Only one response was received to the fabric filter specification. Only costs for the high efficiency level were presented, as in the case of all of the fabric filter quotations solicited in this contract.

Capital and operating costs for fabric filters are presented in Tables 132, 133, 136, and 137. The data are plotted in Figures 99, 100, 101, and 102. All of the data are based upon a single quotation.

Capital and operating costs for wet scrubbers are presented in Tables 144, 145, 148, and 149. These data are plotted in Figures 103, 104, 105, and 106. Only those data which represent cleaning efficiencies at the levels designated in the

TABLE 129

DISTRIBUTION OF DOMESTIC FERROALLOY FURNACES

Furnace Type	Number In Use	% of Total
Submerged Arc – Open Hood	100-150	71-76
Submerged Arc – Closed Hood	30-35	21-18
Open Arc	12	8-6

Alloy Type	Approximate Percent of Total Production Facilities
Silicon Alloys	40
Chromium Alloys	25
Manganese Alloys	20
Calcium Carbide	10

equipment specification have been presented. Graphs for the ferrosilicon furnaces are limited to the LA–Process Weight Case in order to avoid presentation of data based on extrapolation to higher efficiency levels than those within the experience of any of the participants in this study.

TABLE 130

FABRIC FILTER PROCESS DESCRIPTION FOR FERROSILICON FURNACE SPECIFICATION

The air pollution abatement system is to serve a new ferroalloy furnace installation. The furnace is the submerged arc type and has been equipped with an open hood by the furnace supplier. The furnace is charged with raw material continuously and is tapped intermittently on a two hour cycle. Hooding of the tap holes has also been installed by the furnace supplier.

The abatement system shall include the following:

(a) *Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.*

(b) *A mechanical collector upstream of the baghouse to help protect the bags from burning particles.*

(c) *A gas cooler to lower the temperature of the gas going to the baghouse to 400°F during normal operation.*

(d) *Compartmented design of the baghouse which permits shutdown of each section for maintenance.*

(e) *Sufficient capacity for operation with one compartment out of service.*

(f) *Bags with a temperature rating of* $\geq 500^{o}F$.

(g) *A high temperature bypass around the fabric filter for use during operational upsets.*

(h) *Dust hoppers and conveyors.*

(i) *Dust storage bins with 24 hour capacity.*

Two sizes of fabric collectors have been specified for each of the two efficiency levels. Vendors responses should, however, consist of only one quotation for each of the two sizes, with a representation of the efficiency expected.

TABLE 131

FABRIC FILTER OPERATING CONDITIONS FOR FERROSILICON FURNACE SPECIFICATION

	Small	*Large*
Furnace Size, mw	*10*	*40*
*Alloy Production Rate, ton/hr**	*2*	*8*
Process Weight, ton/hr	*4.4*	*17.6*
Gas to Dilution Cooler		
Flow, ACFM	*63,700*	*255,000*
Temp., °F	*460*	*460*
Flow, SCFM	*36,000*	*144,000*
Gas to Collector		
Flow, ACFM	*72,500*	*290,100*
Temp., °F	*400*	*400*
Flow, SCFM	*44,750*	*180,000*
Particulate Loading, gr/ACF	*0.91*	*0.91*
lb/hr	*463*	*1,852*
Case 1 – Medium Efficiency		
Outlet Loading, lb/hr	*9.23*	*40.0*
Outlet Loading, gr/ACF	*0.0181*	*0.0196*
Efficiency, wt. %	*98.0*	*97.8*
Case 2 – High Efficiency		
Outlet Loading, lb/hr	*5.10*	*20.4*
Outlet Loading, gr/ACF	*0.01*	*0.01*
Efficiency, wt. %	*98.9*	*98.9*

**Average over operating cycle*

TABLE 132

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR FABRIC FILTERS
FOR FERROSILICON FURNACES

			High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			63,700	255,000
°F			460	460
SCFM			36,000	144,000
Moisture Content, Vol. %			-	-
Effluent Dust Loading				
gr/ACF			.85	.85
lb/hr			463	1,852
Cleaned Gas Flow				
ACFM			72,500	290,100
°F			400	400
SCFM			44,750	180,000
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF			<<0.01	<< 0.01
lb/hr			<< 5.9	<< 5.9
Cleaning Efficiency, %			99.9+	99.9+
(1) Gas Cleaning Device Cost			126,350	489,470
(2) Auxiliaries Cost				
(a) Fan(s)			20,000	107,000
(b) Pump(s)			0	0
(c) Damper(s)			4,000	9,500
(d) Conditioning, Equipment			4,500	11,900
(e) Dust Disposal Equipment			12,000	25,800
(3) Installation Cost				
(a) Engineering			7,200	17,000
(b) Foundations & Support			163,400	359,200
(c) Ductwork			6,620	12,280
(d) Stack			10,140	26,000
(e) Electrical			5,750	23,000
(f) Piping			5,750	23,000
(g) Insulation			-	-
(h) Painting			2,140	3,440
(i) Supervision			19,300	43,000
(j) Startup			2,140	4,000
(k) Performance Test			Incl.	Startup
(l) Other - erection			83,780	316,480
(4) Total Cost			473,070	1,471,070

TABLE 133

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS FOR FERROSILICON FURNACES

Operating Cost Item	Unit Cost			High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$6/hr	18,000	18,000		
Supervisor	$8/hr	1,200	1,200		
Total Operating Labor		19,200	19,200		
Maintenance					
Labor					
Materials					
Total Maintenance		4,560	11,800		
Replacement Parts					
Total Replacement Parts		7,500	31,640		
Utilities					
Electric Power	$.011/kw-Hr	17,730	62,300		
Fuel		-	-		
Water (Process)		-	-		
Water (Cooling)		-	-		
Chemicals, Specify		-	-		
Total Utilities		17,730	62,300		
Total Direct Cost		48,990	124,940		
Annualized Capital Charges		47,300	147,100		
Total Annual Cost		98,290	272,040		

FIGURE 99
CAPITAL COSTS FOR FABRIC FILTERS FOR FERROSILICON FURNACES

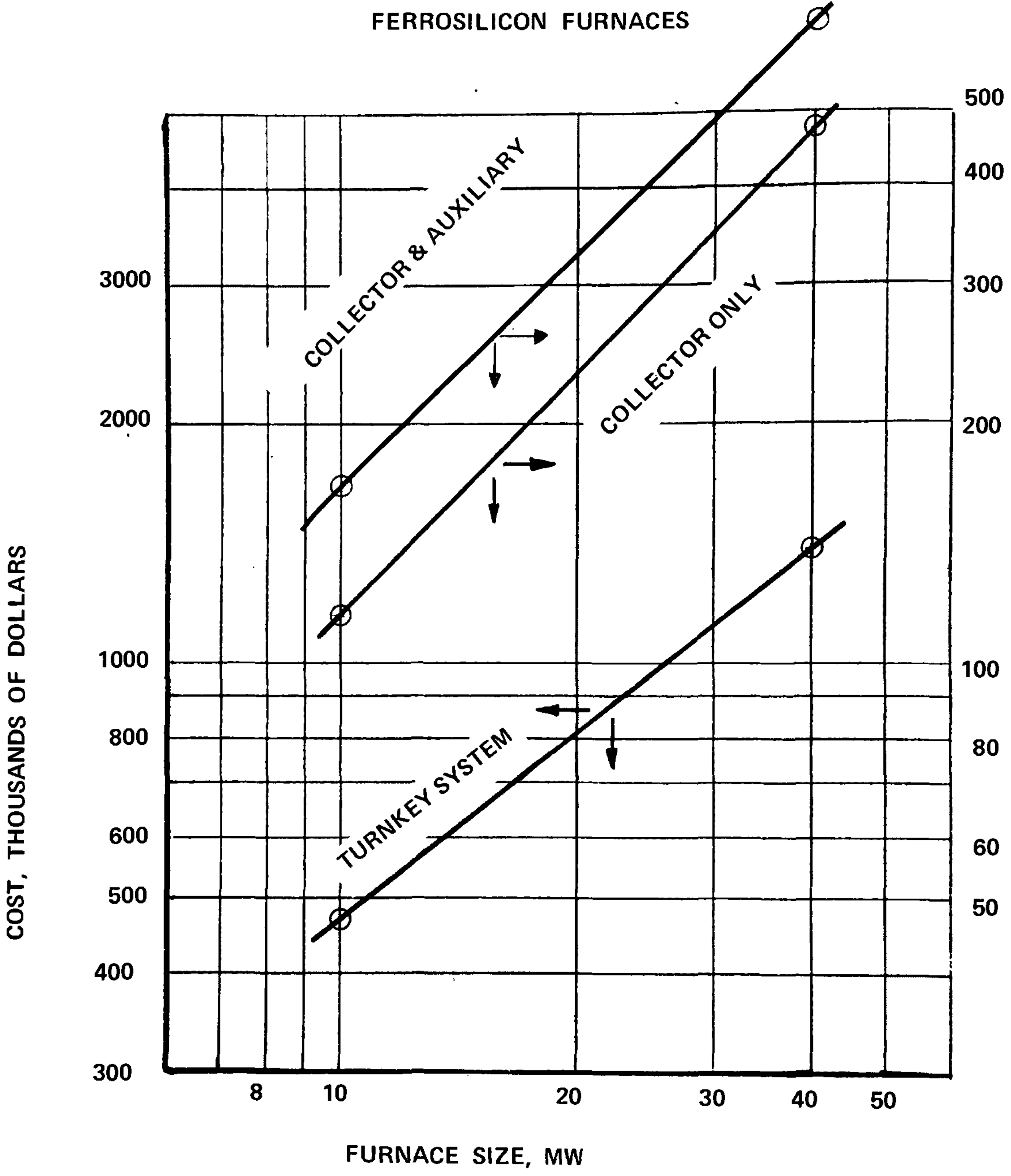


FIGURE 100
ANNUAL COSTS FOR FABRIC FILTERS FOR FERROSILICON FURNACES

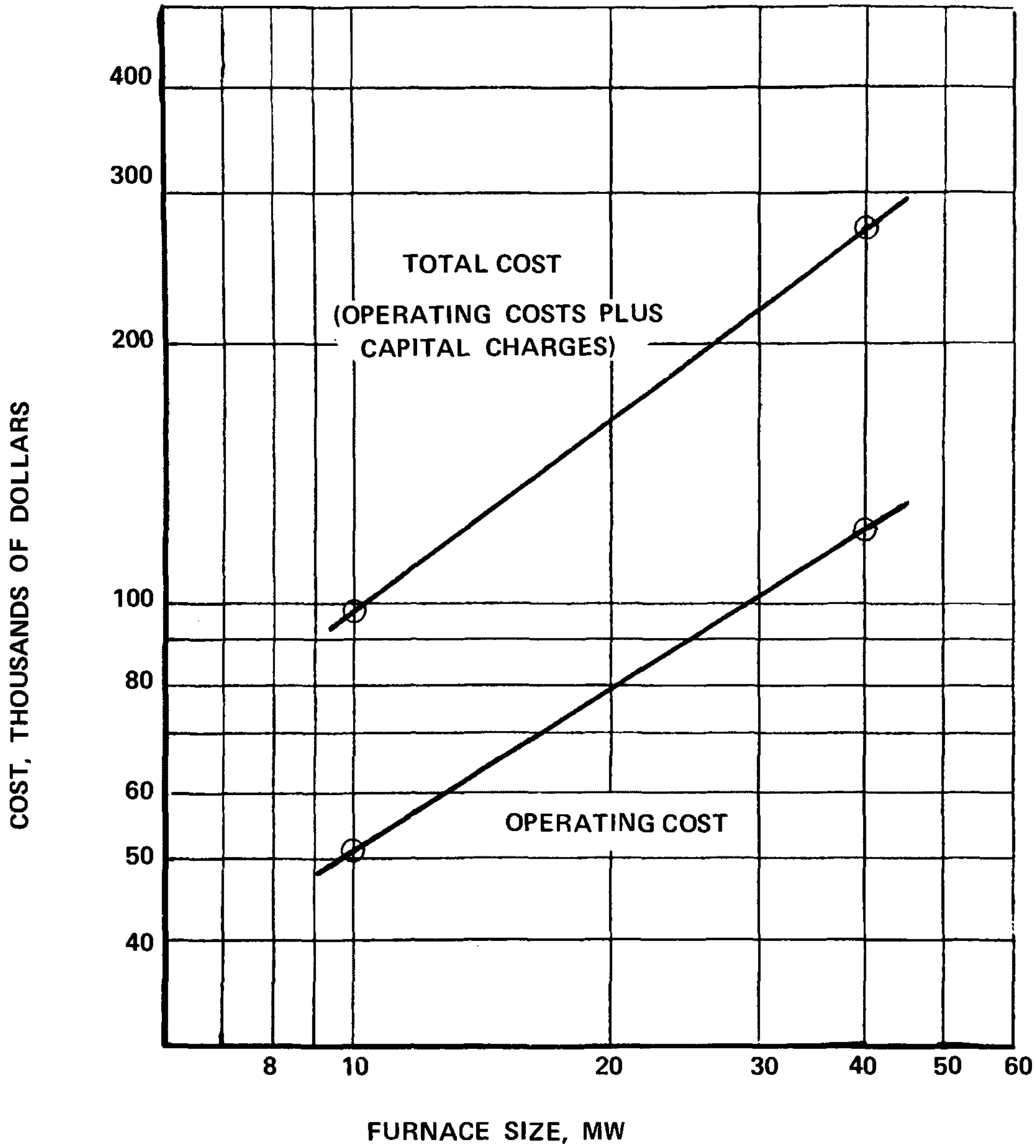


TABLE 134

FABRIC FILTER PROCESS DESCRIPTION FOR FERROCHROME FURNACE SPECIFICATION

The air pollution abatement system is to serve a new ferroalloy furnace installation. The furnace is the submerged arc type and has been equipped with an open hood by the furnace supplier. The furnace is charged with raw material continuously and is tapped intermittently on a two hour cycle. Hooding of the tap holes has also been installed by the furnace supplier. The abatement system shall include the following:

(a) Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.

(b) A mechanical collector upstream of the baghouse to help protect the bags from burning particles.

(c) A gas cooler to lower the temperature of the gas going to the baghouse to 400°F during normal operations.

(d) Compartmented design of the baghouse which permits shutdown of one section for maintenance.

(e) Sufficient capacity for operation with compartment out of service.

(f) Bags with a temperature rating of $\geq 500^{o}F$.

(g) A high temperature bypass around the fabric filter for use during operational upsets.

(h) Dust hoppers and conveyors.

(i) Dust storage with a capacity of 24 hours.

Two sizes of fabric collectors have been specified for each of two efficiency levels. Vendors responses should, however, consist of only one quotation for each of the two sizes with a representation of the efficiency expected.

TABLE 135

FABRIC FILTER OPERATING CONDITIONS FOR FERROCHROME FURNACE SPECIFICATION

	Small	*Large*
Furnace Size, mw	*8*	*30*
*Alloy Production Rate, ton/hr**	*1.9*	*7.1*
Process Weight, ton/hr	*4.9*	*18.3*
Gas to Dilution Cooler		
Flow, ACFM	*33,200*	*125,000*
Temp., °F	*480*	*480*
Flow, SCFM	*18,400*	*69,000*
Gas to Collector		
Flow, ACFM	*39,400*	*148,200*
Temp., °F	*400*	*400*
Flow, SCFM	*23,300*	*91,500*
Particulate Loading		
gr/ACF	*0.67*	*0.67*
lb/hr	*174*	*650*
	Case 1 – Medium Efficiency	
Outlet Loading, lb/hr	*10.25*	*26.32*
Outlet Loading, gr/ACF	*0.0394*	*0.0269*
Efficiency, wt. %	*94.1*	*95.9*
	Case 2 – High Efficiency	
Outlet Loading, lb/hr	*2.60*	*9.76*
Outlet Loading, gr/ACF	*0.01*	*0.01*
Efficiency, wt. %	*98.5*	*98.5*

**Average over operating cycle.*

TABLE 136

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR FABRIC FILTERS
FOR FERROCHROME FURNACES

			High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM			33,200	125,000
°F			480	480
SCFM			18,400	69,000
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF			0.61	0.61
lb/hr			174	650
Cleaned Gas Flow				
ACFM			39,400	148,200
°F			400	400
SCFM			23,300	91,500
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
gr/ACF			≪0.01	≪0.01
lb/hr			<<2.60	<<2.60
Cleaning Efficiency, %			99.9+	99.9+
(1) Gas Cleaning Device Cost			102,270	283,260
(2) Auxiliaries Cost				
(a) Fan(s)			17,000	57,000
(b) Pump(s)			0	0
(c) Damper(s)			2,900	3,200
(d) Conditioning, Equipment			3,600	4,000
(e) Dust Disposal Equipment			12,000	15,700
(3) Installation Cost				
(a) Engineering			7,200	10,700
(b) Foundations & Support			132,300	185,800
(c) Ductwork			3,870	8,070
(d) Stack			8,400	14,230
(e) Electrical			5,750	13,000
(f) Piping			5,750	13,000
(g) Insulation			-	-
(h) Painting			1,700	3,000
(i) Supervision			17,000	28,500
(j) Startup				
(k) Performance Test			1,700	2,150
(l) Other			75,940	180,990
(4) Total Cost			397,080	822,600

TABLE 137

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS FOR FERROCHROME FURNACES

Operating Cost Item	Unit Cost			High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$6/hr	18,000	18,000		
Supervisor	$8/hr	1,200	1,200		
Total Operating Labor		19,200	19,200		
Maintenance					
Labor					
Materials					
Total Maintenance		4,400	6,600		
Replacement Parts					
Total Replacement Parts		6,540	17,840		
Utilities					
Electric Power	$.011/kw-hr	10,600	32,200		
Fuel		-	-		
Water (Process)		-	-		
Water (Cooling)		-	-		
Chemicals, Specify		-	-		
Total Utilities		10,600	32,200		
Total Direct Cost		40,740	75,840		
Annualized Capital Charges		39,700	82,300		
Total Annual Cost		80,440	158,140		

FIGURE 101
CAPITAL COSTS FOR FABRIC FILTERS FOR FERROCHROME FURNACES

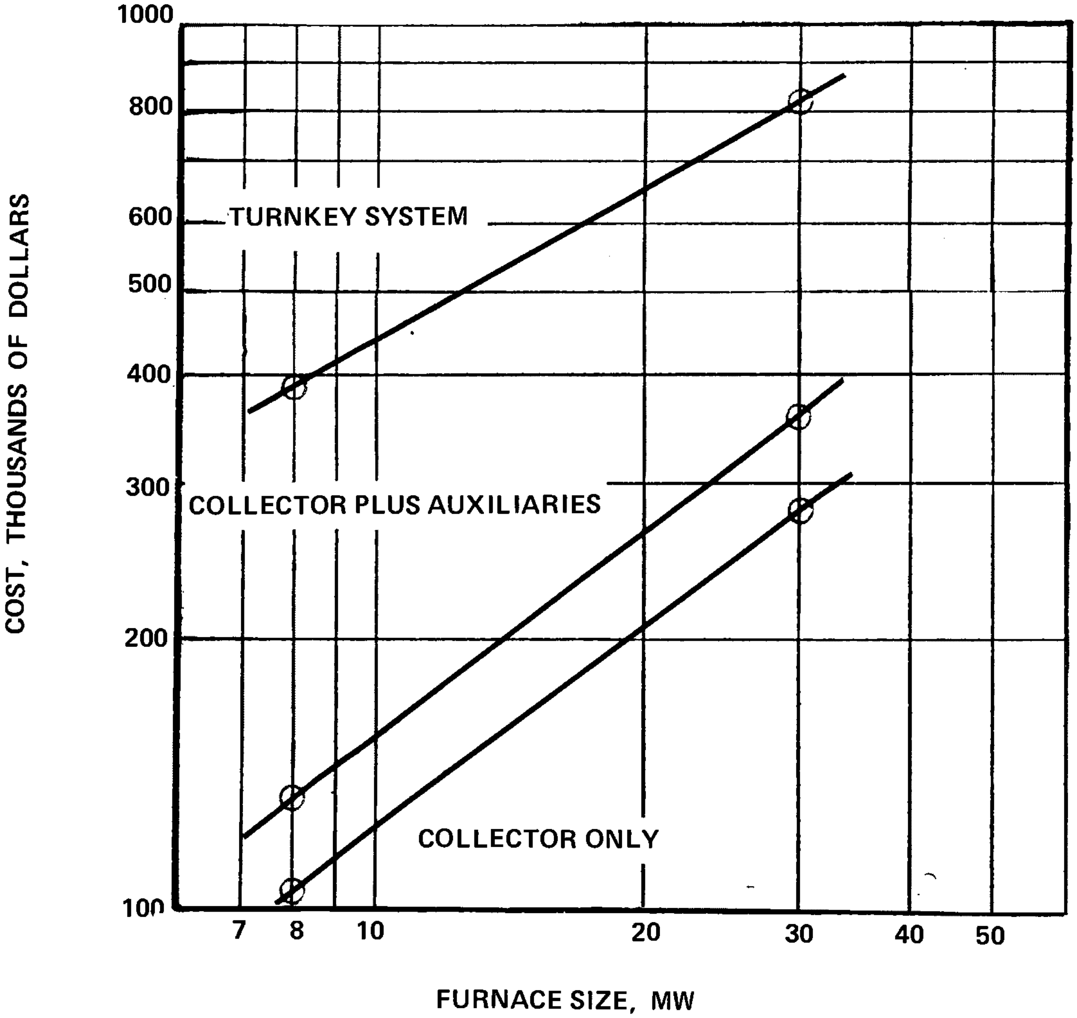


FIGURE 102
ANNUAL COSTS FOR FABRIC FILTERS FOR FERROCHROME FURNACES

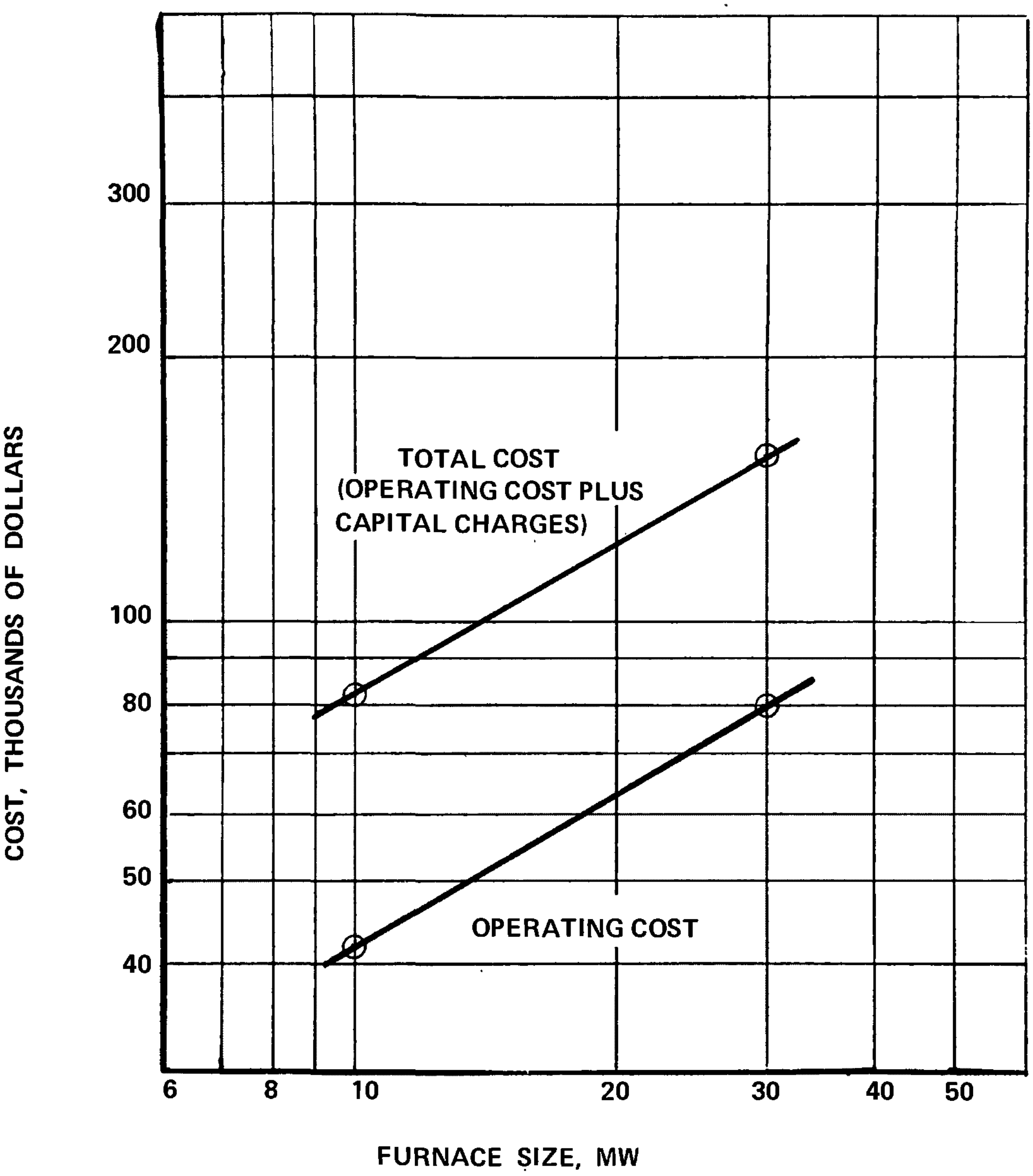


TABLE 138

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR FERROSILICON FURNACE SPECIFICATION

The air pollution abatement system is to serve a new ferroalloy furnace installation. The furnace is the submerged arc type and has been equipped with an open hood by the furnace supplier. The furnace is charged with raw material continuously and is tapped intermittently on a two hour cycle. Hooding of the tap holes has also been installed by the furnace supplier. The abatement system shall include the following:

(a) A gas conditioning system to overcome the high resistivity of the particulate emitted.

(b) Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.

(c) A precipitator with a minimum of two fields in the direction of gas flow.

(d) A safety interlock system which prevents access to the precipitator internals unless the electrical circuitry is disconnected or grounded.

(e) Dust hoppers and conveyors.

(f) Dust storage with 24 hour capacity.

(g) A model study for the precipitator gas distribution.

Two sizes of precipitators are to be quoted for each of two efficiency levels. Vendors quotes should consist of four separate and independent sets of figures.

TABLE 139

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR FERROSILICON FURNACE SPECIFICATION

	Small	*Large*
Furnace Size, mw	*10*	*40*
*Alloy Production Rate, ton/hr**	*2*	*8*
Process Weight, ton/hr	*4.4*	*17.6*
Gas to Conditioner		
Flow, ACFM	*63,700*	*253,000*
Temp., °F	*460*	*460*
Flow, SCFM	*36,000*	*144,000*
Gas to Collector		
Flow, ACFM	*84,000*	*336,000*
Temp., °F	*185*	*185*
Flow, SCFM	*67,700*	*271,000*
Humidity, lb H_2O/lb DA	*0.55*	*0.55*
Particulate loading		
gr/ACF	*0.64*	*0.61*
lb/hr	*463*	*1,852*
	Case 1 – Medium Efficiency	
Outlet Loading, lb/hr	*9.23*	*43.1*
Outlet Loading, gr/ACF	*0.0128*	*0.0139*
Efficiency, wt. %	*98.0*	*97.8*
	Case 2 – High Efficiency	
Outlet Loading, lb/hr	*7.20*	*28.8*
Outlet Loading, gr/ACF	*0.01*	*0.01*
Efficiency, wt. %	*98.4*	*98.4*

**Average over operating cycle.*

TABLE 140

ELECTROSTATIC PRECIPITATOR PROCESS DESCRIPTION FOR FERROCHROME FURNACE SPECIFICATION

The air pollution abatement system is to serve a new ferroalloy furnace installation. The furnace is the submerged arc type and has been equipped with an open hood by the furnace supplier. The furnace is charged with raw material continuously and is tapped intermittently on a two hour cycle. Hooding of the tap holes has also been installed by the furnace supplier. The abatement system shall include the following:

(a) A gas conditioning system to combat the high resistivity of the particulate emitted.

(b) Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.

(c) A precipitator with a minimum of two fields in the direction of gas flow.

(d) A safety interlock system which prevents access to the precipitator internals unless the electrical circuitry is disconnected or grounded.

(e) Dust hoppers and conveyors.

(f) Dust storage with 24 hour capacity.

(g) A model study for the precipitator gas distribution.

Two sizes of precipitators are to be quoted for each of two efficiency levels. Vendors quotes should consist of four separate and independent sets of figures.

TABLE 141

ELECTROSTATIC PRECIPITATOR OPERATING CONDITIONS FOR FERROCHROME FURNACE SPECIFICATION

	Small	*Large*
Furnace Size, mw	*8*	*30*
*Alloy Production Rate, ton/hr**	*1.9*	*7.1*
Process Weight, ton/hr	*4.9*	*18.3*
Gas to Conditioner		
Flow, ACFM	*33,200*	*125,000*
Temp., ^{o}F	*480*	*480*
Flow, SCFM	*18,400*	*69,000*
Gas to Collector		
Flow, SCFM	*37,400*	*140,000*
Temp., ^{o}F	*185*	*185*
Flow, SCFM	*30,200*	*113,000*
Humidity, lb H_2O/lb DA	*0.40*	*0.40*
Particulate Loading		
gr/ACF	*0.54*	*0.54*
lb/hr	*174*	*650*
	Case 1 — Medium Efficiency	
Outlet Loading, lb/hr	*10.25*	*26.32*
Outlet Loading, gr/ACF	*0.032*	*0.022*
Efficiency, wt. %	*94.1*	*95.9*
	Case 2 — High Efficiency	
Outlet Loading, lb/hr	*3.21*	*12.00*
Outlet Loading, gr/ACF	*0.01*	*0.01*
Efficiency, wt. %	*98.2*	*98.2*

**Average over operating cycle.*

TABLE 142

WET SCRUBBER PROCESS DESCRIPTION FOR FERROSILICON FURNACE SPECIFICATION

The air pollution abatement system is to serve a new ferroalloy furnace installation. The furnace is the submerged arc type and has been equipped with an open hood by the furnace supplier. The furnace is charged with raw material continuously and is tapped intermittently on a two hour cycle. Hooding of the tap holes has also been installed by the furnace supplier. The abatement system shall include the following:

(a) Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.

(b) A Venturi type scrubber with a liquid to gas ratio in excess of 7 GPM/1000 ACFM (saturated).

(c) An entrainment separator which will limit entrained water in the effluent.

(d) Aftercoolers capable of reducing the effluent gas temperature to 105°F by countercurrent contact with 90°F cooling water.

(e) A slurry settler capable of producing a reasonably thickened underflow product while returning water fully treated to minimize solids content.

(f) Filters to dewater the slurry product which are capable of producing a filter cake with $\geq$70% solids content suitable for open truck transportation. A minimum of two units shall be provided.

Vendors shall specify the pressure drop at which the scrubber will operate. Two sizes of scrubber have been specified at each of two efficiency levels. Vendors quotations shall consist of four separate and independent sets of numbers.

TABLE 143

WET SCRUBBER OPERATING CONDITIONS FOR FERROSILICON FURNACE SPECIFICATION

	Small	*Large*
Furnace Size, mw	*10*	*40*
*Alloy Production Rate, ton/hr**	*2*	*8*
Process Weight, ton/hr	*4.4*	*17.6*
Gas to Scrubber		
Flow, ACFM	*63,700*	*253,000*
Temp., °F	*460*	*460*
Flow, SCFM	*36,000*	*144,000*
Particulate Loading		
gr/ACF	*0.85*	*0.85*
lb/hr	*463*	*1,852*
Gas from Scrubber		
Flow, ACFM	*45,300*	*180,000*
Temp., °F	*117*	*117*
Flow, SCFM	*40,800*	*162,000*
Moisture Content, mol. %	*11*	*11*
Gas from After Cooler		
Flow, ACFM	*42,400*	*169,000*
Temp., °F	*105*	*105*
Flow, SCFM	*39,000*	*156,000*
Moisture Content, mol. %	*7.6*	*7.6*
Case 1 — Medium Efficiency		
Outlet Loading, lb/hr	*9.23*	*25.4*
Outlet Loading, gr/ACF	*.0254*	*.0175*
Efficiency, wt. %	*98.0*	*98.6*
Case 2 — High Efficiency		
Outlet Loading, lb/hr	*3.63*	*14.48*
Outlet Loading, gr/ACF	*0.01*	*0.01*
Efficiency, wt. %	*99.2*	*99.2*

**Average over the operating cycle*

TABLE 144

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS
FOR FERROSILICON FURNACES

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	63,700	253,000	63,700	253,000
°F	460	460	460	460
SCFM	36,000	144,000	36,000	144,000
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF	0.85	0.85	0.85	0.85
lb/hr	463	1,852	463	1,852
Cleaned Gas Flow				
ACFM	42,400	169,000	42,400	169,000
°F	105	105	105	105
SCFM	39,000	156,000	39,000	156,000
Moisture Content, Vol. %	7.6	7.6	7.6	7.6
Cleaned Gas Dust Loading				
gr/ACF	.025	0.0175	.01	.01
lb/hr	9.2	25.4	3.6	14.5
Cleaning Efficiency, %	98.0	98.6	99.2	99.2
(1) Gas Cleaning Device Cost	40,200	134,900	40,200	134,900
(2) Auxiliaries Cost (a) Fan(s) (b) Pump(s) (c) Damper(s) (d) Conditioning, Equipment (e) Dust Disposal Equipment	129,700	299,700	181,500	400,000
(3) Installation Cost (a) Engineering (b) Foundations & Support (c) Ductwork (d) Stack (e) Electrical (f) Piping (g) Insulation (h) Painting (i) Supervision (j) Startup (k) Performance Test (l) Other	874,100	1,750,400	929,300	1,877,200
(4) Total Cost	1,044,000	2,185,000	1,151,000	2,413,000

TABLE 145

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR FERROSILICON FURNACES

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor		3,600	4,800	3,600	4,800
Maintenance					
Labor					
Materials					
Total Maintenance		52,000	109,000	57,500	122,000
Replacement Parts					
Total Replacement Parts		31,000	65,500	34,500	72,000
Utilities *					
Electric Power	$.011/kw-hr	66,000	286,550	119,900	490,600
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)	$.05/M gal	36,750	148,040	44,005	173,155
Chemicals, Specify		-	-	-	-
Total Utilities		102,750	434,590	163,905	663,755
Total Direct Cost		189,350	613,890	259,505	861,555
Annualized Capital Charges		104,400	218,500	115,100	241,300
Total Annual Cost		293,750	832,390	374,605	1,102,855

FIGURE 103

CAPITAL COSTS FOR WET SCRUBBERS
FOR FERROSILICON FURNACES

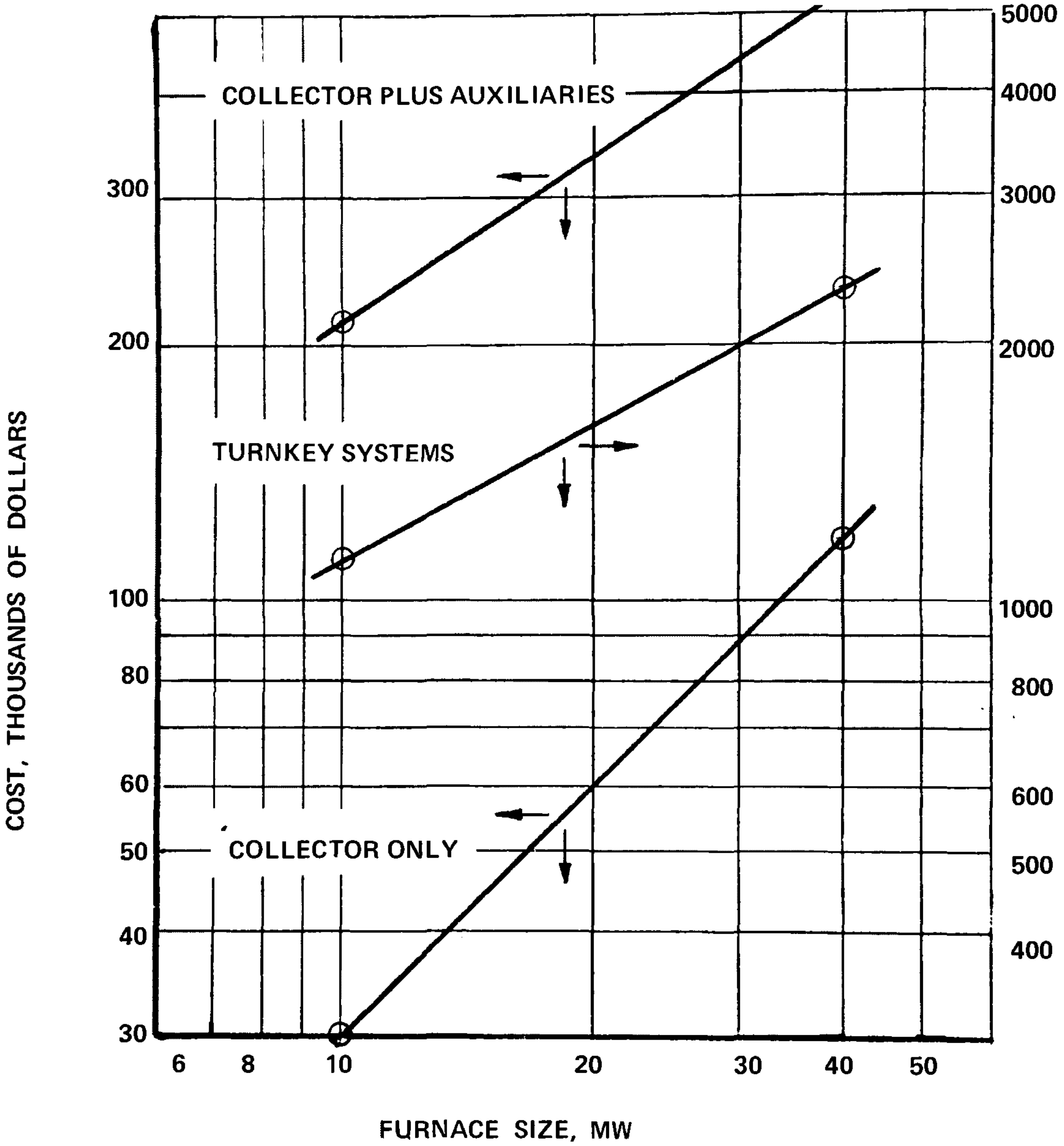


FIGURE 104
ANNUAL COSTS FOR WET SCRUBBERS FOR FERROSILICON FURNACES

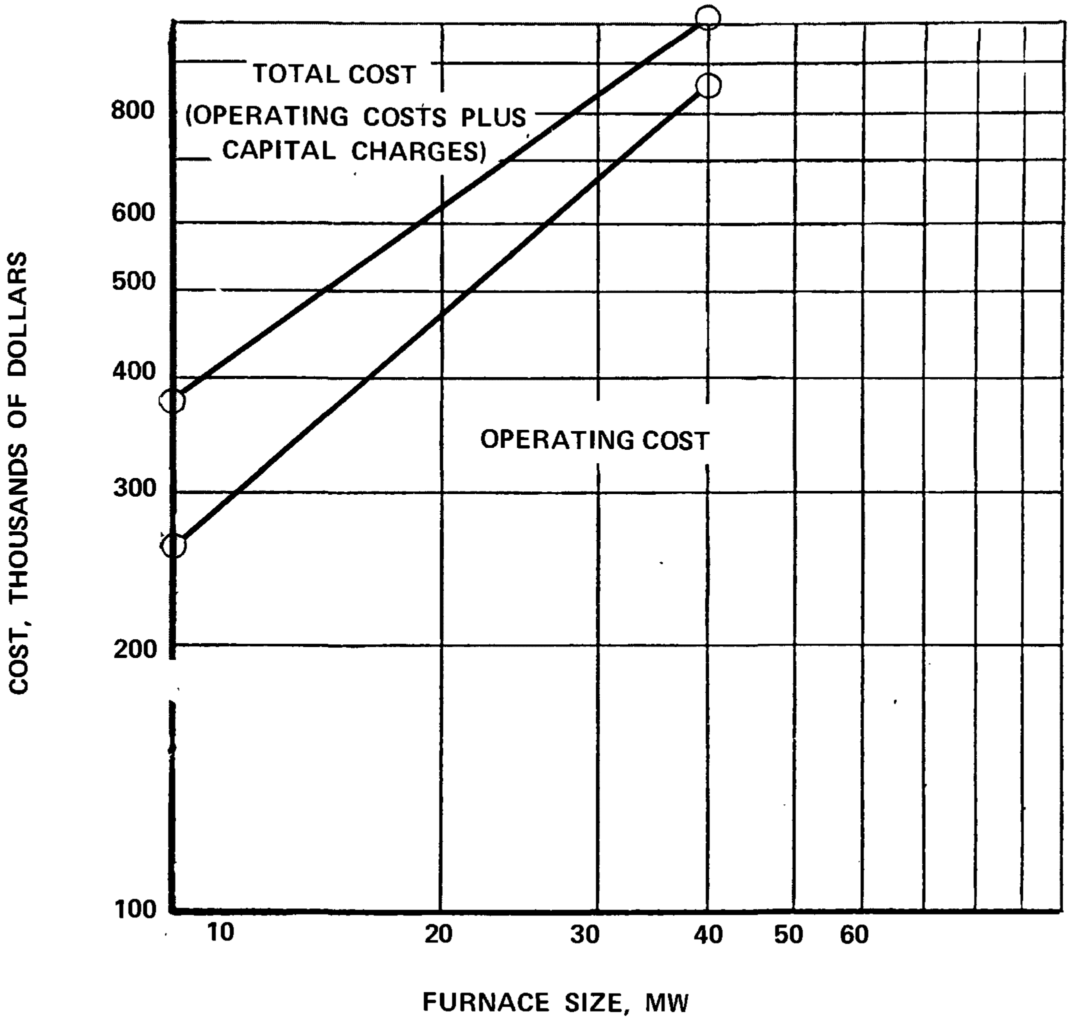


TABLE 146

WET SCRUBBER PROCESS DESCRIPTION FOR FERROCHROME FURNACE SPECIFICATION

The air pollution abatement system is to serve a new ferroalloy furnace installation. The furnace is the submerged arc type and has been equipped with an open hood by the furnace supplier. The furnace is charged with raw material continuously and is tapped intermittently on a two hour cycle. Hooding of the tap holes has also been installed by the furnace supplier.

The abatement system shall include the following:

(a) Fans sized with at least 20% excess capacity when operating at the design pressure drop and 90% of the maximum recommended operating speed.

(b) A Venturi-type scrubber with a liquid to gas ratio in excess of 5 GPM/1000 ACFM (saturated).

(c) An entrainment separator which will limit entrained water in the effluent.

(d) Aftercoolers capable of reducing the effluent gas temperature to 105°F by countercurrent contact with 90°F cooling water.

(e) Slurry settler capable of producing a reasonably thickened underflow product while returning water fully treated to minimize solids content.

(f) Filters to dewater the slurry product which are capable of producing a filter cake with $\geq$70% solids content suitable for open truck transportation. A minimum of two units shall be provided.

Vendors shall specify the pressure drop at which the scrubber will operate. Two sizes of scrubbers have been specified at each of two efficiency levels. Vendors quotations shall consist of four separate and independent sets of numbers.

TABLE 147

WET SCRUBBER OPERATING CONDITIONS
FOR FERROCHROME FURNACE SPECIFICATION

	Small	*Large*
Furnace Size, mw	*8*	*30*
*Alloy Production Rate, ton/hr**	*1.9*	*7.1*
Process Weight, ton/hr	*4.9*	*18.3*
Gas to Scrubber		
Flow, ACFM	*33,200*	*125,000*
Temp., °F	*480*	*480*
Flow, SCFM	*18,400*	*69,000*
Particulate Loading		
gr/ACF	*0.61*	*0.61*
lb/hr	*174*	*650*
Gas from Scrubber		
Flow, ACFM	*23,200*	*87,000*
Temp., °F	*119*	*119*
Flow, SCFM	*20,800*	*78,100*
Moisture Content, mol. %	*12*	*12*
Gas from Cooling Tower		
Flow, ACFM	*21,500*	*81,000*
Temp., °F	*105*	*105*
Flow, SCFM	*19,800*	*74,500*
Moisture Content, mol. %	*7.6*	*7.6*
Case 1 — Medium Efficiency		
Outlet Loading, lb/hr	*10.25*	*26.32*
Outlet Loading, gr/ACF	*.056*	*.038*
Efficiency, wt. %	*94.1*	*95.9*
Case 2 — High Efficiency		
Outlet Loading, lb/hr	*1.84*	*6.95*
Outlet Loading, gr/ACF	*0.01*	*0.01*
Efficiency, wt. %	*98.9*	*98.9*

**Average over the operating cycle*

TABLE 148

ESTIMATED CAPITAL COST DATA
(COSTS IN DOLLARS)
FOR WET SCRUBBERS
FOR FERROCHROME FURNACES

	LA Process Wt.		High Efficiency	
	Small	Large	Small	Large
Effluent Gas Flow				
ACFM	33,200	125,000	33,200	125,000
°F	480	480	480	480
SCFM	18,400	69,000	18,400	69,000
Moisture Content, Vol. %				
Effluent Dust Loading				
gr/ACF	0.61	0.61	0.61	0.61
lb/hr	174	650	174	650
Cleaned Gas Flow				
ACFM	25,400	95,000	31,000	116,000
°F	105	105	105	105
SCFM	20,140	75,325	20,550	76,860
Moisture Content, Vol. %				
Cleaned Gas Dust Loading				
*gr/ACF	.05	.03	.01	.01
*lb/hr	10.0	26.0	1.8	6.9
Cleaning Efficiency, %				
(1) Gas Cleaning Device Cost	23,225	50,625	26,200	62,100
(2) Auxiliaries Cost (a) Fan(s) (b) Pump(s) (c) Damper(s) (d) Conditioning, Equipment (e) Dust Disposal Equipment	66,850	165,125	142,100	267,700
(3) Installation Cost (a) Engineering (b) Foundations & Support (c) Ductwork (d) Stack (e) Electrical (f) Piping (g) Insulation (h) Painting (i) Supervision (j) Startup (k) Performance Test (l) Other	463,250	799,200	664,700	1,153,200
(4) Total Cost	553,325	1,014,950	833,000	1,483,000

TABLE 149

ANNUAL OPERATING COST DATA

(COSTS IN $/YEAR)

FOR WET SCRUBBERS FOR FERROCHROME FURNACES

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor		14,900	14,900	14,900	14,900
Maintenance					
Labor					
Materials					
Total Maintenance		27,700	50,800	42,000	74,000
Replacement Parts					
Total Replacement Parts		11,700	20,500	25,000	44,500
Utilities					
Electric Power	$0.011/kw-hr	27,000	95,500	63,700	176,200
Fuel		-	-	-	-
Water (Process) Water (Cooling)	$0.05/M Gal	12,900	47,400	20,000	72,650
Chemicals, Specify		-	-	-	-
Total Utilities		39,900	142,900	83,700	248,850
Total Direct Cost		94,200	229,100	165,600	382,250
Annualized Capital Charges		55,300	101,500	83,300	148,300
Total Annual Cost		149,500	330,600	248,900	530,550

FIGURE 105

CAPITAL COSTS FOR WET SCRUBBERS FOR FERROCHROME FURNACES (HIGH EFFICIENCY)

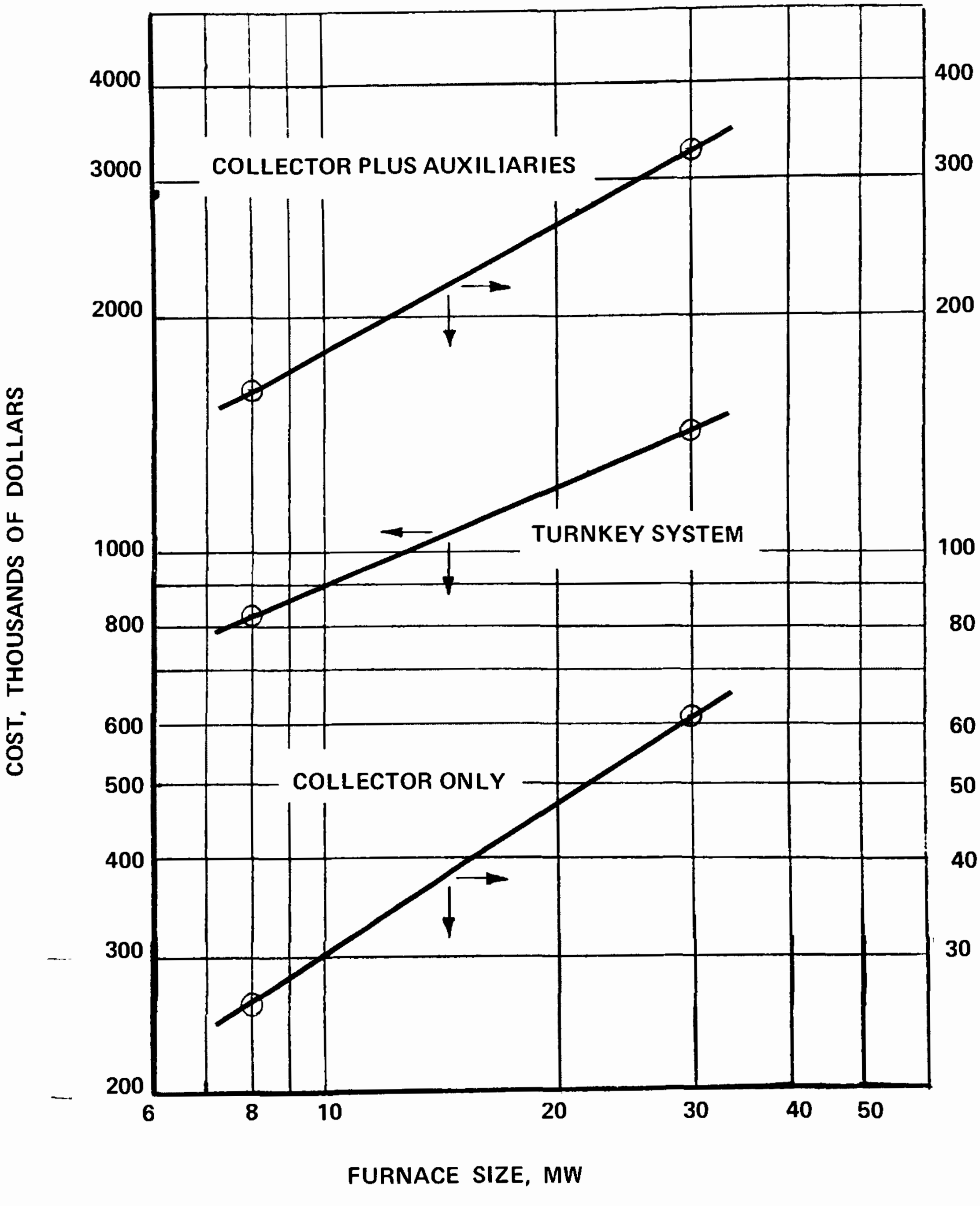
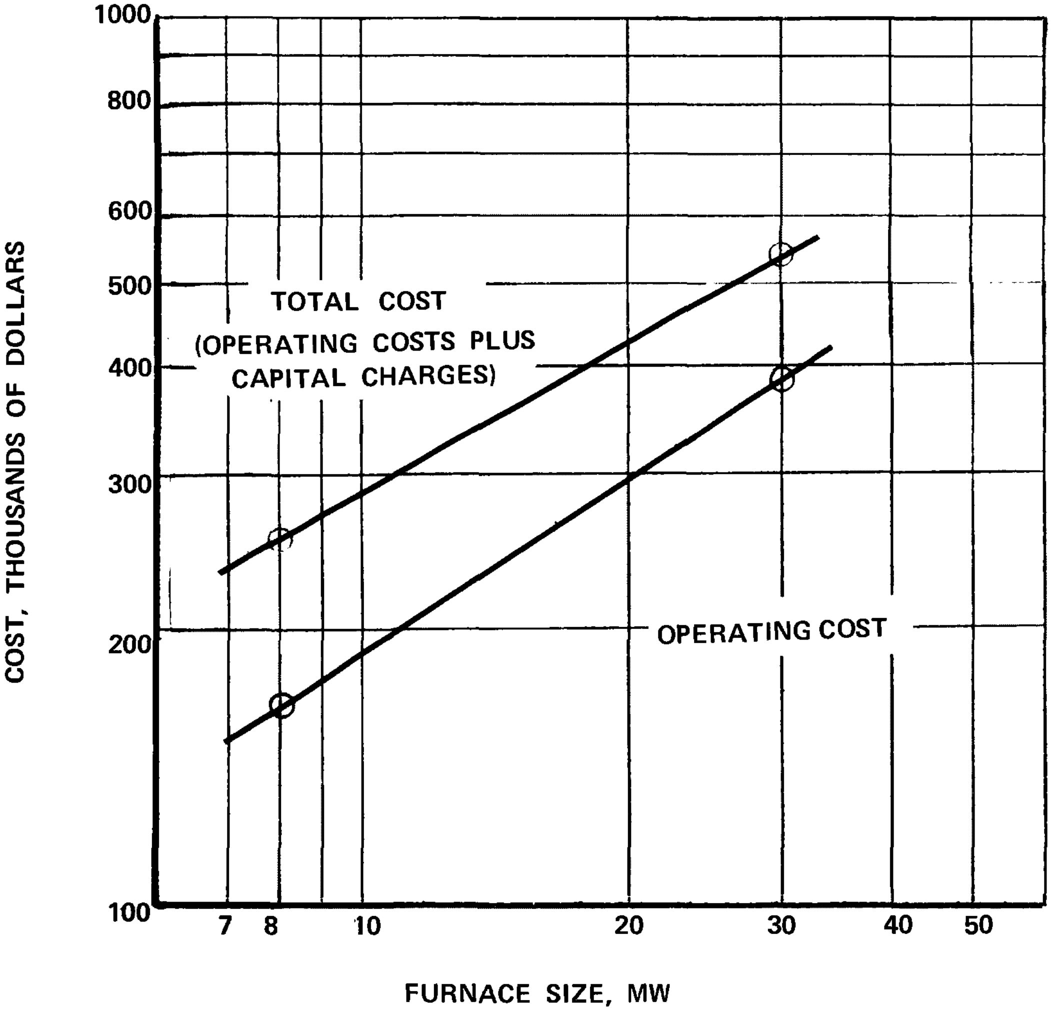


FIGURE 106
ANNUAL COSTS FOR WET SCRUBBERS FOR FERROCHROME FURNACES (HIGH EFFICIENCY)



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COST CORRELATIONS

C. Additional Cost Data

The previous section of this report has dealt with the costs of air pollution control for specific processing applications. This section deals with generalized cost correlations based upon the data obtained for the specific applications. Four sections are presented:

1. A brief discussion of the basis for presenting annual operating costs, including the capital charge portion of this cost

2. Derived capital cost indices for each specific process application

3. A presentation of the annual operating cost data for each process area calculated at two different levels of utility costs

4. Graphical correlations of capital and operating costs for each type of control equipment.

1. DISCUSSION OF COST BASIS

As previously noted in Section II A, the total annual cost for a particular process is the sum of the direct annual operating cost and an annual capital charge.

The direct annual operating cost includes the following cost items:

Operating (operator and supervisor) Labor
Maintenance Labor and Materials
Replacement Parts
Utilities and Supplies

The annual costs for these operating items are calculated from two sets of unit cost data; one approaching the upper limit of unit cost, the other the lower limit. An intermediate value was used in calculating annual operating costs in the preceding section of this report.

The approach to calculation of the capital charge portion of the annual operating cost for a pollution control system used in this program represents an attempt at spreading the investment cost of the system, including taxes and interest, across the useful life of the equipment. Many schemes for quantifying this charge have been proposed. These schemes fall into three major categories:

1. Straight line method which applies the capital charges at a fixed rate over the useful life of the control system.

2. Accelerated methods which apply the capital charges at a declining rate over the useful life, on the theory that aging or loss in value of equipment occurs to a greater degree on new equipment than on old equipment.

3. Methods which relate capital charges to some measure of equipment usage. These methods are seldom applied to processing equipment. The most common example is mileage-based depreciation of automobiles.

Of the two kinds of methods applicable to processing equipment, the most commonly used is the straight line method and it is the one used for the data presented in this report. Reasons for its common use are:

1. It is easy to understand and calculate.

2. It is thought by many to be the best approximation to the rate of obsolescence of process equipment.

3. It makes alternative control systems comparable on an annualized cost basis since the capital charges based upon this method are constant from year to year.

Once the decision has been made to use this method, the only critical issue is what value to use for the useful life of the control system. The useful life of any control system is, in reality, a composite of the useful lives of its component parts. Some of those parts have relatively long lives, others relatively short lives. The value chosen for the economic evaluation of a control system depends upon: the nature of the primary control device, the differences in expected useful life of similar equipment from different manufacturers, the maintenance practices of the owning firm, the battery limits defined for the system, the number and kind of structures built, and the accounting practices of the owning firm, among others. For these reasons, the value chosen will vary from firm to firm even for similar systems.

Taxes may also play a part in the determination of useful life. Under normal circumstances, control systems are depreciated over their normal useful lives. They may, however, be depreciated for tax purposes at an accelerated rate. Under certain circumstances, defined by the Internal Revenue Service, all or part of the air pollution control equipment may be amortized over a sixty month period. In most cases, this period is much shorter than the normal useful life. Accelerated depreciation for tax purposes, especially the sixty month amortization, has the effect of decreasing effective operating cost by deferring tax payments into the future. The discounted value of the cash outflow caused by the operation of the pollution control system is thereby reduced.

The money market at the time of equipment purchase is another important variable in the determination of capital charges. The rate at which money is available varies widely from firm to firm as well as with overall economic considerations. The cost of capital for financing by means other than borrowing also varies over a wide range from firm to firm. Variations in the cost of financing can be large enough to affect the choice between alternative control systems.

For the purpose of presenting the annual operating cost data in this report, it was decided to use the same fixed percentage of total installed cost as the capital charge for all of the applications studied. The rate chosen was 10%. It was based upon an estimated useful equipment life of 15 to 20 years, debt capital availability at 6 to 8%, and a correction for the tax incentives available to installers of pollution control hardware of 2 to 4%. Although the rate chosen is a good general estimate, it does not purport to be the correct rate for any specific situation. It is used only as a good estimate to assist the cost presentations in this report.

2. DERIVED CAPITAL COST INDICES

In each of the process applications discussed in the previous section of this report, capital costs have been presented for two different sizes of equipment. This permits development and evaluation of a mathematical expression for capital cost as a function of size for each application. The mathematical form chosen was the expotential form usually used for relating cost and size of equipment.

$$\text{Capital Cost} = K\ (\text{Size})^{x}$$

Where

K and x are constants, and
Size is the plant capacity of the process to which the abatement equipment is being applied.

This relationship assumes that a log-log plot of cost and size is a straight line. For most types of equipment, this assumption is good.

The constants K and x were evaluated by computer for each abatement application studied. Calculations were made for each of the three capital cost categories presented in each application:

1. Collector only
2. Collector plus auxiliaries
3. Turnkey system

Calculations were made using the computer program listed in Dartmouth Basic Language in Table 150.

The units of the "Size" term in the equation for each application are the same as those used in the prior discussion of that application. They are summarized in Table 151.

The results of these calculations for generating capital costs in dollars, are presented in the following tables:

Process Area	Table Numbers
Rendering	152 157
FCC	158 159
Asphalt Batching	160 161
BOF Steelmaking	162 164
Coal Cleaning	165
Brick and Tile	166 - 167
Copper Smelting	168 - 170
Bark Boilers	171 172
Ferroalloys	173 - 176

Also shown on these tables are the ratios of turnkey system cost to collector cost, total equipment cost to collector cost, and turnkey system cost to total equipment cost.

Generalization of the results of these calculations is difficult. Calculated values of the exponents for the power function vary from 0.165 to 1.069. No pattern seems apparent. The only general conclusion which can be drawn is that, on average, the cost of pollution control equipment goes up faster with size than the 0.6 exponent usually assumed.

The use of the derived capital cost equations outside the range of the data from which they were calculated is valid within certain limitations. Very small equipment installations tend to have relatively high capital costs which do not correlate well with size. Small systems cost roughly the same regardless of the treated gas throughput. Very large systems are frequently based on different designs than their smaller counterparts, or are composed of several smaller units which are joined together. Cost correlations based upon data from smaller units consequently will be inaccurate for these larger sizes. Numerical values for these large and small limitations depend upon both the nature of the abatement equipment and the nature of the process to which it is applied. Generalizations of these numerical values can be made, however, and they are presented below as guidelines.

	Small Limit, ACFM	Large Limit, ACFM
Scrubbers	2,000	100,000
Fabric Filters	2,000	–
Precipitators	50,000	–
Incinerators	2,000	50,000

The basic capital cost data collected were also used to calculate the cost per SCFM for each application. Results of these calculations are presented in the following tables:

Process Area	Table Numbers
Rendering	177 - 182
FCC	183 184
Asphalt Batching	185 186
BOF Steelmaking	187 - 189
Coal Cleaning	190
Brick and Tile	191 - 192
Copper Smelting	193 195
Bark Boilers	196 197
Ferroalloys	198 201

TABLE 150
COMPUTER PROGRAM FOR COST INDICES CALCULATIONS

```
IGCA   15:43   08/14/72

100 INPUT J$
110 F$ = " -"
120 FILES COST
130 INPUT #1,T,N$
140 INPUT #1,E$,C$
150 IF J=1 GOTO 230
160 PRINT USING 520,T
170 PRINT
180 PRINT USING 530,N$
185 PRINT
187 PRINT
188 PRINT
190 PRINT
200 PRINT USING 550,"COLLECTOR TYPE"," K*"," X*"," B/A"," C/A"," C/B"
210
230 PRINT
240 FOR M = 1 TO 4
250 FOR N = 1 TO 2
260 INPUT #1, A(M,N)
270 NEXT N
280 NEXT M
290 FOR N = 1 TO 2
310 NEXT N
320 FOR M = 1 TO 3
330 X(M) = (LOG(A(M,1))-LOG(A(M,2)))/(LOG(A(4,1))-LOG(A(4,2)))
340 P(M) = (LOG(A(M,1))+LOG(A(M,2)))-X(M)*(LOG(A(4,1))+LOG(A(4,2)))
350 P(M) = EXP(P(M)/2)
360 NEXT M
370 FOR N = 1 TO 2
375 R(1,N)=A(2,N)/A(1,N)
380 R(2,N) = A(3,N)/A(1,N)
390 R(3,N)= A(3,N)/A(2,N)
400 NEXT N
410 PRINT USING 560,E$
415 PRINT USING 560,C$
420 PRINT USING 540,"COLLECTOR ONLY(A)",P(1),X(1),F$,F$,F$
430 PRINT USING 540,"TOTAL EQUIPMENT(B)",P(2),X(2),F$,F$,F$
440 PRINT USING 540,"TURNKEY(C)",P(3),X(3),F$,F$,F$
450 PRINT
460 PRINT USING 540,"  SMALL",F$,F$,R(1,1),R(2,1),R(3,1)
470 PRINT USING 540,"  LARGE",F$,F$,R(1,2),R(2,2),R(3,2)
480 PRINT
490 IF END #1 GOTO 650
500 J = 1
510 GOTO 140
```

```
520:                                       TABLE  ###
530:                      DERIVED COST INDICES FOR #####################
########
540:          #####################  #######     #.###    #.###  ##.###
 ##.###
550:        #######################  #######   #######  #######  ######
 ######
560:        #######################
570:          #####################
580 PRINT
590 PRINT
600 PRINT "        *FOR USE IN EQUATION  COST = K*(SIZE)*EXP(X)"
610 FOR N = 1 TO 30
620 PRINT
630 NEXT N
640 END
650 FOR Y=1 TO 12
660 PRINT
670 NEXT Y
680 GOTO 600
READY
```

TABLE 151

UNITS OF PLANT SIZE FOR EACH PROCESS AREA

Process Area	Plant Size Units
Rendering	ACFM exhaust rate
Fluid Catalytic Cracking	bbls. combined feed/stream day
Asphalt Batching	ton/hr hot mix product
BOF Steelmaking	ton/heat product
Coal Cleaning	ton/hr dried coal product
Brick and Tile Kilns	ton/day product
Copper Smelting	ton/day product
Bark Boilers	lb steam/hr
Ferroalloys	megawatts

TABLE 152

DERIVED COST INDICES FOR RENDERING COOKERS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS					
MED. EFFICIENCY					
COLLECTOR ONLY(A)	51	.468	-	-	-
TOTAL EQUIPMENT(B)	1687	.231	-	-	-
TURNKEY(C)	2297	.266	-	-	-
SMALL	-	-	5.177	9.330	1.802
LARGE	-	-	4.130	7.699	1.864
WET SCRUBBERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	50	.511	-	-	-
TOTAL EQUIPMENT(B)	1335	.272	-	-	-
TURNKEY(C)	2020	.292	-	-	-
SMALL	-	-	4.071	7.223	1.774
LARGE	-	-	3.239	5.859	1.809

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 153

DERIVED COST INDICES FOR RENDERING ROOM VENTS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS					
MED. EFFICIENCY					
COLLECTOR ONLY(A)	42	.510	-	-	-
TOTAL EQUIPMENT(B)	733	.310	-	-	-
TURNKEY(C)	1936	.282	-	-	-
SMALL	-	-	3.520	7.460	2.120
LARGE	-	-	2.587	5.256	2.032
WET SCRUBBERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	46	.521	-	-	-
TOTAL EQUIPMENT(B)	655	.333	-	-	-
TURNKEY(C)	1719	.303	-	-	-
SMALL	-	-	3.135	6.486	2.069
LARGE	-	-	2.347	4.636	1.976

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 154

DERIVED COST INDICES FOR RENDERING COMBINED VENTS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS MED. EFFICIENCY					
COLLECTOR ONLY(A)	11	.640	-	-	-
TOTAL EQUIPMENT(B)	698	.330	-	-	-
TURNKEY(C)	776	.390	-	-	-
SMALL	-	-	4.429	8.253	1.864
LARGE	-	-	2.927	5.908	2.019
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY(A)	17	.629	-	-	-
TOTAL EQUIPMENT(B)	501	.382	-	-	-
TURNKEY(C)	639	.423	-	-	-
SMALL	-	-	3.455	6.286	1.819
LARGE	-	-	2.481	4.770	1.922

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 155

DERIVED COST INDICES FOR RENDERING COOKERS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
INCINERATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	1314	.249	-	-	-
TOTAL EQUIPMENT(B)	1347	.258	-	-	-
TURNKEY(C)	4278	.197	-	-	-
SMALL	-	-	1.098	2.198	2.002
LARGE	-	-	1.107	2.097	1.894

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 156

DERIVED COST INDICES FOR RENDERING ROOM VENTS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
INCINERATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	471	.382	-	-	-
TOTAL EQUIPMENT(B)	438	.401	-	-	-
TURNKEY(C)	1464	.332	-	-	-
SMALL	-	-	1.089	2.085	1.915
LARGE	-	-	1.123	1.931	1.720

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 157

DERIVED COST INDICES FOR RENDERING COMBINED VENTS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
INCINERATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	283	.429	-	-	-
TOTAL EQUIPMENT(B)	264	.451	-	-	-
TURNKEY(C)	963	.375	-	-	-
SMALL	-	-	1.118	2.141	1.915
LARGE	-	-	1.151	1.992	1.731

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 158

DERIVED COST INDICES FOR FCC UNITS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
PRECIPITATOR					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	85	.738	-	-	-
TOTAL EQUIPMENT(B)	231	.661	-	-	-
TURNKEY(C)	438	.692	-	-	-
SMALL	-	-	1.331	3.369	2.530
LARGE	-	-	1.179	3.133	2.657

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 159

DERIVED COST INDICES FOR FCC UNITS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
CYCLONE					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	1	1.203	-	-	-
TOTAL EQUIPMENT(B)	2	1.147	-	-	-
TURNKEY(C)	4	1.105	-	-	-
SMALL	-	-	1.141	1.435	1.258
LARGE	-	-	1.044	1.231	1.179

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 160

DERIVED COST INDICES FOR ASPHALT BATCHING

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	12914	.294	-	-	-
TOTAL EQUIPMENT(B)	16637	.278	-	-	-
TURNKEY(C)	23583	.275	-	-	-
SMALL	-	-	1.201	1.676	1.395
LARGE	-	-	1.189	1.654	1.392

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 161

DERIVED COST INDICES FOR ASPHALT BATCHING

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS MED. EFFICIENCY					
COLLECTOR ONLY(A)	2577	.294	-	-	-
TOTAL EQUIPMENT(B)	4169	.351	-	-	-
TURNKEY(C)	10986	.316	-	-	-
SMALL	-	-	2.104	4.726	2.246
LARGE	-	-	2.189	4.800	2.193
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY(A)	2049	.387	-	-	-
TOTAL EQUIPMENT(B)	3396	.436	-	-	-
TURNKEY(C)	9829	.364	-	-	-
SMALL	-	-	2.072	4.318	2.084
LARGE	-	-	2.143	4.251	1.983

FOR USE IN EQUATION COST ≐ K(SIZE)*EXP(X)

TABLE 162

DERIVED COST INDICES FOR BOF STEELMAKING

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
PRECIPITATOR MED. EFFICIENCY					
COLLECTOR ONLY(A)	9331	.887	-	-	-
TOTAL EQUIPMENT(B)**	0	.000	-	-	-
TURNKEY(C)	590734	.467	-	-	-
SMALL	-	-	.000	7.964	******
LARGE	-	-	.000	6.244	******
PRECIPITATOR HIGH EFFICIENCY					
COLLECTOR ONLY(A)	10957	.841	-	-	-
TOTAL EQUIPMENT(B)**	0	.000	-	-	-
TURNKEY(C)	659736	.442	-	-	-
SMALL	-	-	.000	8.371	******
LARGE	-	-	.000	6.641	******

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

**TOTAL EQUIPMENT COST NOT AVAILABLE

TABLE 163

DERIVED COST INDICES FOR BOF STEELMAKING

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBER,OPEN HOOD MED. EFFICIENCY					
COLLECTOR ONLY(A)	13461	.619	-	-	-
TOTAL EQUIPMENT(B)	294677	.461	-	-	-
TURNKEY(C)	713875	.400	-	-	-
SMALL	-	-	10.028	17.971	1.792
LARGE	-	-	9.150	15.829	1.730
WET SCRUBBER,OPEN HOOD HIGH EFFICIENCY					
COLLECTOR ONLY(A)	13461	.619	-	-	-
TOTAL EQUIPMENT(B)	296702	.461	-	-	-
TURNKEY(C)	721013	.399	-	-	-
SMALL	-	-	10.067	18.033	1.791
LARGE	-	-	9.183	15.871	1.728

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 164

DERIVED COST INDICES FOR BOF STEELMAKING

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBER,CLOSED HOOD MED. EFFICIENCY					
COLLECTOR ONLY(A)	568	1.069	-	-	-
TOTAL EQUIPMENT(B)**	0	.000	-	-	-
TURNKEY(C)	643736	.328	-	-	-
SMALL	-	-	.000	29.038	******
LARGE	-	-	.000	18.890	******
WET SCRUBBER,CLOSED HOOD HIGH EFFICIENCY					
COLLECTOR ONLY(A)	568	1.069	-	-	-
TOTAL EQUIPMENT(B)**	227623	.473	-	-	-
TURNKEY(C)	1055911	.376	-	-	-
SMALL	-	-	*****	60.455	2.863
LARGE	-	-	*****	40.442	2.705

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)
**TOTAL EQUIPMENT COST NOT AVAILABLE

TABLE 165

DERIVED COST INDICES FOR COAL CLEANING

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS MED. EFFICIENCY					
COLLECTOR ONLY(A)	196	.995	-	-	-
TOTAL EQUIPMENT(B)	254	1.049	-	-	-
TURNKEY(C)	1103	.917	-	-	-
SMALL	-	-	1.832	3.418	1.865
LARGE	-	-	1.945	3.138	1.613
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY(A)	189	.999	-	-	-
TOTAL EQUIPMENT(B)	375	.981	-	-	-
TURNKEY(C)	1638	.852	-	-	-
SMALL	-	-	1.765	3.385	1.918
LARGE	-	-	1.730	2.880	1.665

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 166

DERIVED COST INDICES FOR BRICK AND TILE KILNS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	1196	.529	-	-	-
TOTAL EQUIPMENT(B)	1195	.607	-	-	-
TURNKEY(C)	22702	.295	-	-	-
SMALL	-	-	1.428	6.447	4.516
LARGE	-	-	1.533	5.200	3.393

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 167

DERIVED COST INDICES FOR BRICK AND TILE KILNS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
INCINERATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	3018	.613	-	-	-
TOTAL EQUIPMENT(B)	3242	.646	-	-	-
TURNKEY(C)	16881	.476	-	-	-
SMALL	-	-	1.245	2.965	2.382
LARGE	-	-	1.282	2.613	2.038

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 168

DERIVED COST INDICES FOR COPPER ROASTING FURNACE

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
COMBINED SYSTEM					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	1958	.796	-	-	-
TOTAL EQUIPMENT(B)	3127	.758	-	-	-
TURNKEY(C)	5908	.705	-	-	-
SMALL	-	-	1.281	1.795	1.401
LARGE	-	-	1.233	1.641	1.331

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 169

DERIVED COST INDICES FOR COPPER REV. FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
PRECIPITATORS					
MED. EFFICIENCY					
COLLECTOR ONLY(A)	860	.888	-	-	-
TOTAL EQUIPMENT(B)	1581	.830	-	-	-
TURNKEY(C)	4570	.760	-	-	-
SMALL	-	-	1.299	2.478	1.907
LARGE	-	-	1.232	2.205	1.790
PRECIPITATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	4475	.651	-	-	-
TOTAL EQUIPMENT(B)	4797	.671	-	-	-
TURNKEY(C)	20276	.550	-	-	-
SMALL	-	-	1.211	2.473	2.042
LARGE	-	-	1.234	2.254	1.827

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 170

DERIVED COST INDICES FOR COPPER REV. FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS MED. EFFICIENCY					
COLLECTOR ONLY(A)	980	.614	-	-	-
TOTAL EQUIPMENT(B)	694	.904	-	-	-
TURNKEY(C)	1397	.834	-	-	-
SMALL	-	-	4.030	5.320	1.320
LARGE	-	-	5.257	6.507	1.238
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY(A)	980	.614	-	-	-
TOTAL EQUIPMENT(B)	763	.909	-	-	-
TURNKEY(C)	1711	.825	-	-	-
SMALL	-	-	4.572	6.197	1.356
LARGE	-	-	5.993	7.522	1.255

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 171

DERIVED COST INDICES FOR BARK BOILERS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
PRECIPITATORS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	19	.754	-	-	-
TOTAL EQUIPMENT(B)	46	.712	-	-	-
TURNKEY(C)	147	.659	-	-	-
SMALL	-	-	1.437	2.537	1.765
LARGE	-	-	1.371	2.284	1.666

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 172

DERIVED COST INDICES FOR BARK BOILERS

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	.37	.986	-	-	-
TOTAL EQUIPMENT(B)	5.68	.819	-	-	-
TURNKEY(C)	14.99	.818	-	-	-
SMALL	-	-	2.257	5.892	2.611
LARGE	-	-	1.879	4.899	2.608

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 173

DERIVED COST INDICES FOR FERROSILICON FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS HIGH EFFICIENCY					
COLLECTOR ONLY(A)	13466	.974	-	-	-
TOTAL EQUIPMENT(B)	17719	.974	-	-	-
TURNKEY(C)	71871	.818	-	-	-
SMALL	-	-	1.315	3.729	2.835
LARGE	-	-	1.315	3.005	2.285

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 174

DERIVED COST INDICES FOR FERROCHROME FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
FABRIC FILTERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	20591	.771	-	-	-
TOTAL EQUIPMENT(B)	29985	.733	-	-	-
TURNKEY(C)	126254	.551	-	-	-
SMALL	-	-	1.347	3.883	2.882
LARGE	-	-	1.282	2.904	2.265

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 175

DERIVED COST INDICES FOR FERROSILICON FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS MED. EFFICIENCY					
COLLECTOR ONLY(A)	5382	.873	-	-	-
TOTAL EQUIPMENT(B)	35702	.678	-	-	-
TURNKEY(C)	306157	.533	-	-	-
SMALL	-	-	4.226	25.970	6.145
LARGE	-	-	3.222	16.197	5.028
WET SCRUBBERS HIGH EFFICIENCY					
COLLECTOR ONLY(A)	5382	.873	-	-	-
TOTAL EQUIPMENT(B)	51338	.635	-	-	-
TURNKEY(C)	336593	.534	-	-	-
SMALL	-	-	5.515	28.632	5.192
LARGE	-	-	3.965	17.887	4.511

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 176

DERIVED COST INDICES FOR FERROCHROME FURNACES

COLLECTOR TYPE	K*	X*	B/A	C/A	C/B
WET SCRUBBERS					
MED. EFFICIENCY					
COLLECTOR ONLY(A)	6816	.590	-	-	-
TOTAL EQUIPMENT(B)	22793	.661	-	-	-
TURNKEY(C)	213053	.459	-	-	-
SMALL	-	-	3.878	23.825	6.143
LARGE	-	-	4.262	20.048	4.704
WET SCRUBBERS					
HIGH EFFICIENCY					
COLLECTOR ONLY(A)	6740	.653	-	-	-
TOTAL EQUIPMENT(B)	58403	.509	-	-	-
TURNKEY(C)	336166	.436	-	-	-
SMALL	-	-	6.424	31.794	4.949
LARGE	-	-	5.311	23.881	4.497

FOR USE IN EQUATION COST = K(SIZE)*EXP(X)

TABLE 177

DERIVED COST PER SCFM* FOR RENDERING COOKERS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER MED. EFFICIENCY		
GAS FLOW, SCFM	2336	6064
COLLECTOR ONLY	.86	.52
TOTAL EQUIPMENT	4.43	2.13
TURNKEY SYSTEM	7.99	3.97
WET SCRUBBER HIGH EFFICIENCY		
GAS FLOW, SCFM	2336	6064
COLLECTOR ONLY	1.19	.75
TOTAL EQUIPMENT	4.84	2.42
TURNKEY SYSTEM	8.59	4.37

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 178

DERIVED COST PER SCFM* FOR RENDERING ROOM VENTS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER		
MED. EFFICIENCY		
GAS FLOW,SCFM	2891	13491
COLLECTOR ONLY	.86	.40
TOTAL EQUIPMENT	3.03	1.05
TURNKEY SYSTEM	6.42	2.12
WET SCRUBBER		
HIGH EFFICIENCY		
GAS FLOW,SCFM	2891	13491
COLLECTOR ONLY	1.04	.50
TOTAL EQUIPMENT	3.26	1.17
TURNKEY SYSTEM	6.74	2.31

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 179

DERIVED COST PER SCFM* FOR RENDERING COMBINED VENTS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER MED. EFFICIENCY		
GAS FLOW, SCFM	5230	19600
COLLECTOR ONLY	.52	.33
TOTAL EQUIPMENT	2.31	.96
TURNKEY SYSTEM	4.31	1.94
WET SCRUBBER HIGH EFFICIENCY		
GAS FLOW, SCFM	5230	19600
COLLECTOR ONLY	.75	.46
TOTAL EQUIPMENT	2.59	1.15
TURNKEY SYSTEM	4.71	2.21

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 180

DERIVED COST PER SCFM* FOR RENDERING COOKERS

COLLECTOR TYPE	SMALL	LARGE
INCINERATORS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	1918	4809
COLLECTOR ONLY	4.56	2.29
TOTAL EQUIPMENT	5.01	2.53
TURNKEY SYSTEM	10.03	4.80

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 181

DERIVED COST PER SCFM* FOR RENDERING ROOM VENTS

COLLECTOR TYPE	SMALL	LARGE
INCINERATORS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	2891	13491
COLLECTOR ONLY	3.46	1.33
TOTAL EQUIPMENT	3.77	1.50
TURNKEY SYSTEM	7.21	2.58

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 182

DERIVED COST PER SCFM* FOR RENDERING COMBINED VENTS

COLLECTOR TYPE	SMALL	LARGE
INCINERATORS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	4803	18240
COLLECTOR ONLY	2.29	1.07
TOTAL EQUIPMENT	2.56	1.23
TURNKEY SYSTEM	4.90	2.13

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 183

DERIVED COST PER SCFM* FOR FCC UNITS

COLLECTOR TYPE	SMALL	LARGE
PRECIPITATOR		
HIGH EFFICIENCY		
GAS FLOW,SCFM	39892	190914
COLLECTOR ONLY	1.96	1.31
TOTAL EQUIPMENT	2.61	1.54
TURNKEY SYSTEM	6.61	4.09

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR
INLET INCLUDING WATER VAPOR

TABLE 184

DERIVED COST PER SCFM* FOR FCC UNITS

COLLECTOR TYPE	SMALL	LARGE
CYCLONE		
HIGH EFFICIENCY		
GAS FLOW,SCFM	28000	133300
COLLECTOR ONLY	3.04	4.23
TOTAL EQUIPMENT	3.47	4.41
TURNKEY SYSTEM	4.37	5.20

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 185

DERIVED COST PER SCFM* FOR ASPHALT BATCHING

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	20051	28096
COLLECTOR ONLY	2.49	2.18
TOTAL EQUIPMENT	2.99	2.59
TURNKEY SYSTEM	4.17	3.60

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 186

DERIVED COST PER SCFM* FOR ASPHALT BATCHING

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
MED. EFFICIENCY		
GAS FLOW, SCFM	20022	28070
COLLECTOR ONLY	.50	.44
TOTAL EQUIPMENT	1.05	.95
TURNKEY SYSTEM	2.35	2.09
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW, SCFM	20022	28070
COLLECTOR ONLY	.61	.57
TOTAL EQUIPMENT	1.26	1.22
TURNKEY SYSTEM	2.63	2.41

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 187

DERIVED COST PER SCFM* FOR BOF STEELMAKING

COLLECTOR TYPE	SMALL	LARGE
PRECIPITATOR		
MED. EFFICIENCY		
GAS FLOW,SCFM	286486	487027
COLLECTOR ONLY	2.61	2.57
TOTAL EQUIPMENT**	.00	.00
TURNKEY SYSTEM	20.77	16.02
PRECIPITATOR		
HIGH EFFICIENCY		
GAS FLOW,SCFM	286486	487027
COLLECTOR ONLY	2.44	2.34
TOTAL EQUIPMENT**	.00	.00
TURNKEY SYSTEM	20.46	15.55

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

**TOTAL EQUIPMENT COST NOT AVAILABLE

TABLE 188

DERIVED COST PER SCFM* FOR BOF STEELMAKING

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER,OPEN HOOD		
MED. EFFICIENCY		
GAS FLOW,SCFM	148584	265000
COLLECTOR ONLY	1.93	1.55
TOTAL EQUIPMENT	19.38	14.20
TURNKEY SYSTEM	34.73	24.56
WET SCRUBBER,OPEN HOOD		
HIGH EFFICIENCY		
GAS FLOW,SCFM	148584	265000
COLLECTOR ONLY	1.93	1.55
TOTAL EQUIPMENT	19.45	14.25
TURNKEY SYSTEM	34.85	24.62

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 189

DERIVED COST PER SCFM* FOR BOF STEELMAKING

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBER,CLOSED HOOD		
MED. EFFICIENCY		
GAS FLOW,SCFM	40805	72699
COLLECTOR ONLY	2.74	2.86
TOTAL EQUIPMENT**	.00	.00
TURNKEY SYSTEM	79.60	54.02
WET SCRUBBER,CLOSED HOOD		
HIGH EFFICIENCY		
GAS FLOW,SCFM	40805	72699
COLLECTOR ONLY	2.74	2.86
TOTAL EQUIPMENT	57.88	42.75
TURNKEY SYSTEM	165.71	115.65

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

**TOTAL EQUIPMENT COST NOT AVAILABLE

TABLE 190

DERIVED COST PER SCFM* FOR COAL CLEANING

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
MED. EFFICIENCY		
GAS FLOW,SCFM	154923	464769
COLLECTOR ONLY	.74	.73
TOTAL EQUIPMENT	1.35	1.42
TURNKEY SYSTEM	2.52	2.30
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	154923	464769
COLLECTOR ONLY	.73	.73
TOTAL EQUIPMENT	1.28	1.26
TURNKEY SYSTEM	2.46	2.09

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 191

DERIVED COST PER SCFM* FOR BRICK AND TILE KILNS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	10743	25784
COLLECTOR ONLY	1.27	.86
TOTAL EQUIPMENT	1.82	1.32
TURNKEY SYSTEM	8.22	4.49

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 190

DERIVED COST PER SCFM* FOR COAL CLEANING

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
MED. EFFICIENCY		
GAS FLOW,SCFM	154923	464769
COLLECTOR ONLY	.74	.73
TOTAL EQUIPMENT	1.35	1.42
TURNKEY SYSTEM	2.52	2.30
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	154923	464769
COLLECTOR ONLY	.73	.73
TOTAL EQUIPMENT	1.28	1.26
TURNKEY SYSTEM	2.46	2.09

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 191

DERIVED COST PER SCFM* FOR BRICK AND TILE KILNS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	10743	25784
COLLECTOR ONLY	1.27	.86
TOTAL EQUIPMENT	1.82	1.32
TURNKEY SYSTEM	8.22	4.49

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 192

DERIVED COST PER SCFM* FOR BRICK AND TILE KILNS

COLLECTOR TYPE	SMALL	LARGE
INCINERATORS		
HIGH EFFICIENCY		
GAS FLOW, SCFM	10743	25784
COLLECTOR ONLY	4.74	3.46
TOTAL EQUIPMENT	5.90	4.44
TURNKEY SYSTEM	14.05	9.05

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 193

DERIVED COST PER SCFM* FOR COPPER ROASTING FURNACE

COLLECTOR TYPE	SMALL	LARGE
COMBINED SYSTEM		
HIGH EFFICIENCY		
GAS FLOW,SCFM	13360	35333
COLLECTOR ONLY	13.75	11.35
TOTAL EQUIPMENT	17.61	14.00
TURNKEY SYSTEM	24.67	18.63

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 194

DERIVED COST PER SCFM* FOR COPPER REV. FURNACES

COLLECTOR TYPE	SMALL	LARGE
PRECIPITATORS MED. EFFICIENCY		
GAS FLOW, SCFM	52000	130000
COLLECTOR ONLY	3.38	3.05
TOTAL EQUIPMENT	4.38	3.75
TURNKEY SYSTEM	8.36	6.71
PRECIPITATORS HIGH EFFICIENCY		
GAS FLOW, SCFM	52000	130000
COLLECTOR ONLY	4.25	3.09
TOTAL EQUIPMENT	5.15	3.81
TURNKEY SYSTEM	10.51	6.96

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET. INCLUDING WATER VAPOR

TABLE 195

DERIVED COST PER SCFM* FOR COPPER REV. FURNACES

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
MED. EFFICIENCY		
GAS FLOW, SCFM	52000	130000
COLLECTOR ONLY	.75	.52
TOTAL EQUIPMENT	3.00	2.75
TURNKEY SYSTEM	3.96	3.40
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW, SCFM	52000	130000
COLLECTOR ONLY	.75	.52
TOTAL EQUIPMENT	3.41	3.13
TURNKEY SYSTEM	4.62	3.93

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 196

DERIVED COST PER SCFM* FOR BARK BOILERS

COLLECTOR TYPE	SMALL	LARGE
PRECIPITATORS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	45605	136814
COLLECTOR ONLY	2.51	1.92
TOTAL EQUIPMENT	3.61	2.63
TURNKEY SYSTEM	6.37	4.38

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 197

DERIVED COST PER SCFM* FOR BARK BOILERS

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	40305	120914
COLLECTOR ONLY	.78	.77
TOTAL EQUIPMENT	1.76	1.44
TURNKEY SYSTEM	4.59	3.76

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 198

DERIVED COST PER SCFM* FOR FERROSILICON FURNACES

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	36697	146902
COLLECTOR ONLY	3.46	3.33
TOTAL EQUIPMENT	4.55	4.38
TURNKEY SYSTEM	12.89	10.01

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 199

DERIVED COST PER SCFM* FOR FERROCHROME FURNACES

COLLECTOR TYPE	SMALL	LARGE
FABRIC FILTERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	18719	70479
COLLECTOR ONLY	5.46	4.02
TOTAL EQUIPMENT	7.36	5.15
TURNKEY SYSTEM	21.21	11.67

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 200

DERIVED COST PER SCFM* FOR FERROSILICON FURNACES

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
MED. EFFICIENCY		
GAS FLOW, SCFM	36697	145750
COLLECTOR ONLY	1.10	.93
TOTAL EQUIPMENT	4.63	2.98
TURNKEY SYSTEM	28.45	14.99
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW, SCFM	36697	145750
COLLECTOR ONLY	1.10	.93
TOTAL EQUIPMENT	6.04	3.67
TURNKEY SYSTEM	31.37	16.56

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR INLET INCLUDING WATER VAPOR

TABLE 201

DERIVED COST PER SCFM* FOR FERROCHROME FURNACES

COLLECTOR TYPE	SMALL	LARGE
WET SCRUBBERS		
MED. EFFICIENCY		
GAS FLOW,SCFM	18719	70479
COLLECTOR ONLY	1.24	.72
TOTAL EQUIPMENT	4.81	3.06
TURNKEY SYSTEM	29.56	14.40
WET SCRUBBERS		
HIGH EFFICIENCY		
GAS FLOW,SCFM	18719	70479
COLLECTOR ONLY	1.40	.88
TOTAL EQUIPMENT	8.99	4.68
TURNKEY SYSTEM	44.50	21.04

*BASED ON SCFM AT 70 DEG. F AT COLLECTOR
INLET INCLUDING WATER VAPOR

3. OPERATING COSTS AT VARIOUS UTILITY COST LEVELS

The annual operating costs for air pollution control equipment for specific processing applications were calculated by using an average value of the unit cost for the various operating cost items. These costs were summarized in tables and the direct operating cost and total cost curves (based on two different plant capacities) were then plotted. In this section, the same procedure has been used with the single exception that a high and low value of the unit costs have been used instead of the average one to calculate direct operating costs. The high, intermediate, and low values for the various unit costs are summarized in Table 202. The total cost data are tabulated in Tables 203 - 252. The subsequent cost curves are the upper and lower limits of cost versus plant capacity, and are contained in Figures 107 - 160.

TABLE 202

VARIOUS VALUES FOR UNIT OPERATING COSTS

Unit Cost Item	High	Average	Low
Operating Labor			
Operator	$ 9/hr	$ 6/hr	$ 4/hr
Supervisor	$12/hr	$ 8/hr	$ 6/hr
Maintenance Labor	$ 9/hr	$ 6/hr	$ 4/hr
Utilities			
Electric Power	$.020/kw-hr	$.011/kw-hr	$.005/kw-hr
Fuel	$1.25/MM BTU	$.80/MM BTU	$.50/MM BTU
Water (Process)	$0.50/M gal	$.25/M gal	$.10/M gal
Water (Cooling)	$0.09/M gal	$.05/M gal	$.02/M gal

TABLE 203
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR RENDERING COOKERS AND HOODS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$4/hr	1,674	1,750	1,674	1,750
Supervisor	$6/hr	20	28	20	28
Total Operating Labor		1,694	1,778	1,694	1,778
Maintenance					
Labor					
Materials	$4/hr				
Total Maintenance		1,650	1,750	1,700	1,800
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.005/kw-hr	136	222	164	251
Fuel		-	-	-	-
Water (Process)	$.10/M gal	48	115	48	115
Water (Cooling)		-	-	-	-
Chemicals, Specify * $KMnO_4$	$.38/lb	114,900	269,040	172,368	410,400
Borax	$.0625/lb	101,250	243,000	101,250	243,000
Total Utilities		216,334	512,377	273,830	653,766
Total Direct Cost		219,678	515,905	277,224	657,344
Annualized Capital Charges		1,866	2,406	2,006	2,651
Total Annual Cost		221,544	518,311	279,230	659,995

* Not all quotes used this system of chemicals. Based on only one chemical cost quote, 2 quotes for other operating cost

TABLE 204

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR RENDERING COOKERS AND HOODS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$9/hr	3,768	3,937	3,768	3,937
Supervisor	$12/hr	40	57	40	57
Total Operating Labor		3,808	3,994	3,808	3,994
Maintenance					
Labor					
Materials	$9/hr				
Total Maintenance		1,650	1,750	1,700	1,800
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.020/kw-hr	545	890	658	1,007
Fuel		-	-	-	-
Water (Process)	$.50/M gal	224	578	224	578
Water (Cooling)		-	-	-	-
Chemicals, Specify * $KMnO_4$	$.38/lb	114,900	269,040	172,368	410,400
Borax	$.0625/lb	101,250	243,000	101,250	243,000
Total Utilities		216,919	513,508	274,500	654,985
Total Direct Cost		222,377	519,252	280,008	660,779
Annualized Capital Charges		1,866	2,406	2,006	2,651
Total Annual Cost		224,243	521,658	282,014	663,430

* Not all quotes used this system of chemicals. Based on only one chemical cost quote, 2 quotes for other operating cost

FIGURE 107

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING COOKERS AND HOODS

(Low Unit Cost)

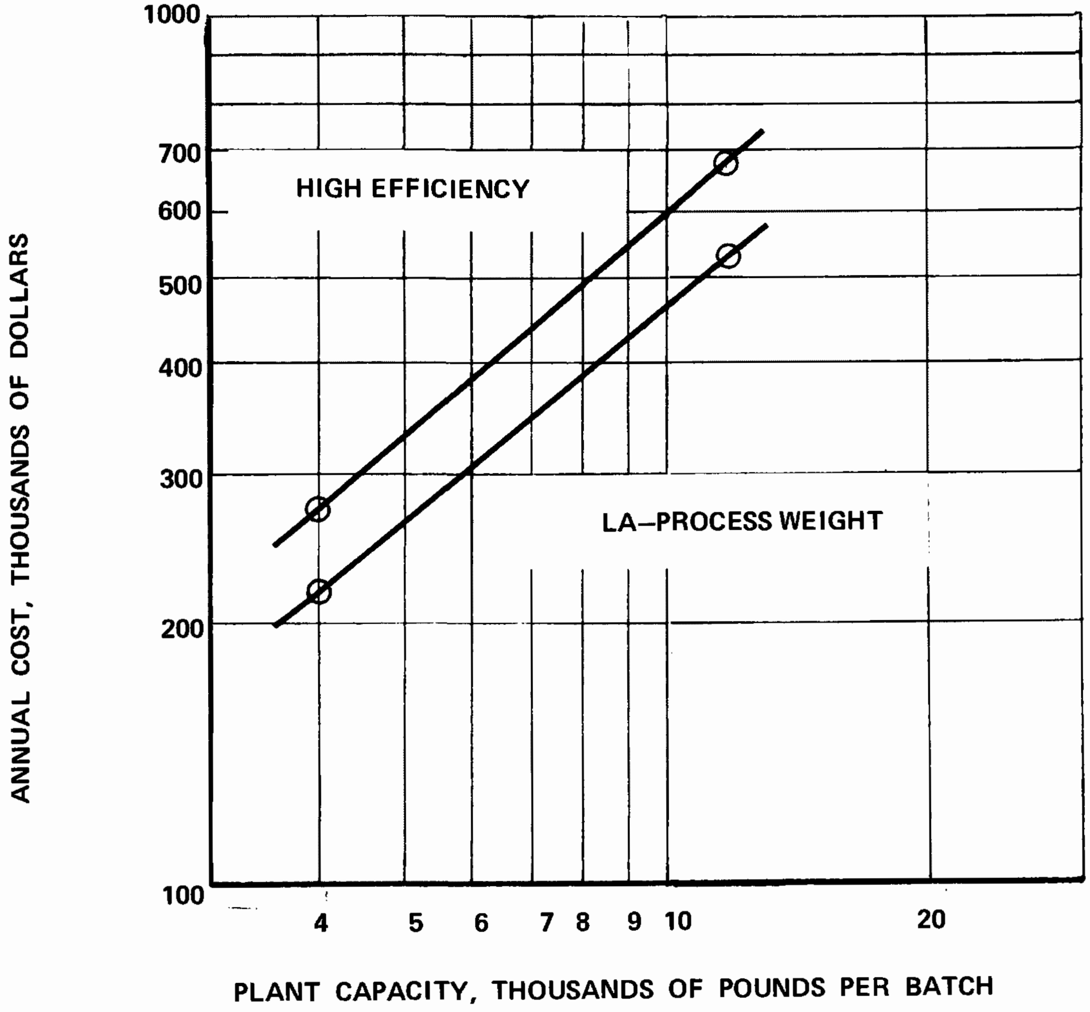


FIGURE 108

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING COOKERS AND HOODS

(High Unit Cost)

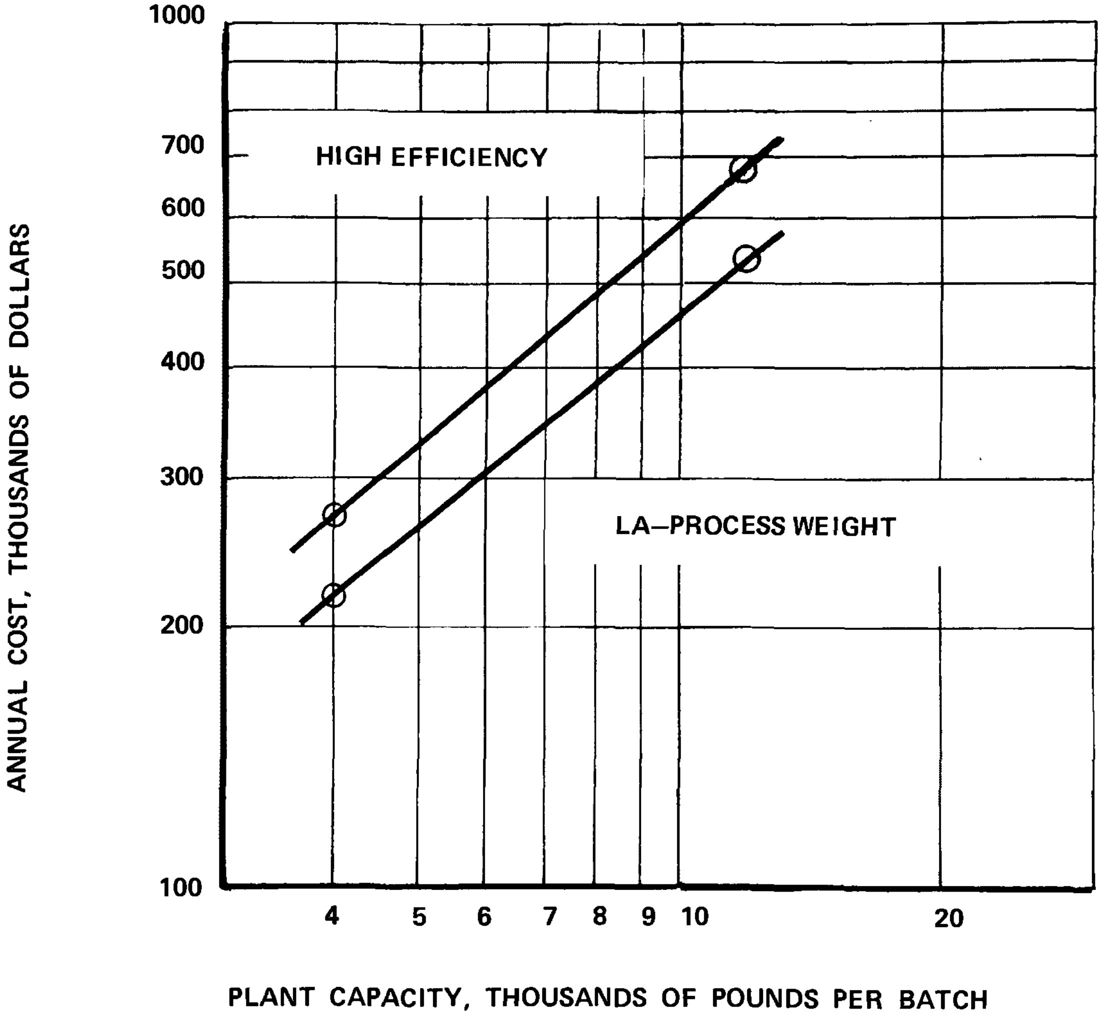


TABLE 205

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR RENDERING ROOM VENTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$4/hr	1,163	1,226	1,163	1,226
Supervisor	$6/hr	17	22	17	22
Total Operating Labor		1,180	1,248	1,180	1,248
Maintenance					
Labor					
Materials	$4/hr	1,100	1,200	1,117	1,268
Total Maintenance					
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.005/kw-hr	146	466	166	570
Fuel		-	-	-	-
Water (Process)	$.10/M gal	67	295	67	295
Water (Cooling)		-	-	-	-
Chemicals, Specify * $KMnO_4$	$.38/lb	123,200	541,728	184,680	820,000
Borax	$.0625/lb	111,375	500,000	111,375	500,000
Total Utilities		234,788	1,042,489	296,288	1,320,865
Total Direct Cost		237,068	1,044,937	298,585	1,323,381
Annualized Capital Charges		1,502	2,533	1,595	2,774
Total Annual Cost		238,570	1,047,470	300,180	1,326,155

* Not all quotes used this system of chemicals. Based on one quote for chemical, three for other cost.

TABLE 206

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR RENDERING ROOM VENTS

High Unit Cost

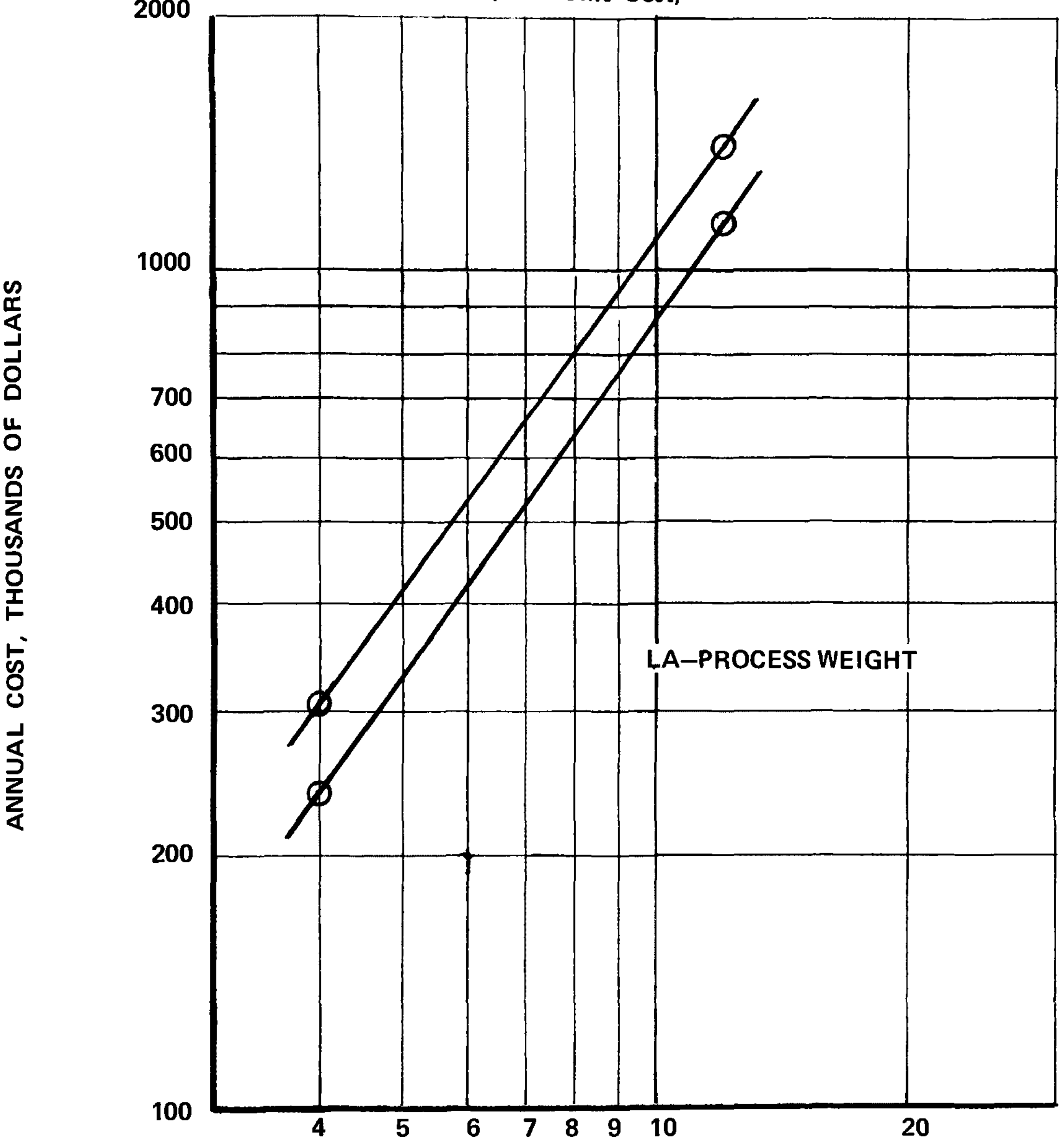
Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$9/hr	2,617	2,760	2,617	2,760
Supervisor	$12/hr	34	45	34	45
Total Operating Labor		2,651	2,805	2,651	2,805
Maintenance					
Labor	$9/hr				
Materials					
Total Maintenance		1,100	1,200	1,117	1,268
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.020/kw-hr	585	1,865	665	2,283
Fuel		-	-	-	-
Water (Process)	$.50/M ga	336	1,470	336	1,476
Water (Cooling)		-	-	-	-
Chemicals, Specify * $KMnO_4$	$.38/lb	123,200	541,728	184,680	820,000
Borax	$.0625/lb	111,375	500,000	111,375	500,000
Total Utilities		235,496	1,045,063	297,056	1,323,759
Total Direct Cost		239,247	1,049,068	300,824	1,327,822
Annualized Capital Charges		1,502	2,533	1,595	2,774
Total Annual Cost		240,749	1,051,601	302,419	1,330,606

* Not all quotes used this system of chemicals. Based on one quote for chemical, three quotes for other costs.

FIGURE 109

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING ROOM VENTS

(Low Unit Cost)



PLANT CAPACITY THOUSANDS OF POUNDS PER BATCH

FIGURE 110

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING ROOM VENTS

(High Unit Cost)

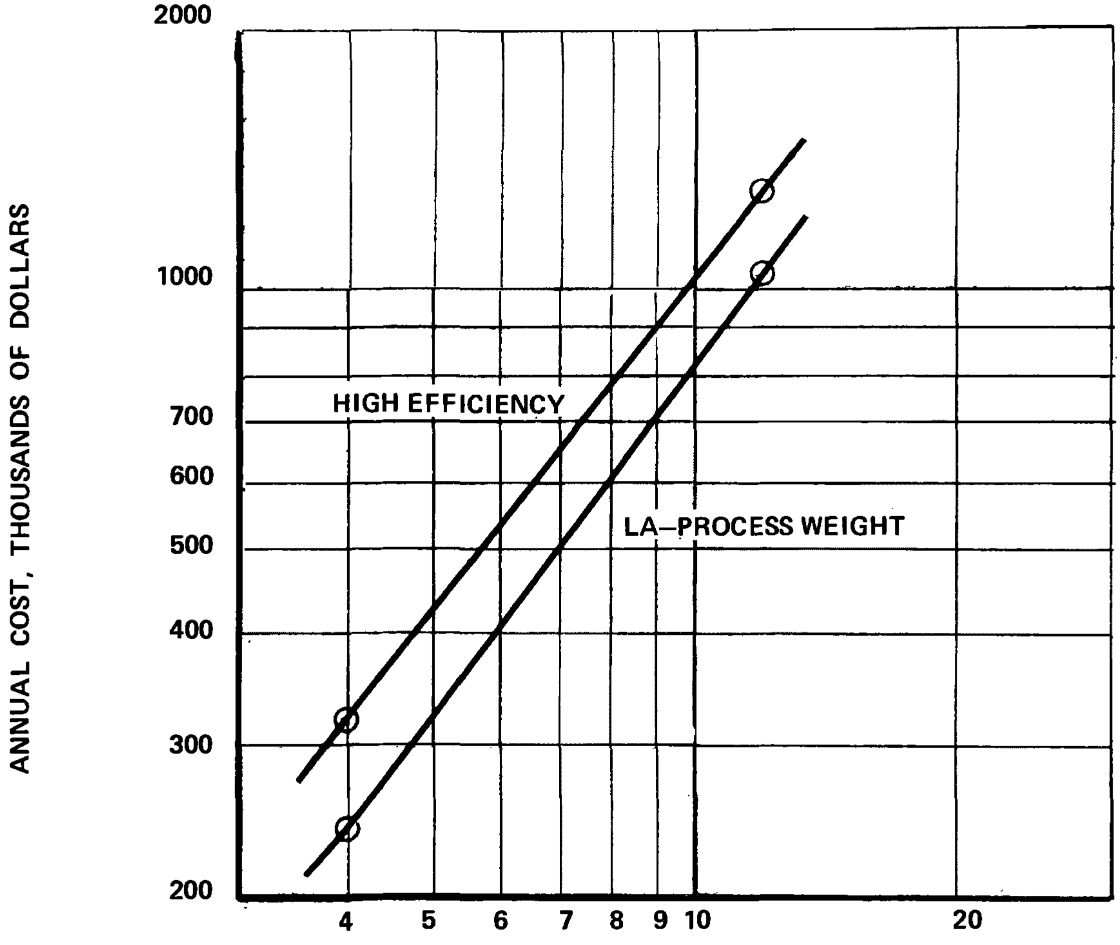


TABLE 207

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR RENDERING COMBINED VENTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$4/hr	1,600	1,800	1,600	1,800
Supervisor	$6/hr	11	33	11	33
Total Operating Labor		1,611	1,833	1,611	1,833
Maintenance					
Labor	$4/hr				
Materials					
Total Maintenance		1,725	1,900	1,750	2,000
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.005/kw-Hr	201	529	255	679
Fuel		-	-	-	-
Water (Process)	$.10/M gal	91	329	91	329
Water (Cooling)		-	-	-	-
Chemicals, Specify * $KMnO_4$	$.38/lb	215,870	820,800	328,320	1,231,200
Borax	$.0625/lb	195,750	742,500	195,750	742,500
Total Utilities		411,912	1,564,158	524,416	1,974,708
Total Direct Cost		415,248	1,567,891	527,777	1,978,541
Annualized Capital Charges		2,253	3,796	2,466	4,341
Total Annual Cost		417,501	1,571,687	530,243	1,982,882

* Not all quotes used this system of chemicals. Based on one quote for chemicals, three quotes for other costs.

TABLE 208

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR RENDERING COMBINED VENTS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$9/hr	3,600	4,050	3,600	4,050
Supervisor	$12/hr	22	67	22	67
Total Operating Labor		3,622	4,117	3,622	4,117
Maintenance					
Labor	$9/hr				
Materials					
Total Maintenance		1,725	1,900	1,750	2,000
Replacement Parts					
Total Replacement Parts		-	-	-	-
Utilities					
Electric Power	$.020/kw-hr	809	2,116	1,021	2,718
Fuel		-	-	-	-
Water (Process)	$.50/M gal	458	1,648	458	1,648
Water (Cooling)		-	-	-	-
Chemicals, Specify $KMnO_4$	$.38/lb	215,870	820,800	328,320	1,231,200
Borax	$.0625/lb	195,750	742,500	195,750	742,500
Total Utilities		412,887	1,567,064	525,549	1,978,066
Total Direct Cost		418,234	1,573,081	530,921	1,984,183
Annualized Capital Charges		2,253	3,796	2,466	4,341
Total Annual Cost		420,487	1,576,877	533,387	1,988,524

FIGURE 111

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING COMBINED VENTS

(Low Unit Cost)

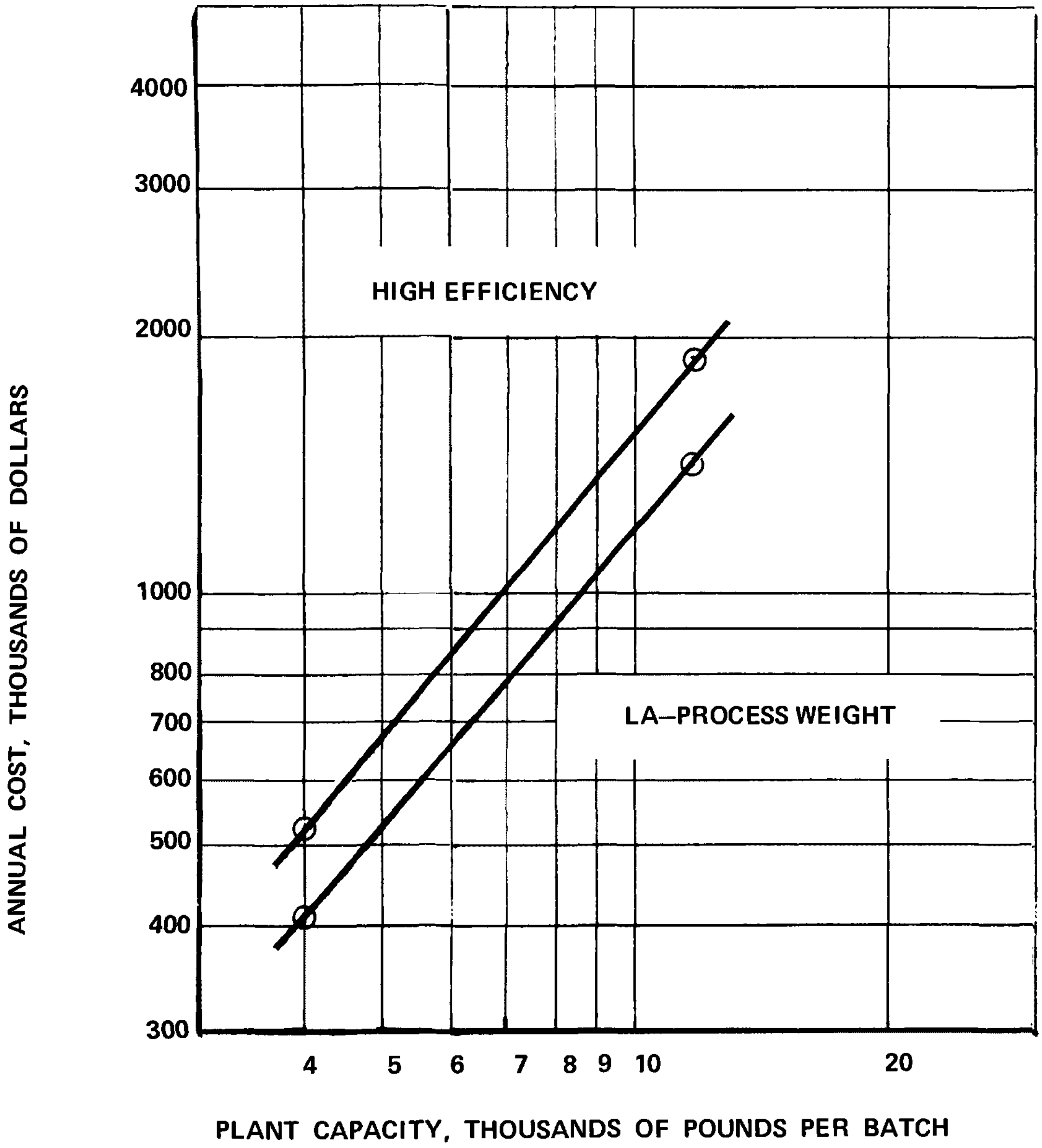


FIGURE 112

ANNUAL COSTS FOR WET SCRUBBERS FOR RENDERING COMBINED VENTS

(High Unit Cost)

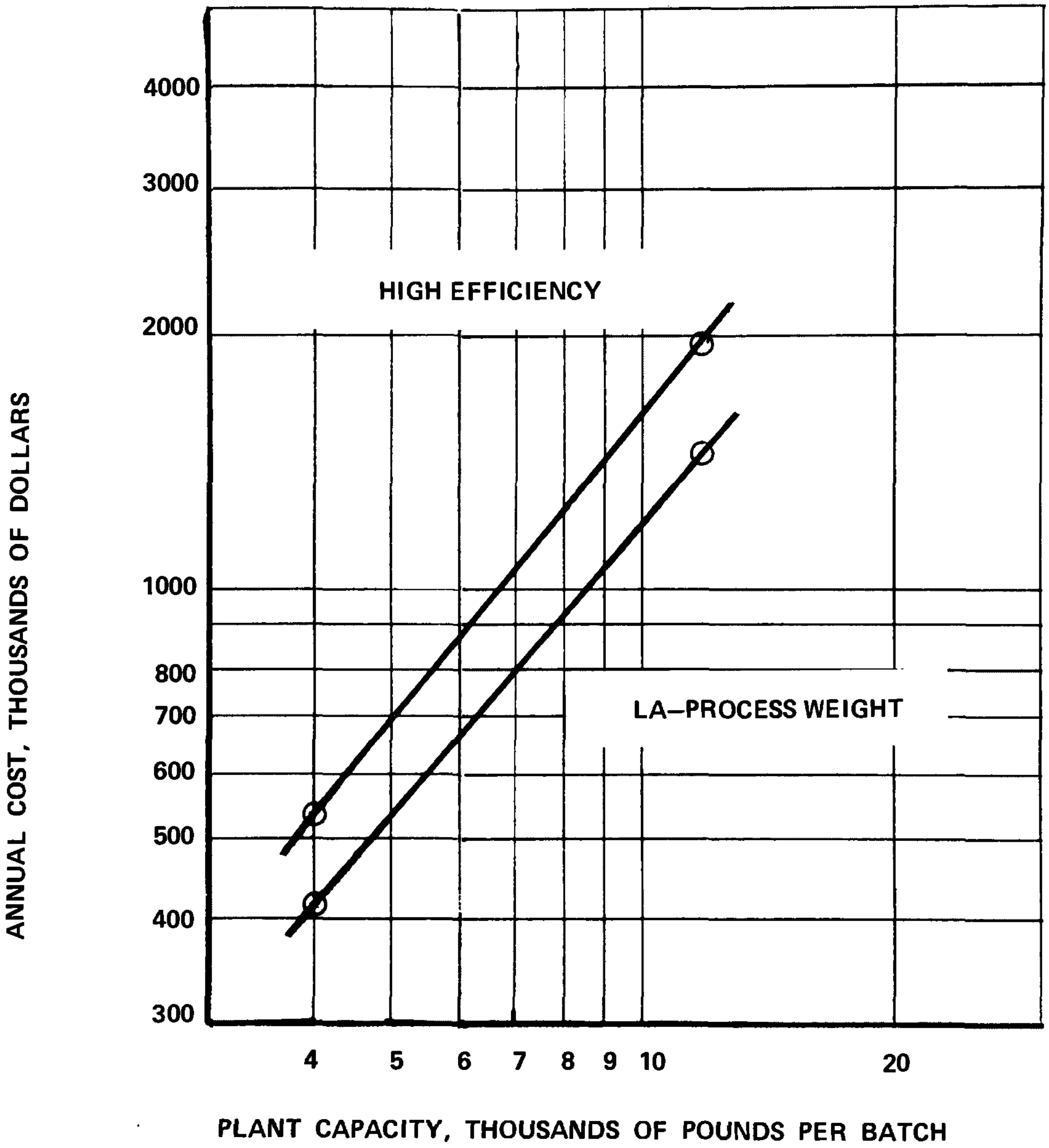


TABLE 209

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR INCINERATORS FOR RENDERING COOKERS AND HOODS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$4/hr			520	520
Supervisor	$6/hr			36	36
Total Operating Labor				556	556
Maintenance					
Labor	$4/hr			256	260
Materials				166	220
Total Maintenance				422	480
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.005/kw-hr			47	82
Fuel	$.50/MM BTU			3,770	9,243
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				3,817	9,325
Total Direct Cost				4,953	10,519
Annualized Capital Charges				1,924	2,306
Total Annual Cost				6,877	12,825

TABLE 210

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR INCINERATORS FOR RENDERING COOKERS AND HOODS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$9/hr			1,170	1,170
Supervisor	$12/hr			72	72
Total Operating Labor				1,242	1,242
Maintenance					
Labor	$9/hr			576	585
Materials				166	220
Total Maintenance				742	805
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.020/kw-hr			186	326
Fuel	$1.25/MM BTU			9,425	23,107
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				9,611	23,433
Total Direct Cost				11,753	25,638
Annualized Capital Charges				1,924	2,306
Total Annual Cost				13,677	27,944

FIGURE 113

ANNUAL COSTS FOR INCINERATORS FOR RENDERING COOKERS AND HOODS

(Low Unit Cost)

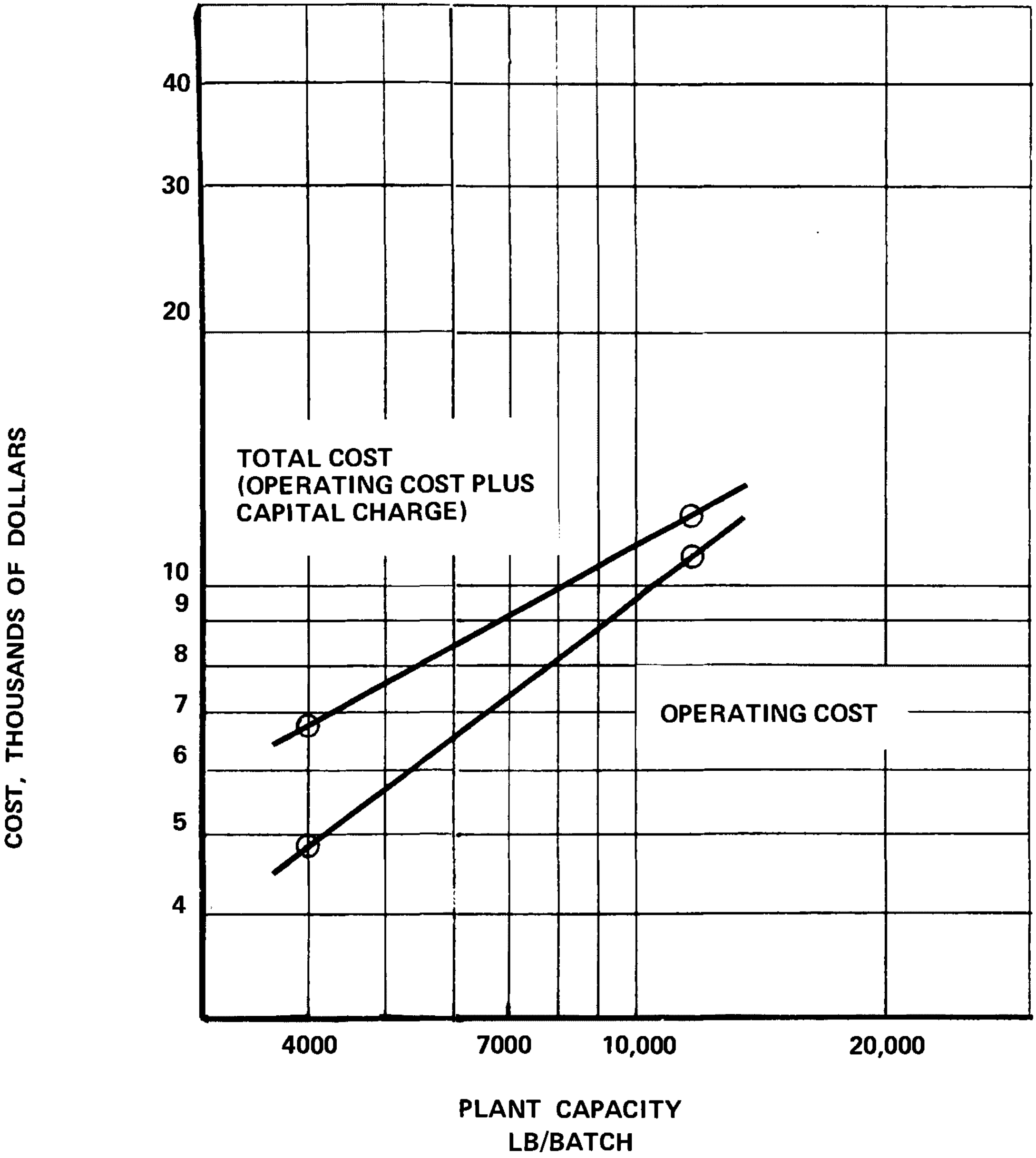


FIGURE 114.

ANNUAL COSTS FOR INCINERATORS FOR RENDERING COOKERS AND HOODS

(High Unit Cost)

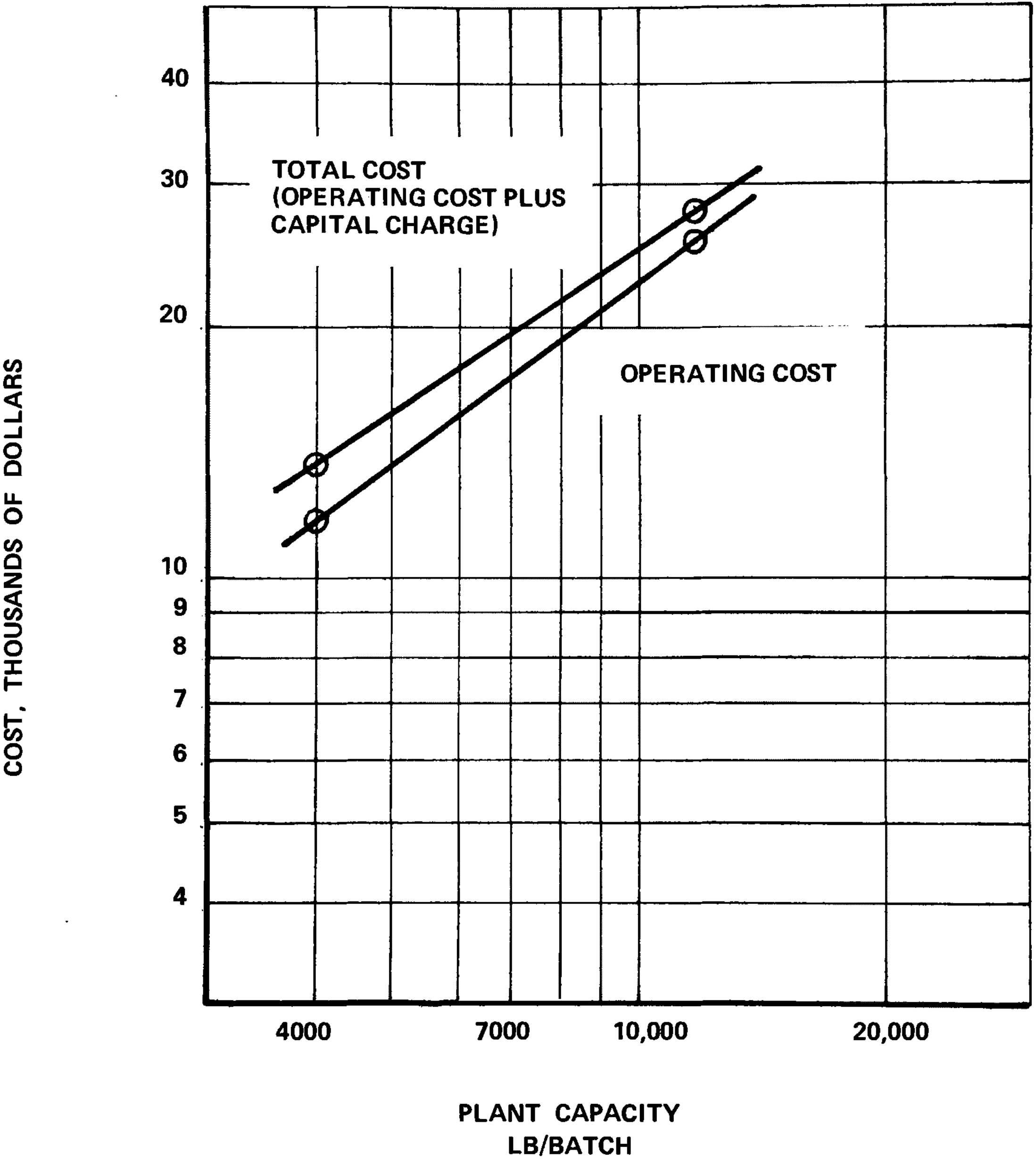


TABLE 211

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR INCINERATORS FOR RENDERING COOKER ROOM VENTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$4/hr			520	520
Supervisor	$6/hr			36	36
Total Operating Labor				556	556
Maintenance					
Labor	$4/hr			260	320
Materials				220	270
Total Maintenance				480	590
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.005/kw-hr			59	279
Fuel	$.50/MM BTU			5,460	25,545
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				5,519	25,824
Total Direct Cost				6,713	27,128
Annualized Capital Charges				2,085	3,476
Total Annual Cost				8,798	30,604

TABLE 212

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR INCINERATORS FOR RENDERING COOKER ROOM VENTS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$9/hr			1,170	1,170
Supervisor	$12/hr			72	72
Total Operating Labor				1,242	1,242
Maintenance					
Labor	$9/hr			585	720
Materials				220	270
Total Maintenance				805	990
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.020/kw-hr			237	1,117
Fuel	$1.25/MM BTU			13,650	63,862
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				13,887	64,979
Total Direct Cost				16,092	67,369
Annualized Capital Charges				2,085	3,476
Total Annual Cost				18,177	70,845

FIGURE 115

ANNUAL COSTS FOR INCINERATORS FOR RENDERING ROOM VENTS

(Low Unit Cost)

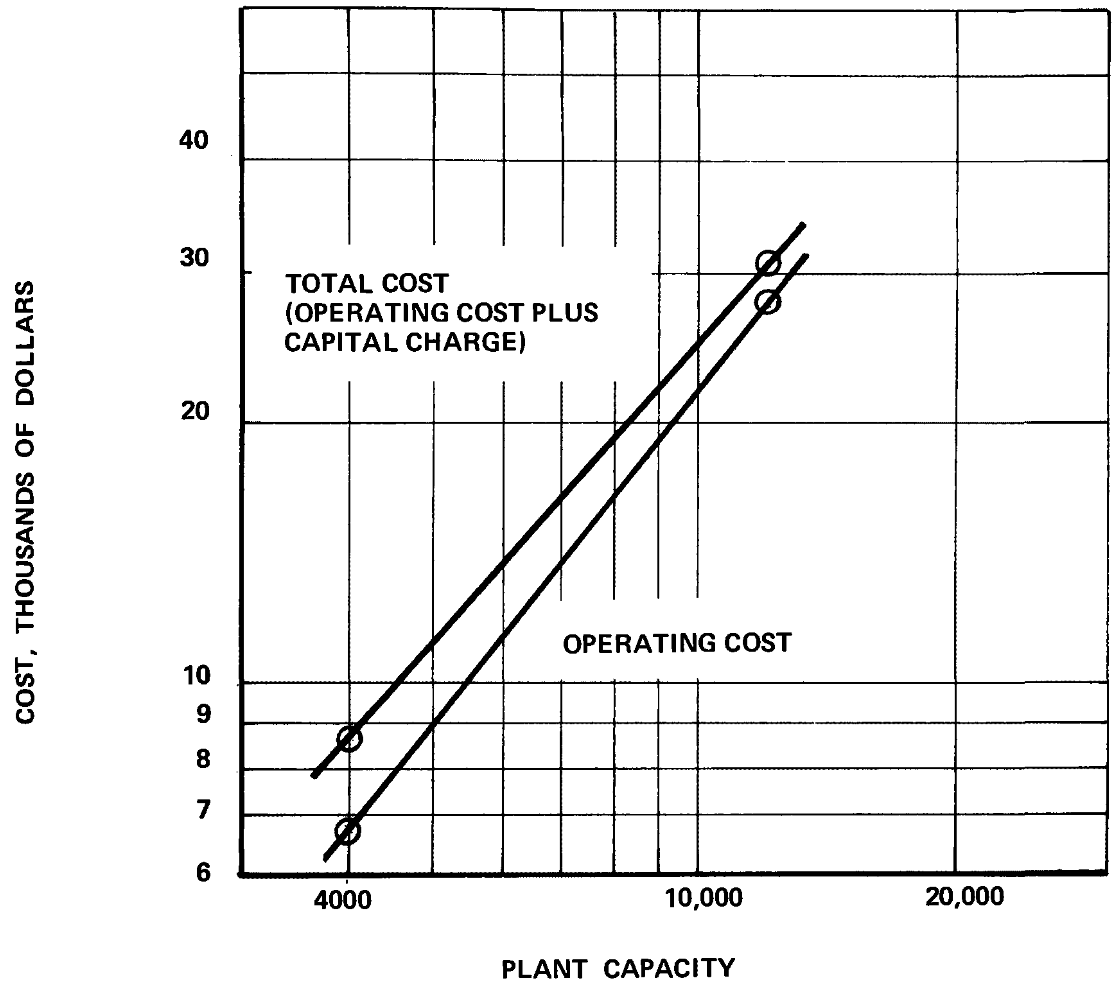


FIGURE 116

ANNUAL COSTS FOR INCINERATORS FOR RENDERING ROOM VENTS

(High Unit Cost)

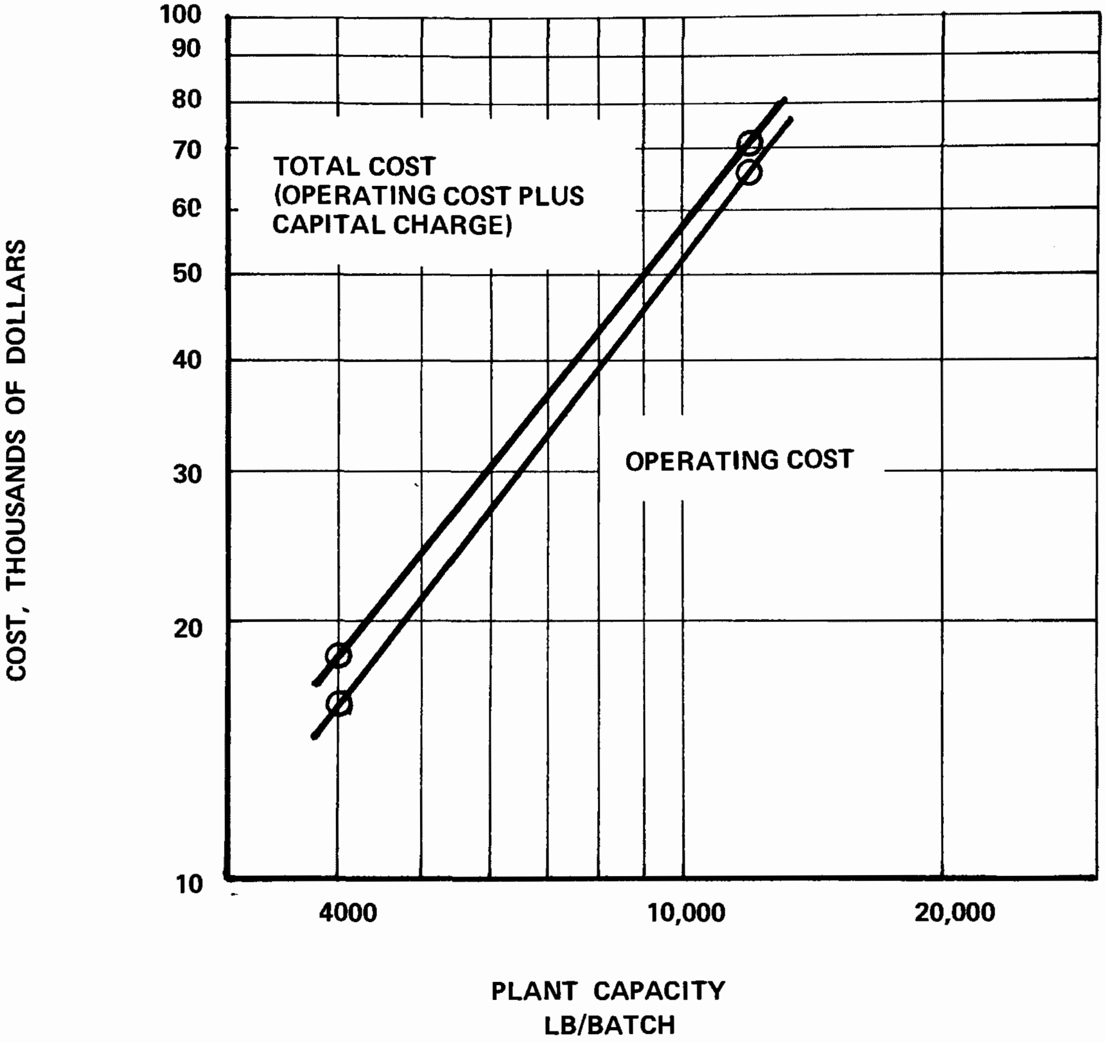


TABLE 213

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR INCINERATORS FOR RENDERING COMBINED VENTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$4/hr			520	520
Supervisor	$6/hr			36	36
Total Operating Labor				556	556
Maintenance					
Labor	$4/hr			256	310
Materials				186	235
Total Maintenance				442	545
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.005/kw-hr			82	304
Fuel	$.50/MM BTU			9,086	34,476
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				9,168	34,780
Total Direct Cost				10,324	36,039
Annualized Capital Charges				2,355	3,884
Total Annual Cost				12,679	39,923

TABLE 214

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR INCINERATORS FOR RENDERING COMBINED VENTS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,600				
Operating Labor (if any)					
Operator	$9/hr			1,170	1,170
Supervisor	$12/hr			72	72
Total Operating Labor				1,242	1,242
Maintenance					
Labor	$9/hr			576	697
Materials				186	235
Total Maintenance				762	932
Replacement Parts					
Total Replacement Parts				158	158
Utilities					
Electric Power	$.020/kw-hr			327	1,217
Fuel	$1.25/MM BTU			22,717	86,190
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				23,046	87,407
Total Direct Cost				25,206	89,739
Annualized Capital Charges				2,355	3,884
Total Annual Cost				27,561	93,623

FIGURE 117

ANNUAL COSTS FOR INCINERATORS FOR RENDERING COMBINED VENTS

(Low Unit Cost)

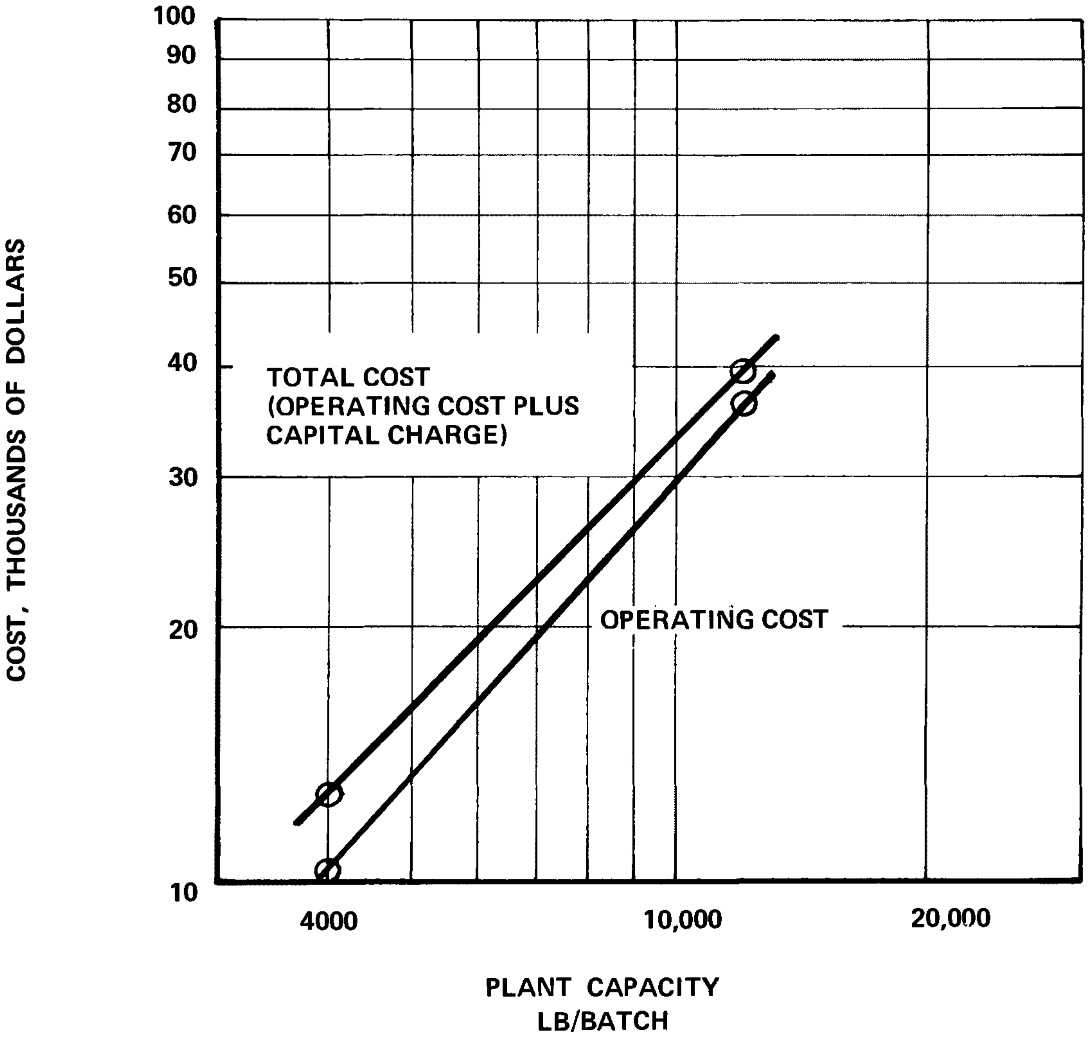


FIGURE 118

ANNUAL COSTS FOR INCINERATORS FOR RENDERING COMBINED VENTS

(High Unit Cost)

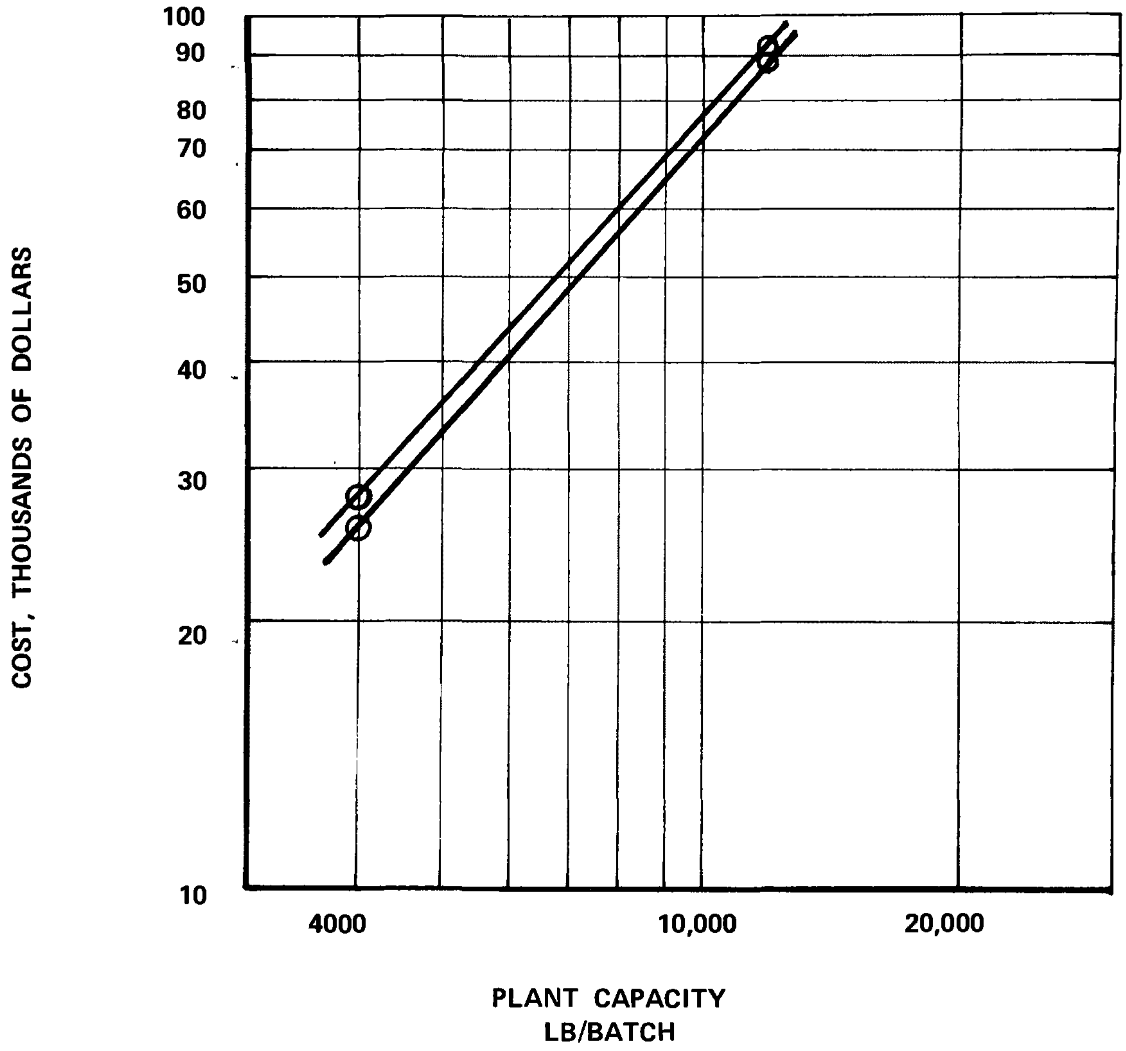


TABLE 215

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR FCC UNITS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,000				
Operating Labor (if any)					
Operator	$4/hr		200	200	200
Supervisor	$6/hr		-	-	-
Total Operating Labor			200	200	200
Maintenance					
Labor	$4/hr		1,312	448	1,312
Materials			500	150	500
Total Maintenance			1,812	598	1,812
Replacement Parts			7,400	2,275	7,400
Total Replacement Parts			7,400	2,275	7,400
Utilities					
Electric Power	$.005/kw-Hr		11,387	7,124	11,387
Fuel			-	-	-
Water (Process)			-	-	-
Water (Cooling)			-	-	-
Chemicals, Specify (ammonia)	$.03/1b		8,940	2,160	8,940
Total Utilities			20,327	9,284	20,327
Total Direct Cost			29,739	12,357	29,739
Annualized Capital Charges			78,117	26,357	78,117
Total Annual Cost			107,856	38,714	107,856

TABLE 216

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR FCC UNITS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,000				
Operating Labor (if any)					
Operator	$9/hr		450	450	450
Supervisor	$12/hr		-	-	-
Total Operating Labor			450	450	450
Maintenance					
Labor	$9/hr		2,952	1,008	2,952
Materials			750	225	750
Total Maintenance			3,702	1,233	3,702
Replacement Parts			7,400	2,275	7,400
Total Replacement Parts			7,400	2,275	7,400
Utilities					
Electric Power	$.020/kw-hr		45,549	28,500	45,549
Fuel			-	-	-
Water (Process)			-	-	-
Water (Cooling)			-	-	-
Chemicals, Specify (ammonia)	$.03/lb		8,940	2,160	8,940
Total Utilities			54,489	30,660	54,489
Total Direct Cost			66,041	34,618	66,041
Annualized Capital Charges			78,117	26,357	78,117
Total Annual Cost			144,158	60,975	144,158

FIGURE 119

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR FCC UNITS
(Low Unit Cost)

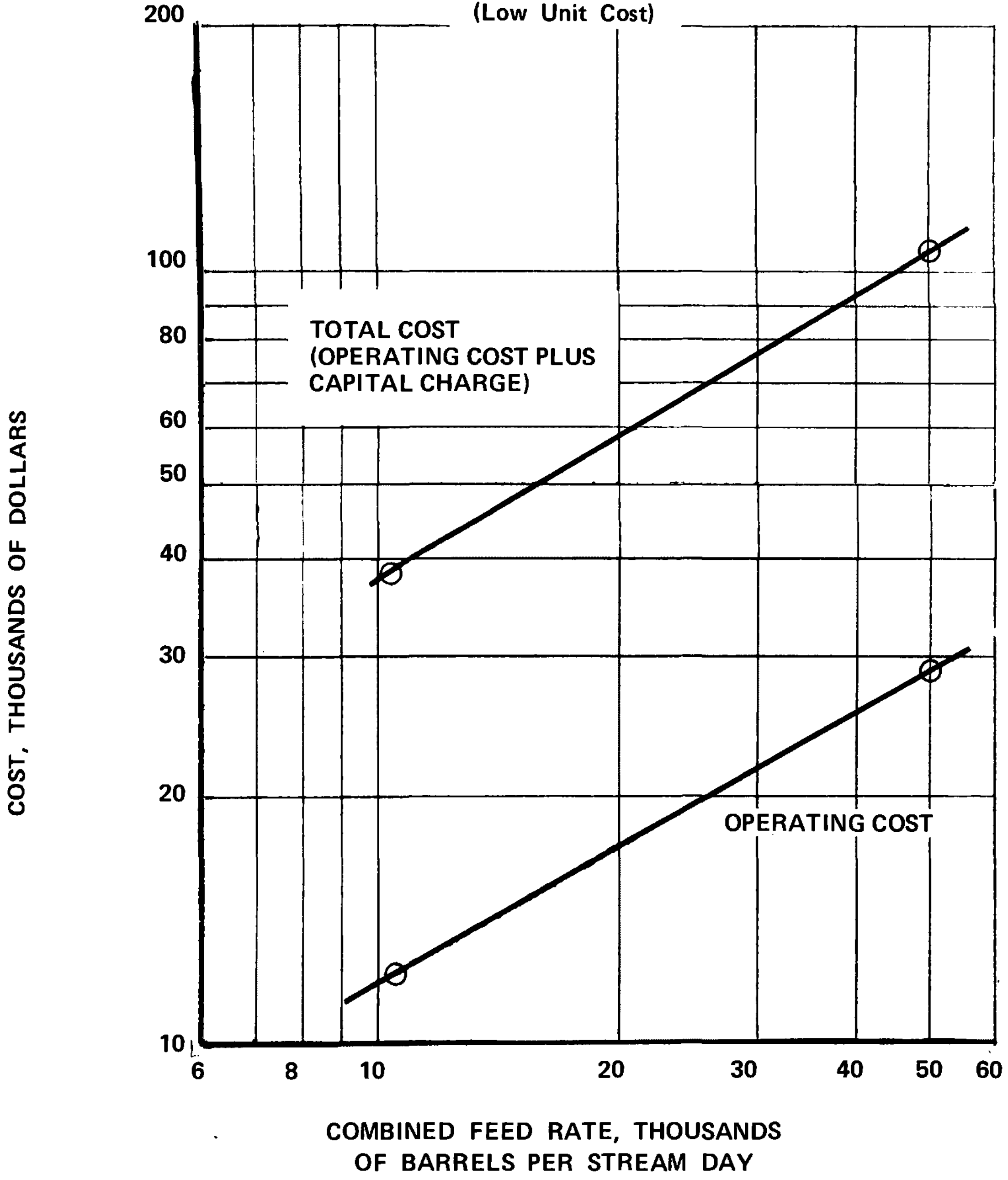


FIGURE 120

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR FCC UNITS

(High Unit Cost)

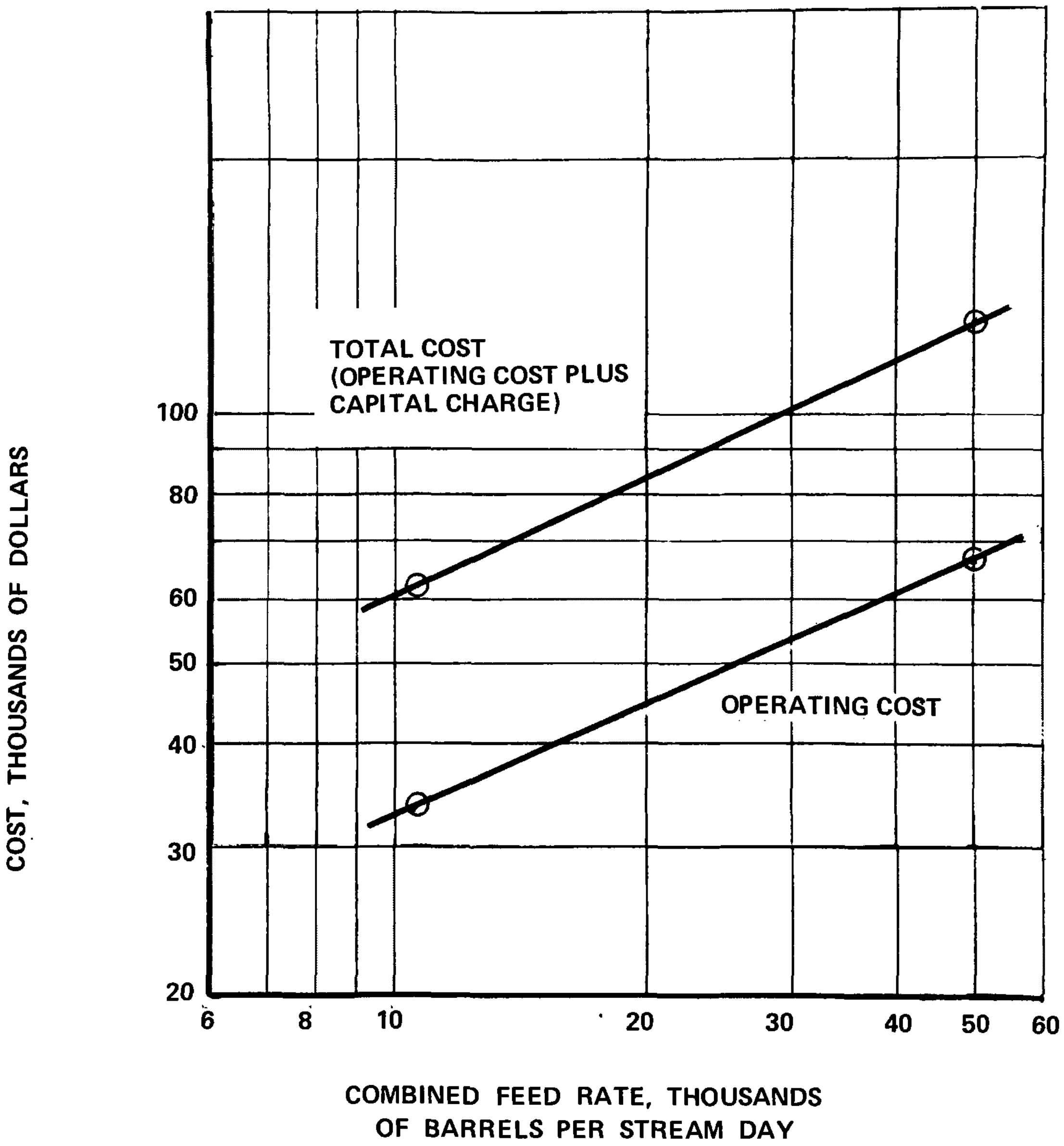


TABLE 217

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR TERTIARY CYCLONES
FOR FCC UNITS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,000				
Operating Labor (if any)					
Operator			-	-	-
Supervisor					
Total Operating Labor					
Maintenance					
Labor			1,000	1,000	1,000
Materials					
Total Maintenance					
Replacement Parts			-	-	-
Total Replacement Parts					
Utilities					
Electric Power					
Fuel					
Water (Process)					
Water (Cooling)					
Chemicals, Specify			-	-	-
Total Utilities					
Total Direct Cost			1,000	1,000	1,000
Annualized Capital Charges			69,340	12,230	69,340
Total Annual Cost			70,340	13,230	70,340

TABLE 218

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR TERTIARY CYCLONES
FOR FCC UNITS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,000				
Operating Labor (if any)					
Operator					
Supervisor			-	-	-
Total Operating Labor					
Maintenance					
Labor			1,000	1,000	1,000
Materials					
Total Maintenance					
Replacement Parts					
Total Replacement Parts			-	-	-
Utilities					
Electric Power					
Fuel					
Water (Process)					
Water (Cooling)			-	-	-
Chemicals, Specify					
Total Utilities					
Total Direct Cost			1,000	1,000	1,000
Annualized Capital Charges			69,340	12,230	69,340
Total Annual Cost			70,340	13,230	70,340

FIGURE 121

ANNUAL COSTS FOR TERTIARY CYCLONES FOR FCC UNITS

(Low Unit Cost)

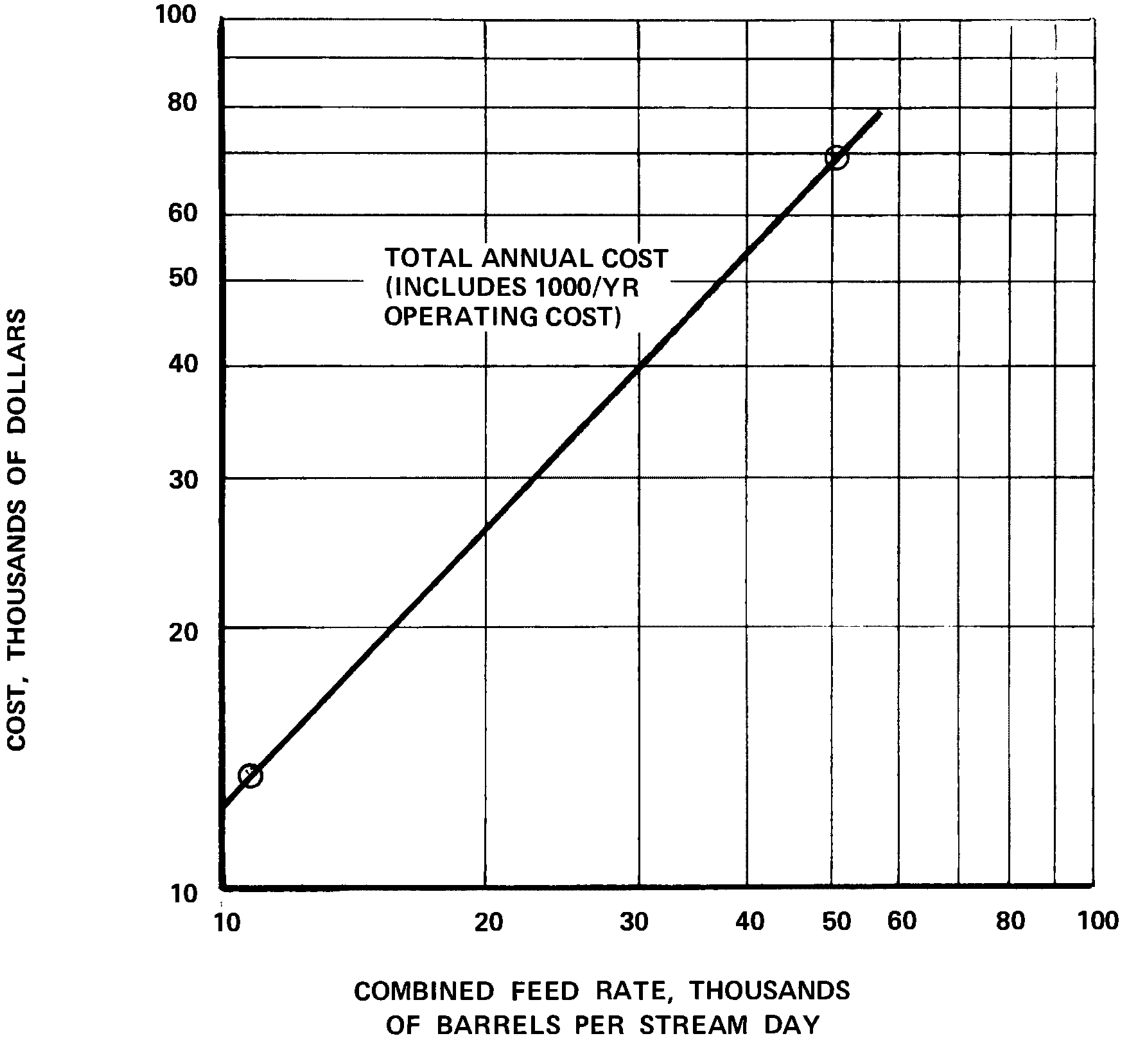


FIGURE 122

ANNUAL COSTS FOR TERTIARY CYCLONES FOR FCC UNITS

(High Unit Cost)

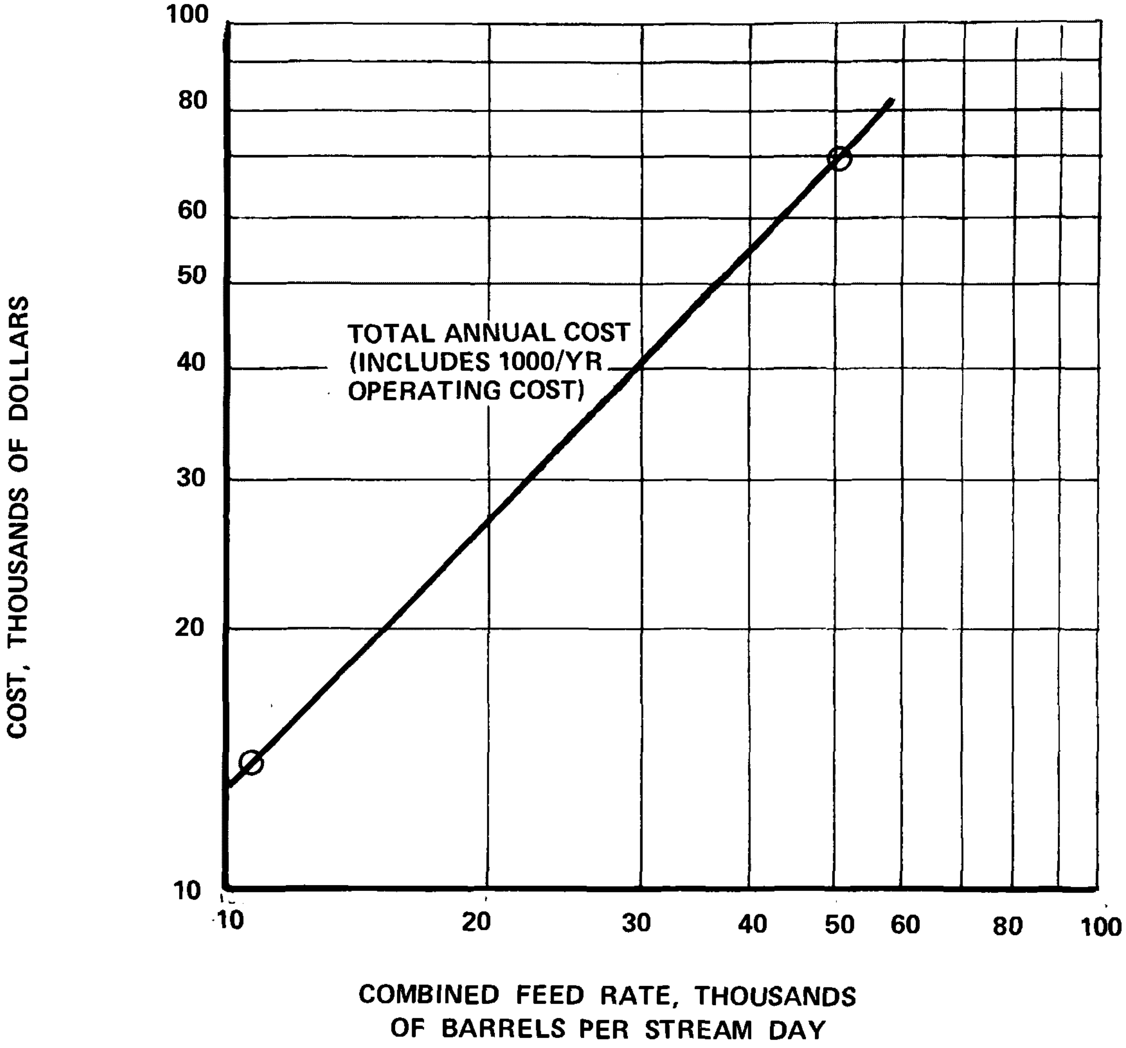


TABLE 219

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	960				
Operating Labor (if any)					
Operator	$4/hr			-	-
Supervisor	$6/hr			180	180
Total Operating Labor				180	180
Maintenance					
Labor	$4/hr			-	-
Materials				200	288
Total Maintenance				200	288
Replacement Parts					
Bag Replacement Per Yr.				2,250	3,075
Total Replacement Parts				2,250	3,075
Utilities					
Electric Power	$.005/kw-hr			1,124	1,124
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				1,124	1,124
Total Direct Cost				3,754	4,579
Annualized Capital Charges				8,363	10,119
Total Annual Cost				12,117	14,698

TABLE 220

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	960				
Operating Labor (if any)					
Operator	$9/hr			-	-
Supervisor	$12/hr			360	360
Total Operating Labor				360	360
Maintenance					
Labor	$9/hr			-	-
Materials				200	288
Total Maintenance				200	288
Replacement Parts					
Bag Replacement Per Yr.				2,250	3,075
Total Replacement Parts				2,250	3,075
Utilities					
Electric Power	$.020/kw-hr			4,500	4,500
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				4,500	4,500
Total Direct Cost				7,310	8,223
Annualized Capital Charges				8,363	10,119
Total Annual Cost				15,673	18,342

FIGURE 123

ANNUAL COSTS FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

(Low Unit Cost)

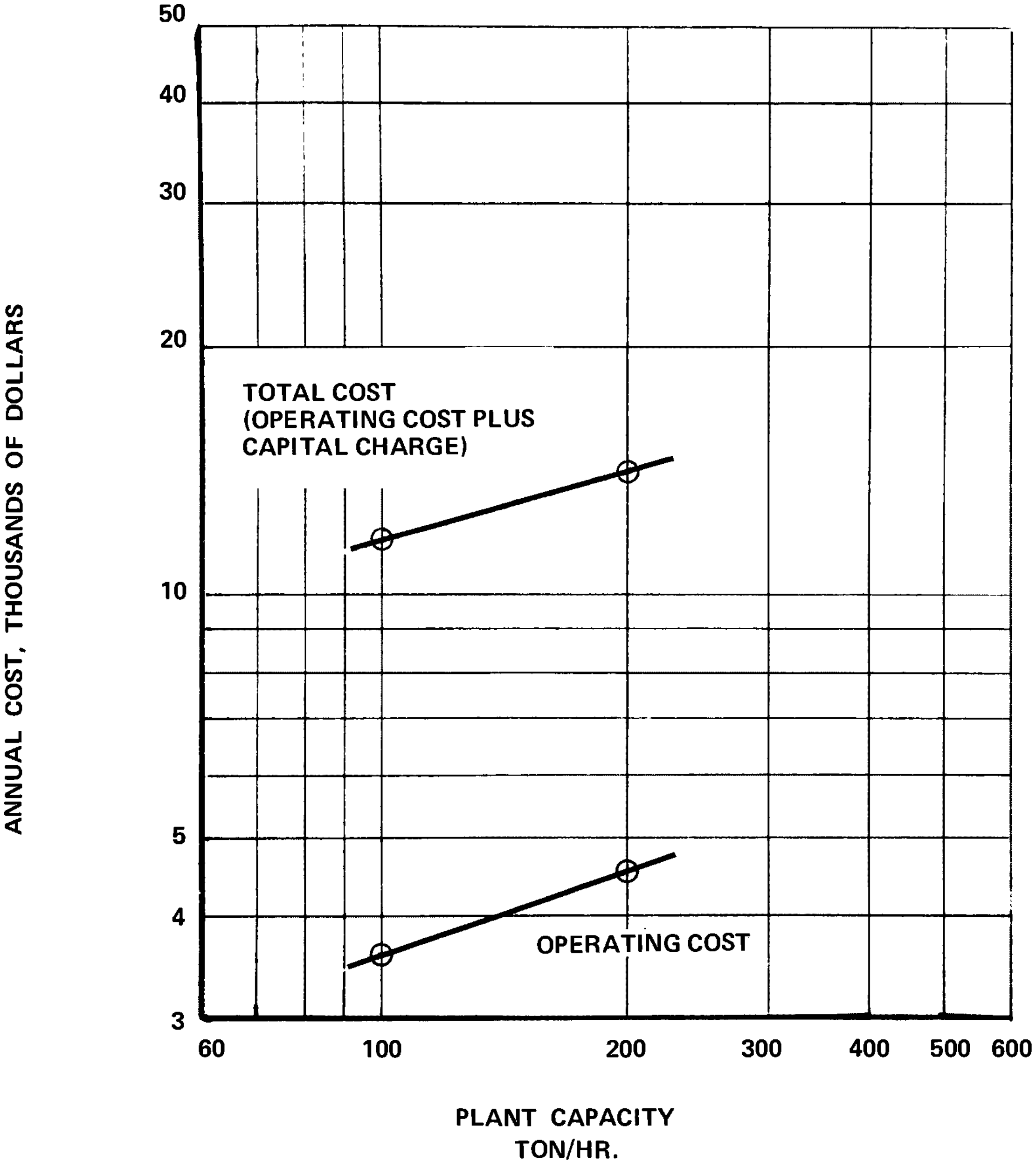


FIGURE 124

ANNUAL COSTS FOR FABRIC COLLECTORS FOR ASPHALT BATCHING PLANTS

(High Unit Cost)

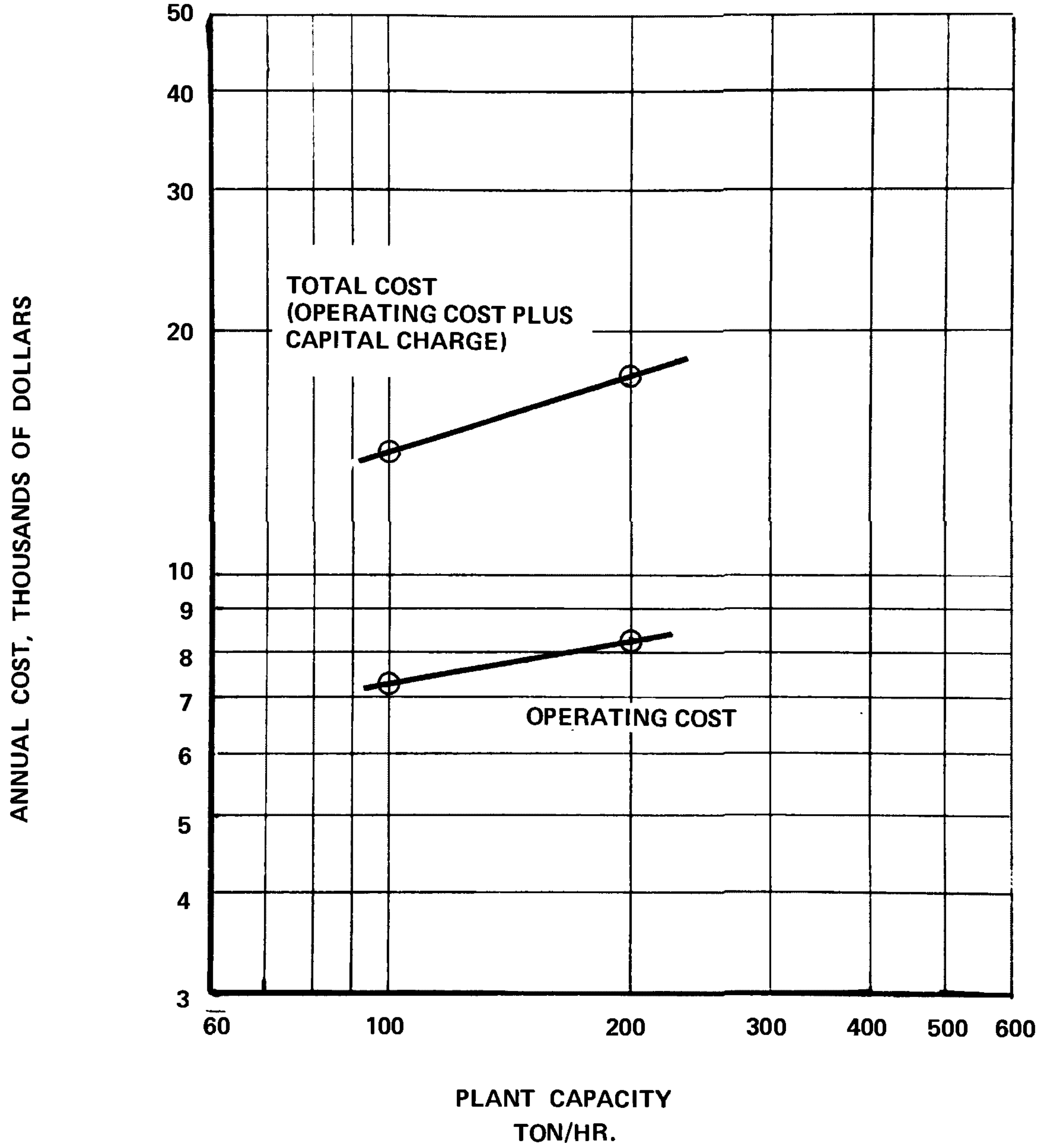


TABLE 221

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	960				
Operating Labor (if any)					
Operator	$4/hr				
Supervisor	$6/hr				
Total Operating Labor					
Maintenance					
Labor	$4/hr	194	188	194	188
Materials		50	75	50	75
Total Maintenance		244	263	244	263
Replacement Parts		185	226	194	244
Total Replacement Parts		185	226	194	244
Utilities					
Electric Power	$.005/kw-hr	838	1,257	1,650	2,456
Fuel		-	-	-	-
Water (Process)	$.10/M Gal	580	761	684	913
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		1,418	2,018	2,334	3,369
Total Direct Cost		1,847	2,507	2,772	3,876
Annualized Capital Charges		4,714	5,870	5,260	6,771
Total Annual Cost		6,561	8,377	8,032	10,647

TABLE 222

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	960				
Operating Labor (if any)					
Operator	$9/hr.	-	-	-	-
Supervisor	$12/hr.				
Total Operating Labor					
Maintenance					
Labor	$9/hr.	328	424	328	424
Materials		50	75	50	75
Total Maintenance		378	499	378	499
Replacement Parts		185	226	194	244
Total Replacement Parts		185	226	194	244
Utilities					
Electric Power	$.020/kw-hr.	3,354	5,030	6,600	9,827
Fuel		-	-	-	-
Water (Process)	$.50/M Gal.	2,900	3,808	3,420	4,568
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		6,254	8,838	10,020	14,395
Total Direct Cost		6,817	9,563	10,592	15,138
Annualized Capital Charges		4,714	5,870	5,260	6,771
Total Annual Cost		11,531	15,433	15,852	21,909

FIGURE 125

ANNUAL COSTS FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS (HIGH EFFICIENCY)

(Low Unit Cost)

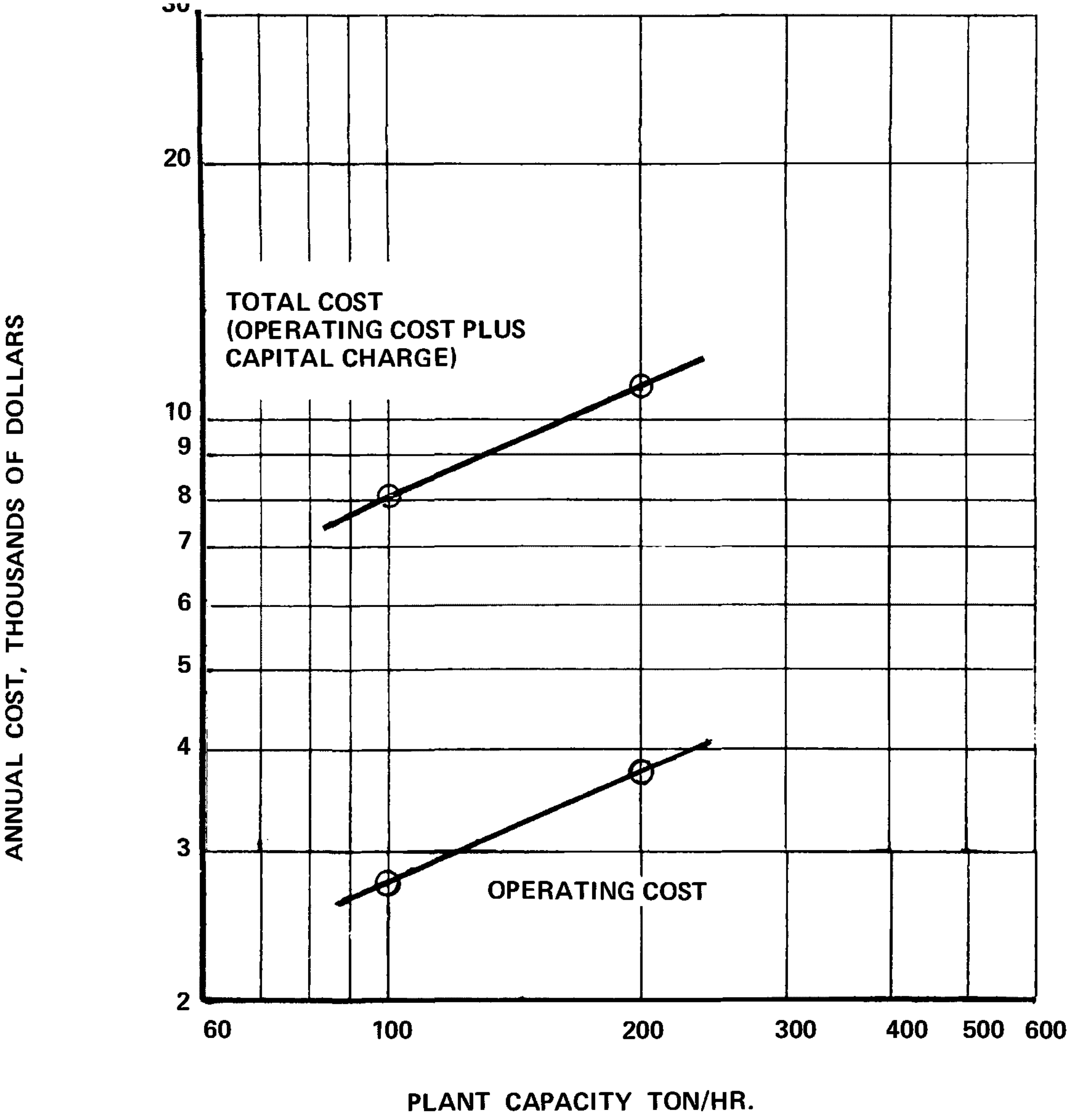


FIGURE 126

ANNUAL COSTS FOR WET SCRUBBERS FOR ASPHALT BATCHING PLANTS (HIGH EFFICIENCY)

(High Unit Cost)

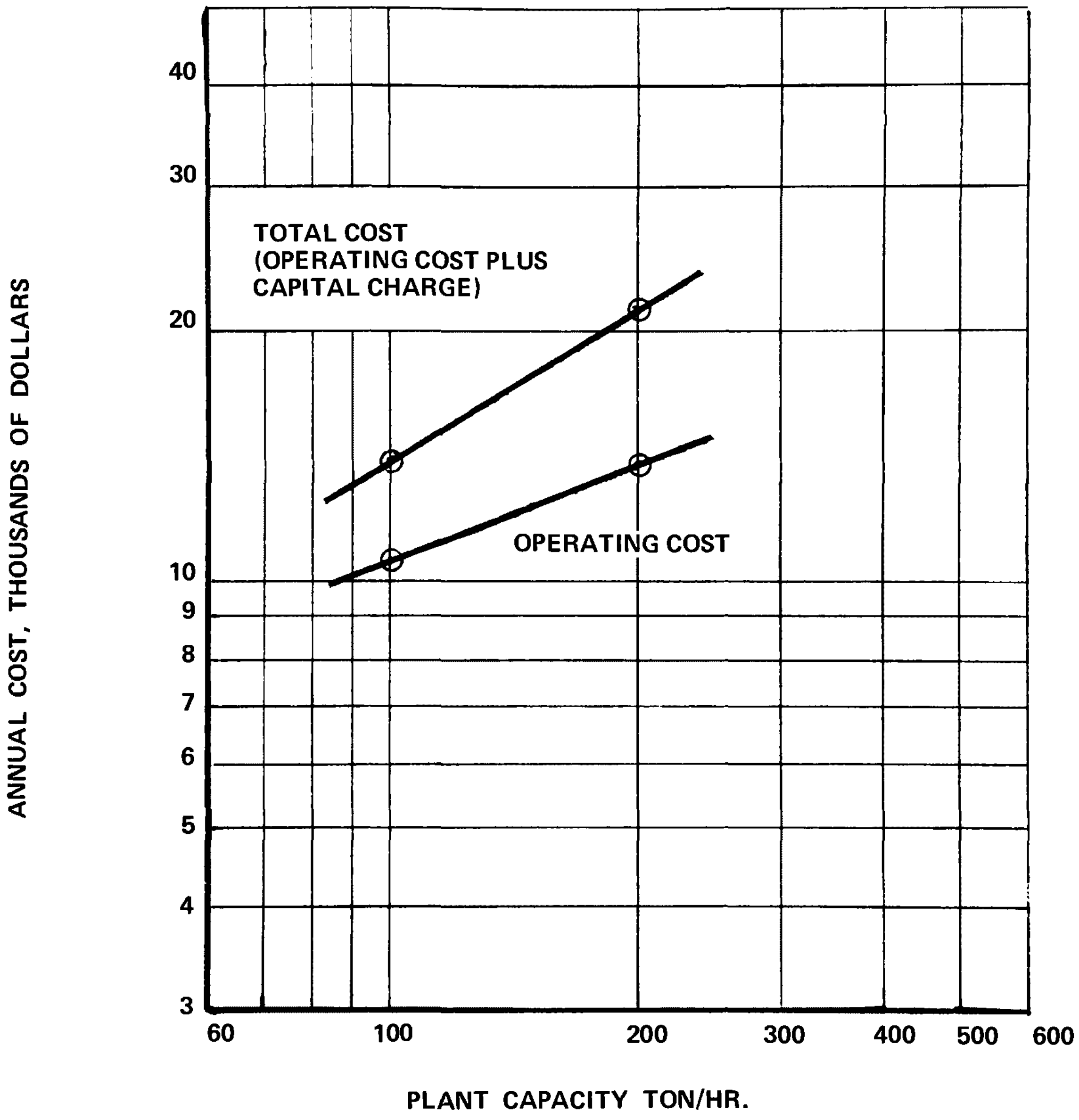


TABLE 223

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR BOF STEELMAKING

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$4/hr	-	-	-	-
Supervisor	$6/hr	-	-	-	-
Total Operating Labor					
Maintenance (2)					
Labor	$4/hr				
Materials					
Total Maintenance		147,400	167,400	147,400	167,400
Replacement Parts (3)					
Total Replacement Parts		29,900	34,200	29,900	34,200
Utilities					
Electric Power	$.005/kw-hr	38,033	59,863	38,033	59,863
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		38,033	59,863	38,033	59,863
Total Direct Cost		215,333	261,463	215,333	261,463
Annualized Capital Charges		594,900	780,072	586,273	757,560
Total Annual Cost		810,233	1,041,535	801,606	1,019,023

(1) Based upon two quotations.
(2) Based on 5% of system cost.
(3) Based on 1% of system cost.

TABLE 224

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR BOF STEELMAKING

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$9/hr	-	-	-	-
Supervisor	$12/hr	-	-	-	-
Total Operating Labor					
Maintenance (2)					
Labor	$9/hr				
Materials					
Total Maintenance		147,400	167,400	147,400	167,400
Replacement Parts (3)					
Total Replacement Parts		29,900	34,200	29,900	34,200
Utilities					
Electric Power	$.020/kw-hr	152,136	239,454	152,136	239,454
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		152,136	239,454	152,136	239,454
Total Direct Cost		329,436	441,054	329,436	441,054
Annualized Capital Charges		594,900	780,072	586,273	757,560
Total Annual Cost		924,336	1,221,126	915,709	1,198,614

(1) Based upon two quotations.
(2) Based on 5% of system cost.
(3) Based on 1% of system cost.

FIGURE 127

ANNUAL COSTS FOR PRECIPITATORS FOR BOF STEELMAKING (INTERMEDIATE EFFICIENCY)

(Low Unit Cost)

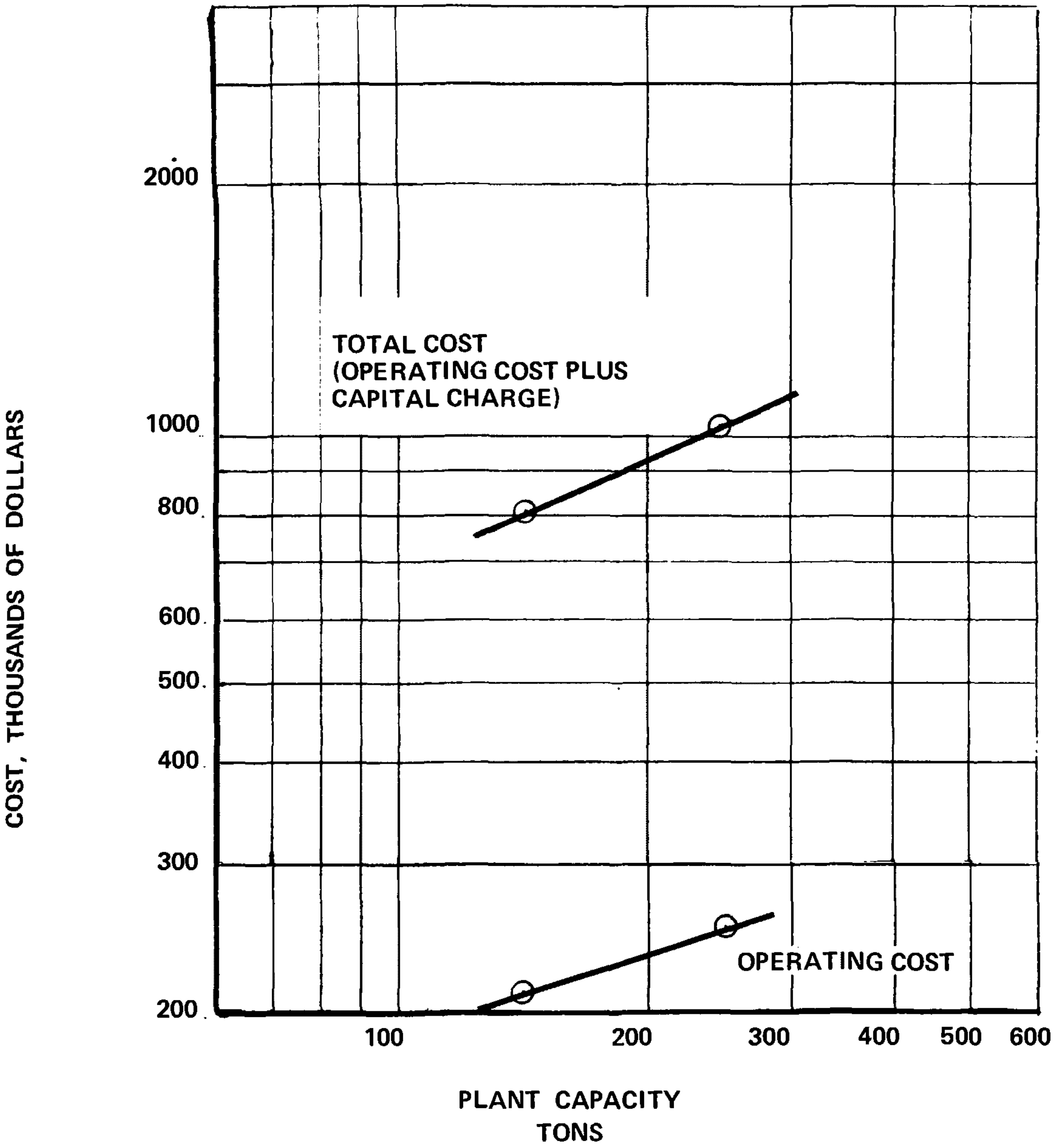


FIGURE 128

ANNUAL COSTS FOR PRECIPITATORS FOR BOF STEELMAKING (INTERMEDIATE EFFICIENCY)

(High Unit Cost)

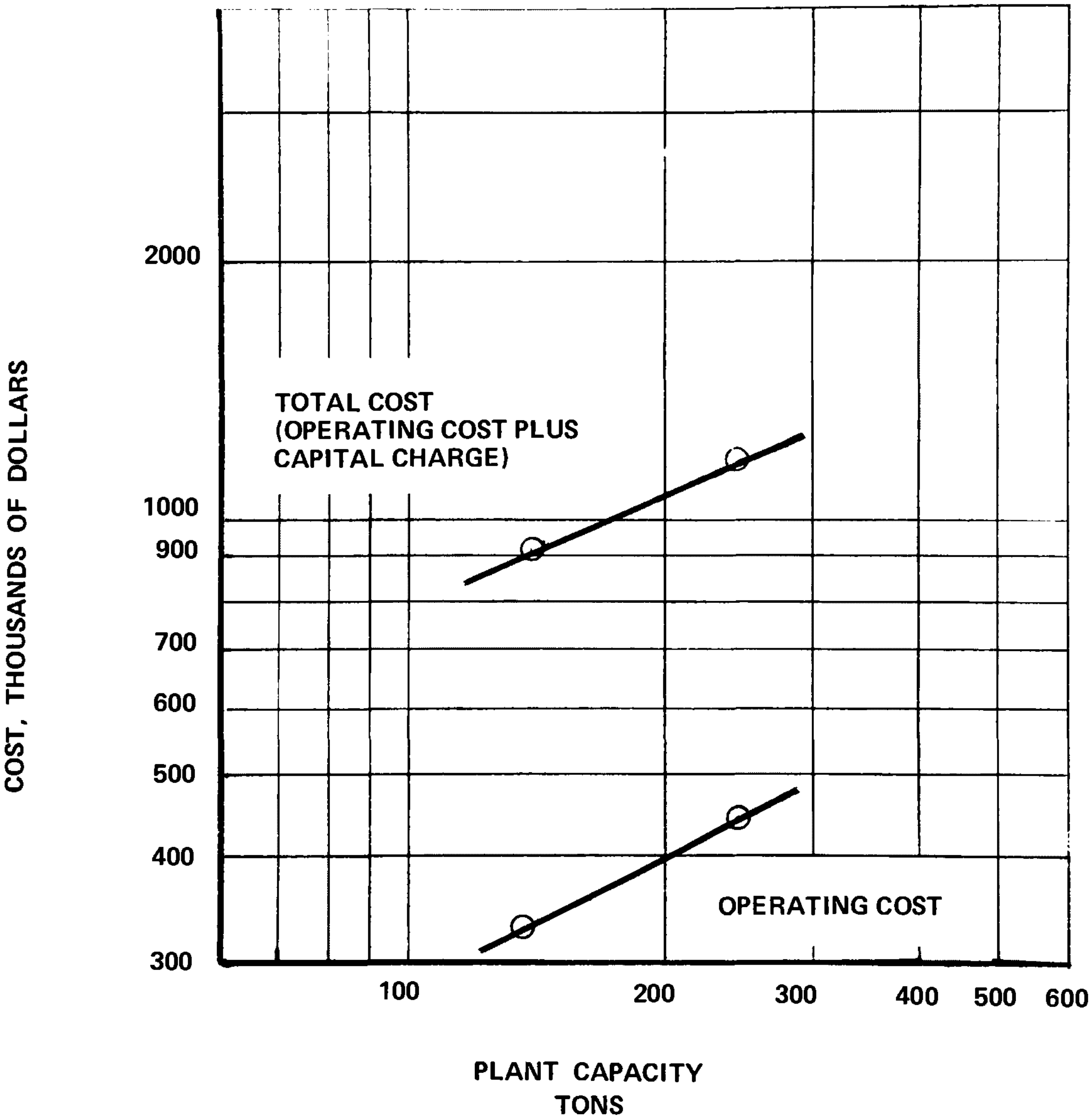


FIGURE 129

ANNUAL COSTS FOR PRECIPITATORS FOR BOF STEELMAKING (HIGH EFFICIENCY)

(Low Unit Cost)

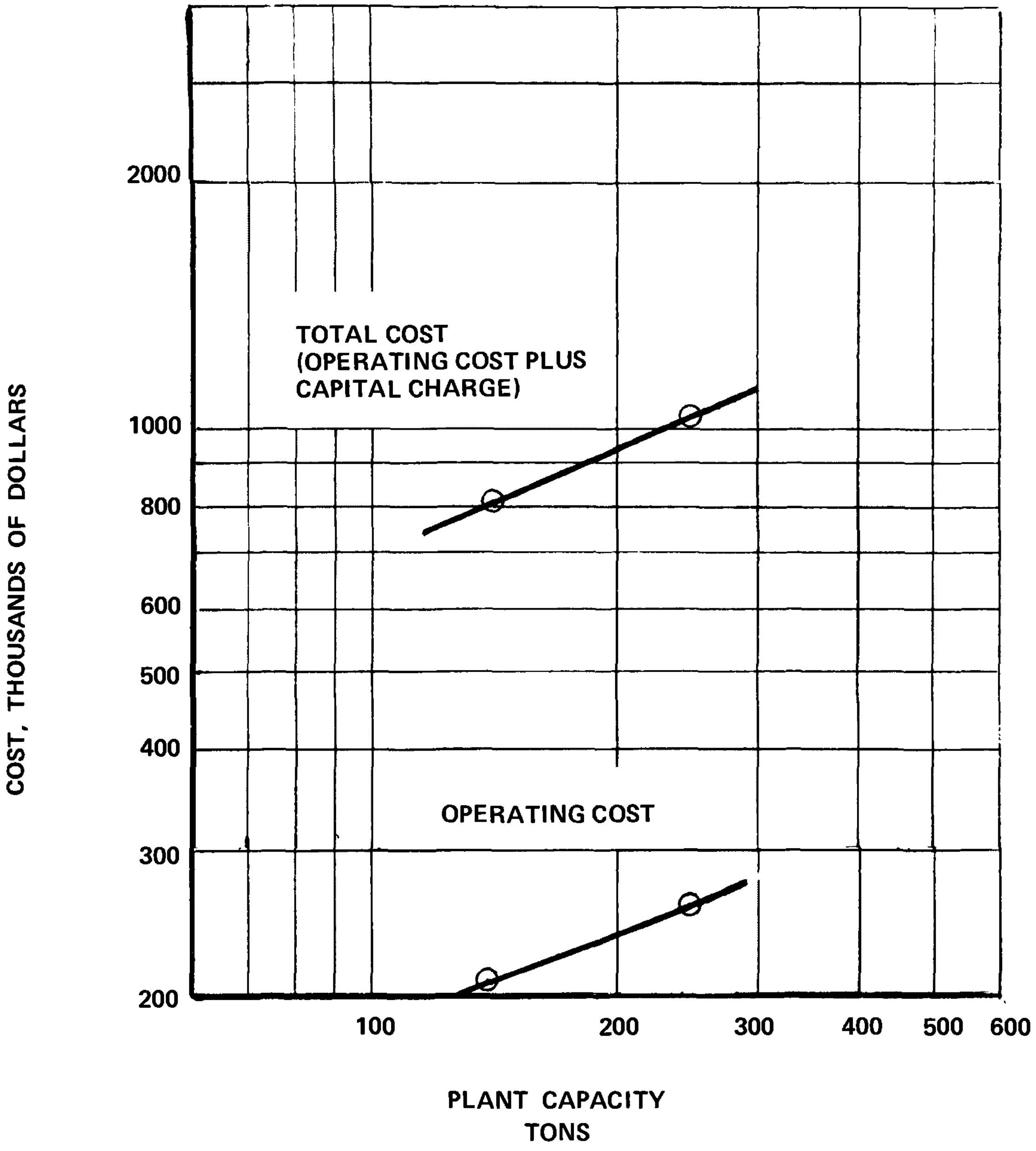


FIGURE 130

ANNUAL COSTS FOR PRECIPITATORS
FOR BOF STEELMAKING
(HIGH EFFICIENCY)
(High Unit Cost)

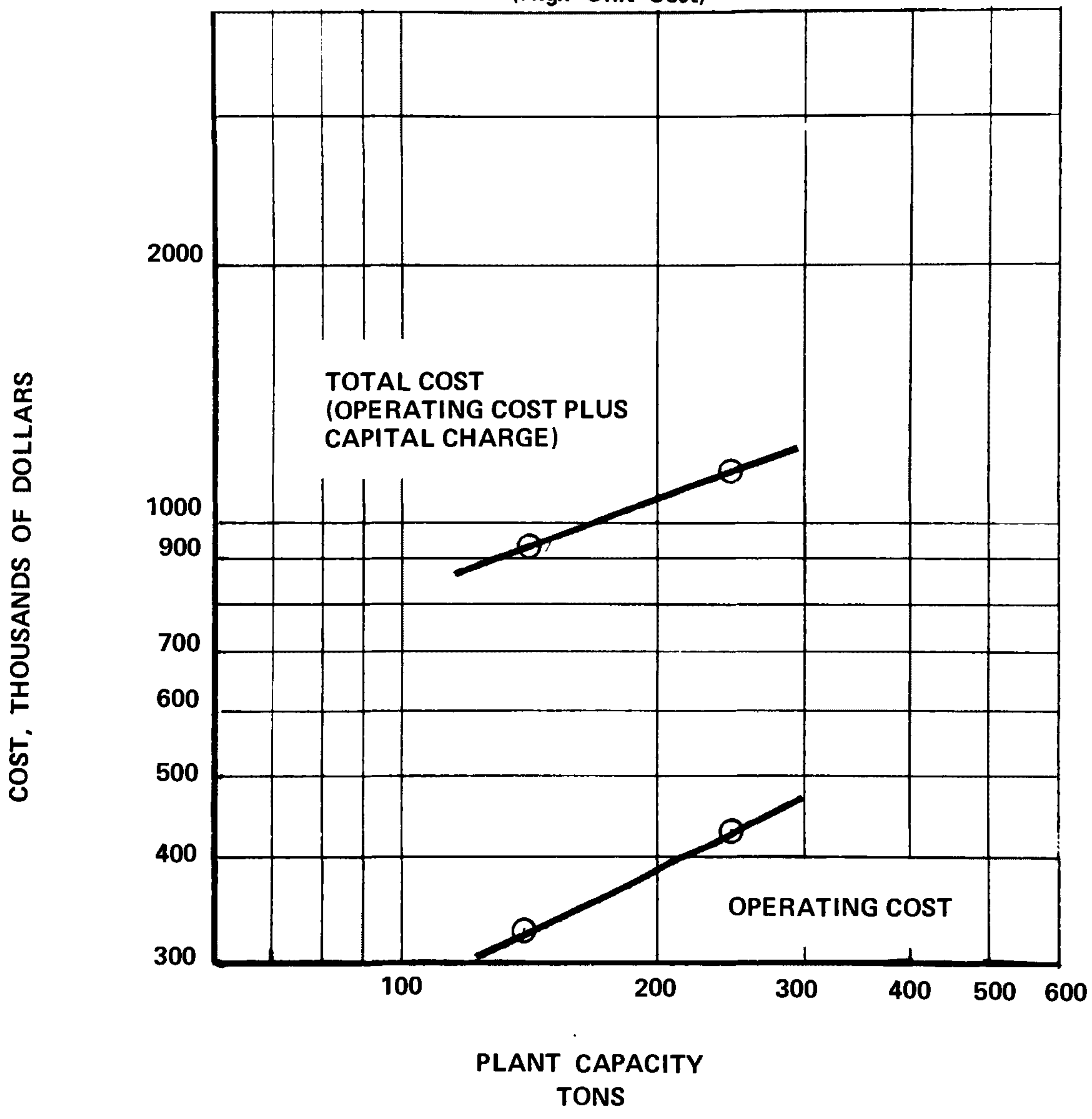


TABLE 225

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING
(OPEN HOOD)

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$4/hr	5,793	5,793	5,793	5,793
Supervisor	$6/hr	-	-	-	-
Total Operating Labor		5,793	5,793	5,793	5,793
Maintenance (1)					
Labor					
Materials	$4/hr	285,500	367,100	286,500	367,800
Total Maintenance		285,500	367,100	286,500	367,800
Replacement Parts (2)					
Total Replacement Parts		57,150	73,810	57,300	73,970
Utilities					
Electric Power	$.005/kw-hr	112,272	220,000	171,500	275,500
Fuel		-	-	-	-
Water (Process)	$.10/M Gal	89,000	161,800	89,000	161,800
Water (Cooling) (3)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		201,272	381,800	260,500	437,300
Total Direct Cost		549,715	828,503	610,093	884,863
Annualized Capital Charges		571,500	738,100	573,000	739,700
Total Annual Cost		1,121,215	1,566,603	1,183,093	1,624,563

(1) Based on 5% of system cost.
(2) Based on 1% of system cost
(3) Closed cooling systems are used. Pump HP is in power cost.

TABLE 226

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING
(OPEN HOOD)

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$9/hr	13,035	13,035	13,035	13,035
Supervisor	$12/hr	-	-	-	-
Total Operating Labor		13,035	13,035	13,035	13,035
Maintenance (1)					
Labor	$9/hr	285,500	367,100	286,500	367,800
Materials					
Total Maintenance		285,500	367,100	286,500	367,800
Replacement Parts (2)					
Total Replacement Parts		57,150	73,810	57,300	73,970
Utilities					
Electric Power	$.020/kw-hr	449,090	880,000	686,000	1,102,000
Fuel		-	-	-	-
Water (Process)	$.50/M Gal	445,000	809,000	445,000	809,000
Water (Cooling) (3)		-	-	-	-
Chemicals, Specify -		-	-	-	-
Total Utilities		894,090	1,689,000	1,131,000	1,911,000
Total Direct Cost		1,249,775	2,142,945	1,487,835	2,365,805
Annualized Capital Charges		571,500	738,100	573,000	739,700
Total Annual Cost		1,821,275	2,881,045	2,060,835	3,105,505

(1) Based on 5% of system cost.
(2) Based on 1% of system cost.
(3) Closed cooling systems are used. Pump HP is in power cost.

FIGURE 131

ANNUAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING (OPEN HOOD – HIGH EFFICIENCY)

(Low Unit Cost)

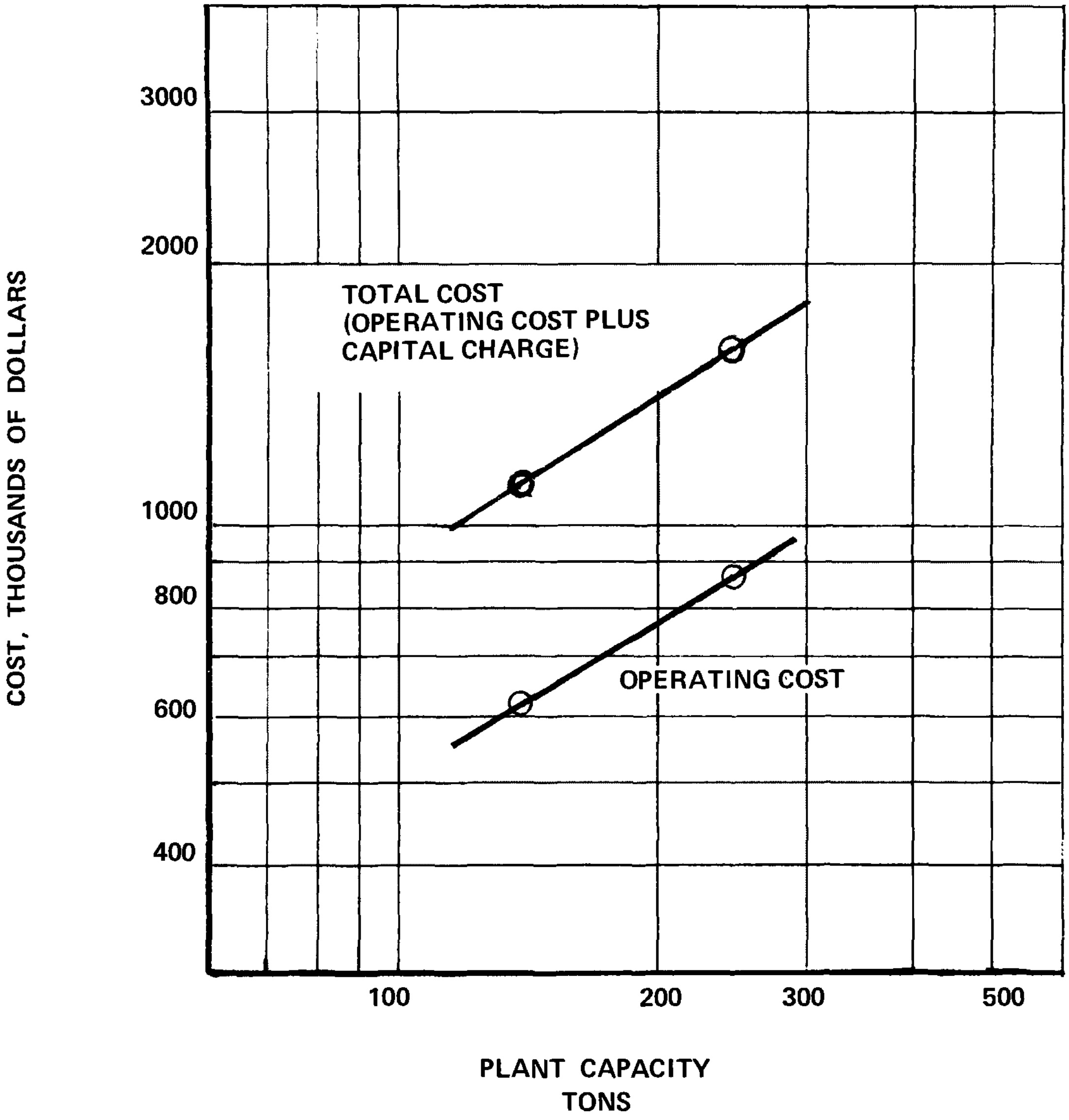


FIGURE 132

ANNUAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING (OPEN HOOD – HIGH EFFICIENCY)

(High Unit Cost)

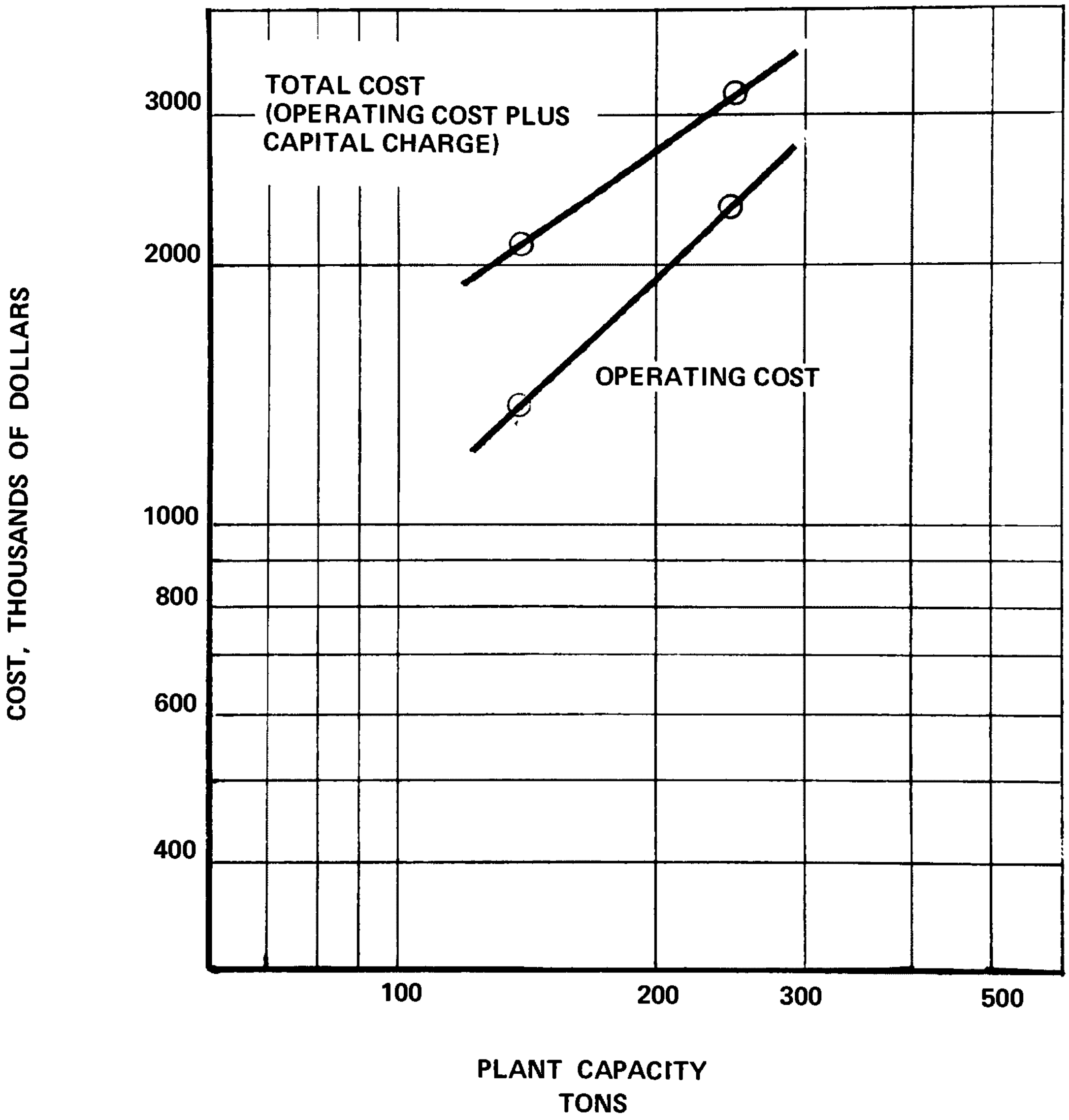


TABLE 227

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING
(CLOSED HOOD)

Low Unit Cost

← Note (1) → ← Note (2) →

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$4/hr	5,793	5,793	5,793	5,793
Supervisor	$6/hr	-	-	-	-
Total Operating Labor		5,793	5,793	5,793	5,793
Maintenance (3)					
Labor	$4/hr				
Materials		162,900	196,300	338,100	420,400
Total Maintenance		162,900	196,300	338,100	420,400
Replacement Parts (4)		32,500	39,300	67,600	84,100
Total Replacement Parts		32,500	39,300	67,600	84,100
Utilities					
Electric Power	$.005/kw-Hr	23,000	42,500	197,727	300,000
Fuel	$.50/MM BTU	-	-	159,375	159,375
Water (Process)	$.10/M gal	18,880	35,400	18,880	35,400
Water (Cooling)		-	-	-	-
Chemicals, Specify (nitrogen)	$2.00/ton	17,500	17,500	17,500	17,500
Total Utilities		59,380	95,400	393,482	512,275
Total Direct Cost		260,573	336,793	804,975	1,022,568
Annualized Capital Charges		571,500	738,100	573,000	739,700
Total Annual Cost		832,073	1,074,893	1,377,975	1,762,268

(1) Closed hood systems are not ordinarily quoted at this low efficiency level.
(2) O.G. system quoted without cooling tower, but with auxiliary cleaning system for tilted furnace
(3) Based on 5% of system cost
(4) Based on 1% of system cost

TABLE 228

ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING
(CLOSED HOOD)

		← Note (1) →		High Unit Cost ← Note (2) →	
Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,850				
Operating Labor (if any)					
Operator	$9/hr	13,035	13,035	13,035	13,035
Supervisor	$12/hr	-	-		
Total Operating Labor		13,035	13,035	13,035	13,035
Maintenance (3)					
Labor	$9/hr	162,900	196,300	338,100	420,400
Materials					
Total Maintenance		162,900	196,300	338,100	420,400
Replacement Parts (4)		32,500	39,300	67,600	84,100
Total Replacement Parts		32,500	39,300	67,600	84,100
Utilities					
Electric Power	$.020/kw-hr	92,000	170,000	790,909	1,200,000
Fuel	$1.25/MM BTU	-	-	398,437	398,437
Water (Process)	$.50/M gal	94,400	177,000	94,400	177,000
Water (Cooling)		-	-	-	-
Chemicals, Specify	$2.00/ton	17,500	17,500	17,500	17,500
Total Utilities		203,900	364,500	1,301,246	1,792,937
Total Direct Cost		412,335	613,135	1,719,981	2,310,472
Annualized Capital Charges		571,500	738,100	573,000	739,700
Total Annual Cost		983,835	1,351,235	2,292,981	3,050,172

(1) Closed hood systems are not ordinarily quoted at this low efficiency level.
(2) O.G. system quoted without cooling tower, but with auxiliary cleaning system for tilted furnace.
(3) Based on 5% of system cost.
(4) Based on 1% of system cost.

FIGURE 133

ANNUAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING (CLOSED HOOD – HIGH EFFICIENCY)

(Low Unit Cost)

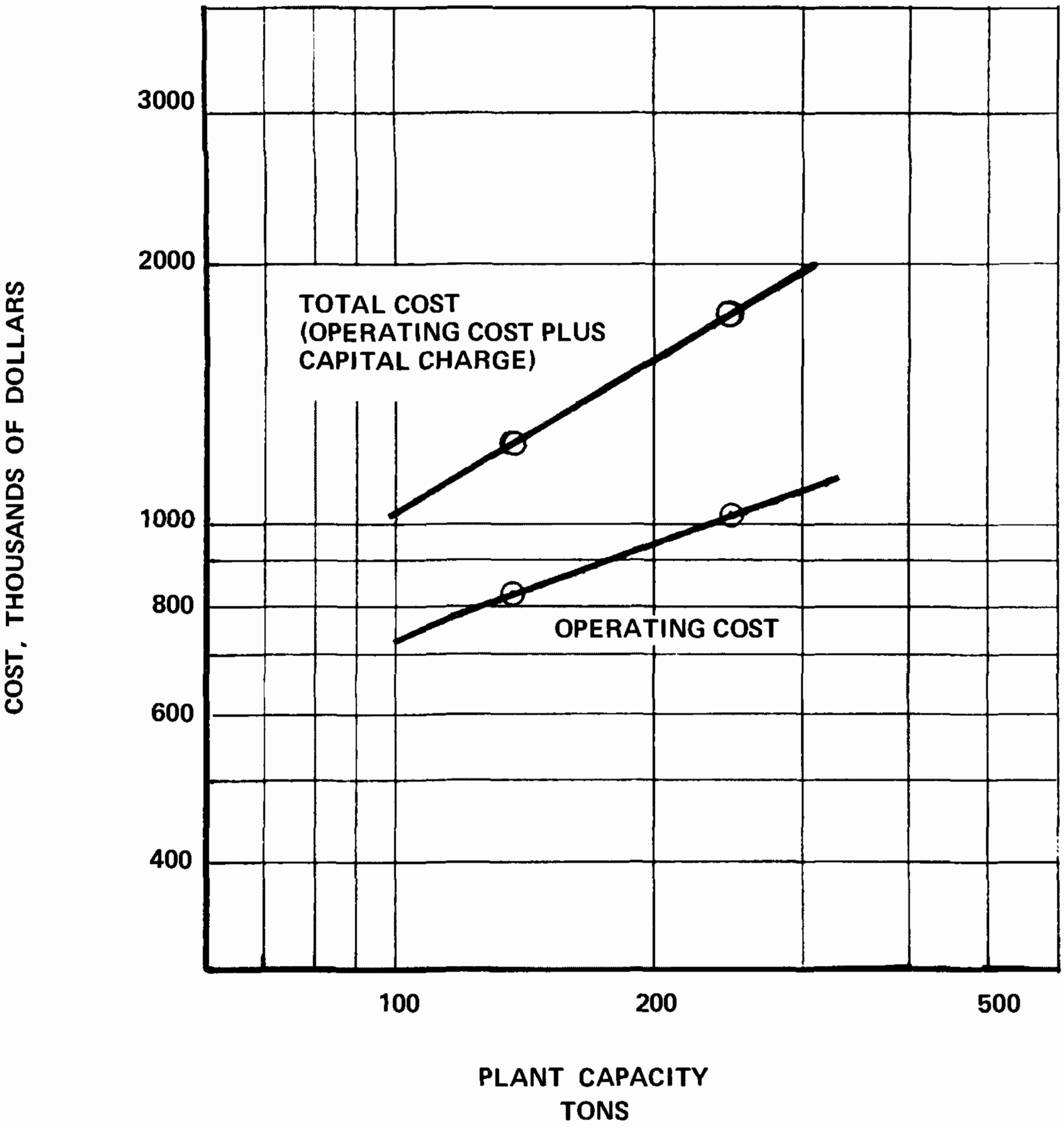


FIGURE 134

ANNUAL COSTS FOR WET SCRUBBER SYSTEMS FOR BOF STEELMAKING (CLOSED HOOD – HIGH EFFICIENCY)

(High Unit Cost)

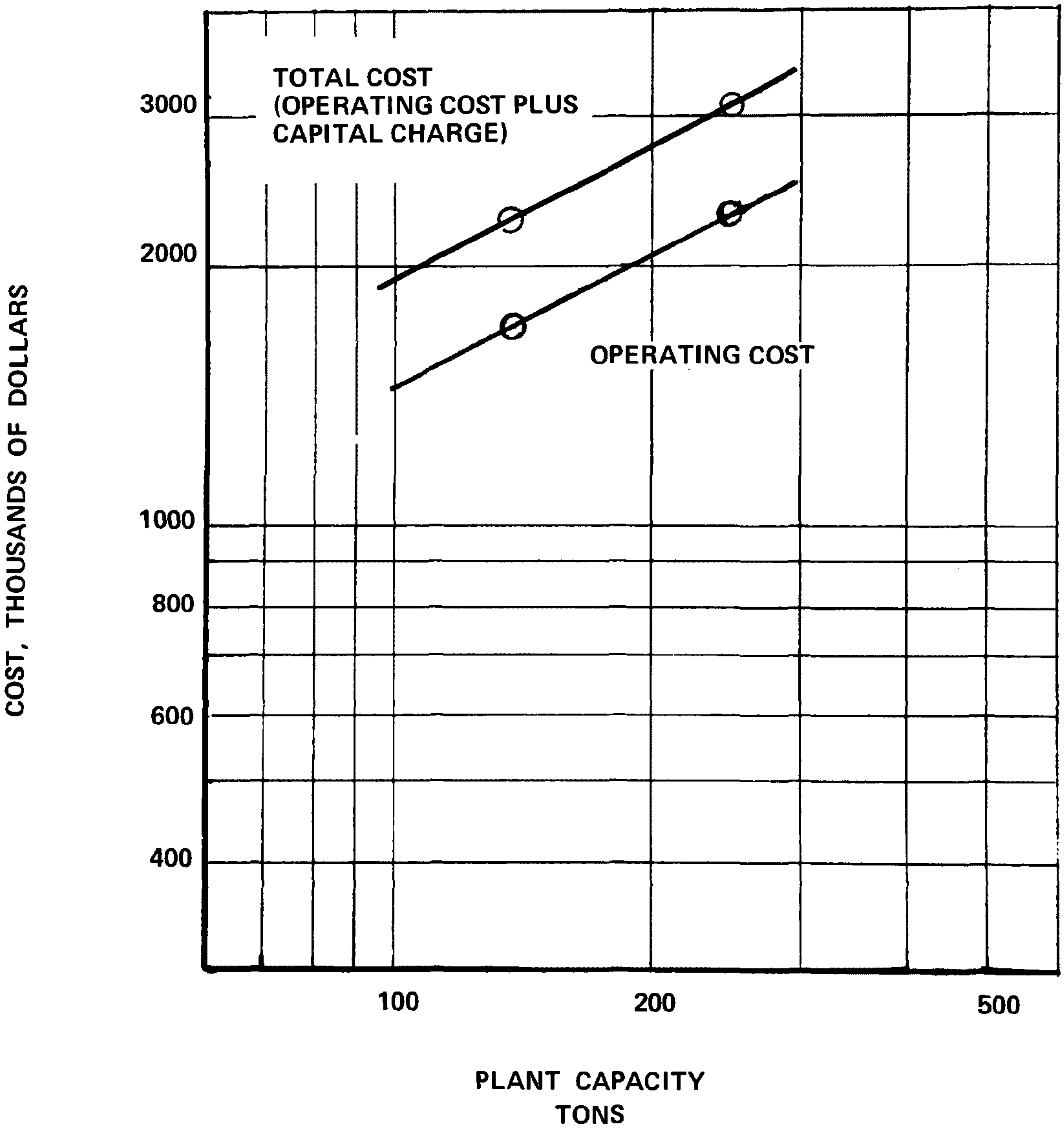


TABLE 229
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,500				
Operating Labor (if any)					
Operator	$4/hr	500	500	500	500
Supervisor	$6/hr	-	-	-	-
Total Operating Labor		500	500	500	500
Maintenance					
Labor					
Materials					
Total Maintenance		1,426	3,604	1,437	3,408
Replacement Parts					
Total Replacement Parts		832	2,870	794	2,258
Utilities					
Electric Power	$.005/kw-hr	20,048	69,393	19,123	60,769
Fuel		-	-	-	-
Water (Process)	$0.10/M gal	1,698	5,092	1,698	5,092
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		21,746	74,485	20,821	65,861
Total Direct Cost		24,504	81,459	23,552	72,027
Annualized Capital Charges		38,994	106,826	38,120	97,191
Total Annual Cost		63,498	188,285	61,672	169,218

Data based on two bids.

TABLE 230
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	2,500				
Operating Labor (if any)					
Operator	$9/hr	1,125	1,125	1,125	1,125
Supervisor	$12/hr	-	-	-	-
Total Operating Labor		1,125	1,125	1,125	1,125
Maintenance					
Labor					
Materials					
Total Maintenance		1,426	3,604	1,437	3,408
Replacement Parts					
Total Replacement Parts		832	2,870	794	2,258
Utilities					
Electric Power	$.020/kw-hr	80,196	277,588	76,497	243,089
Fuel		-	-	-	-
Water (Process)	$0.50/M gal	8,488	25,462	8,488	25,462
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		88,684	303,050	84,985	268,551
Total Direct Cost		92,067	310,649	88,341	275,342
Annualized Capital Charges		38,994	106,826	38,120	97,191
Total Annual Cost		131,061	417,475	126,461	372,533

Data based on two bids.

FIGURE 135

ANNUAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS (LA–PROCESS WEIGHT)

(Low Unit Cost)

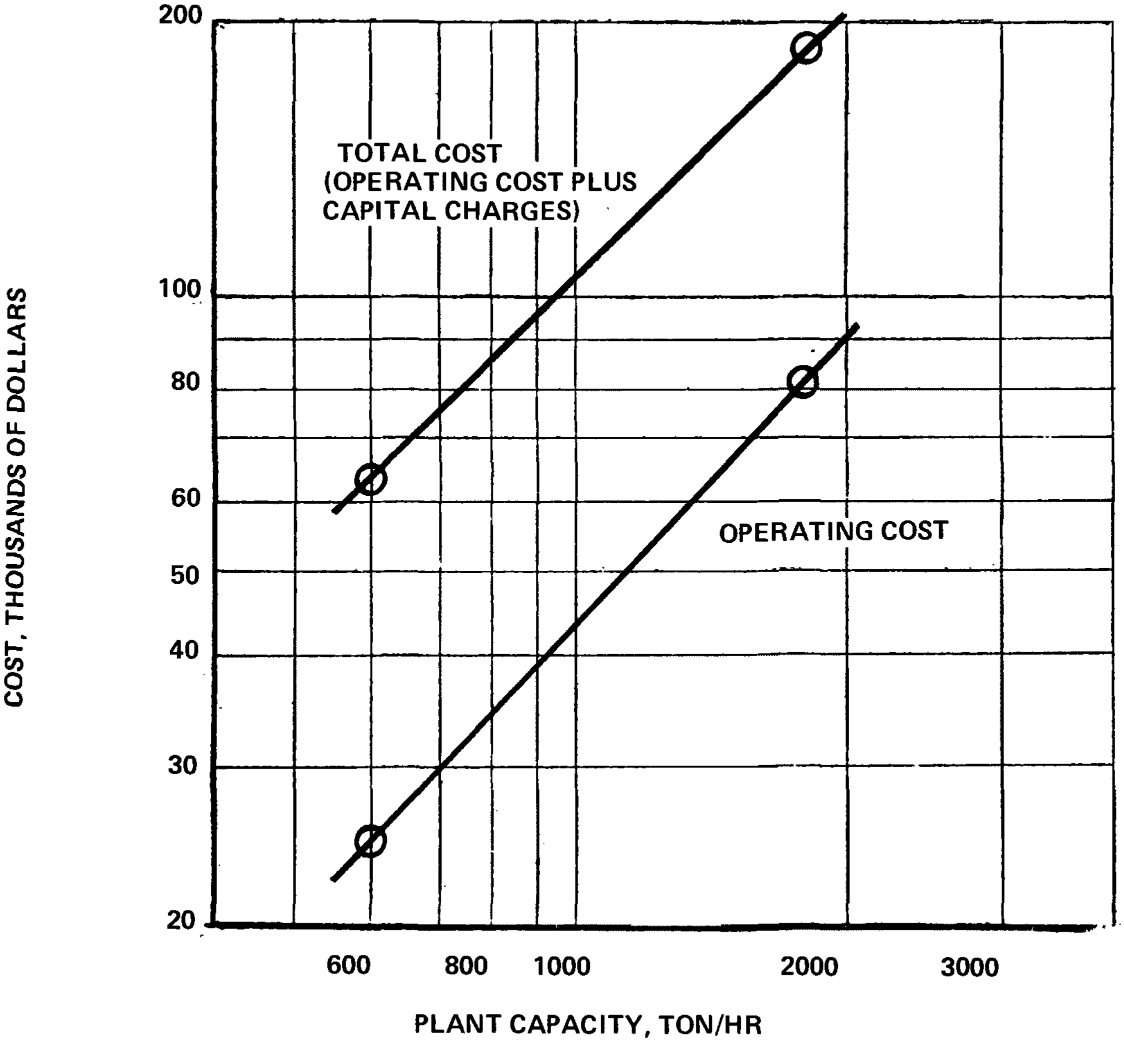


FIGURE 136

ANNUAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS (LA–PROCESS WEIGHT)

(High Unit Cost)

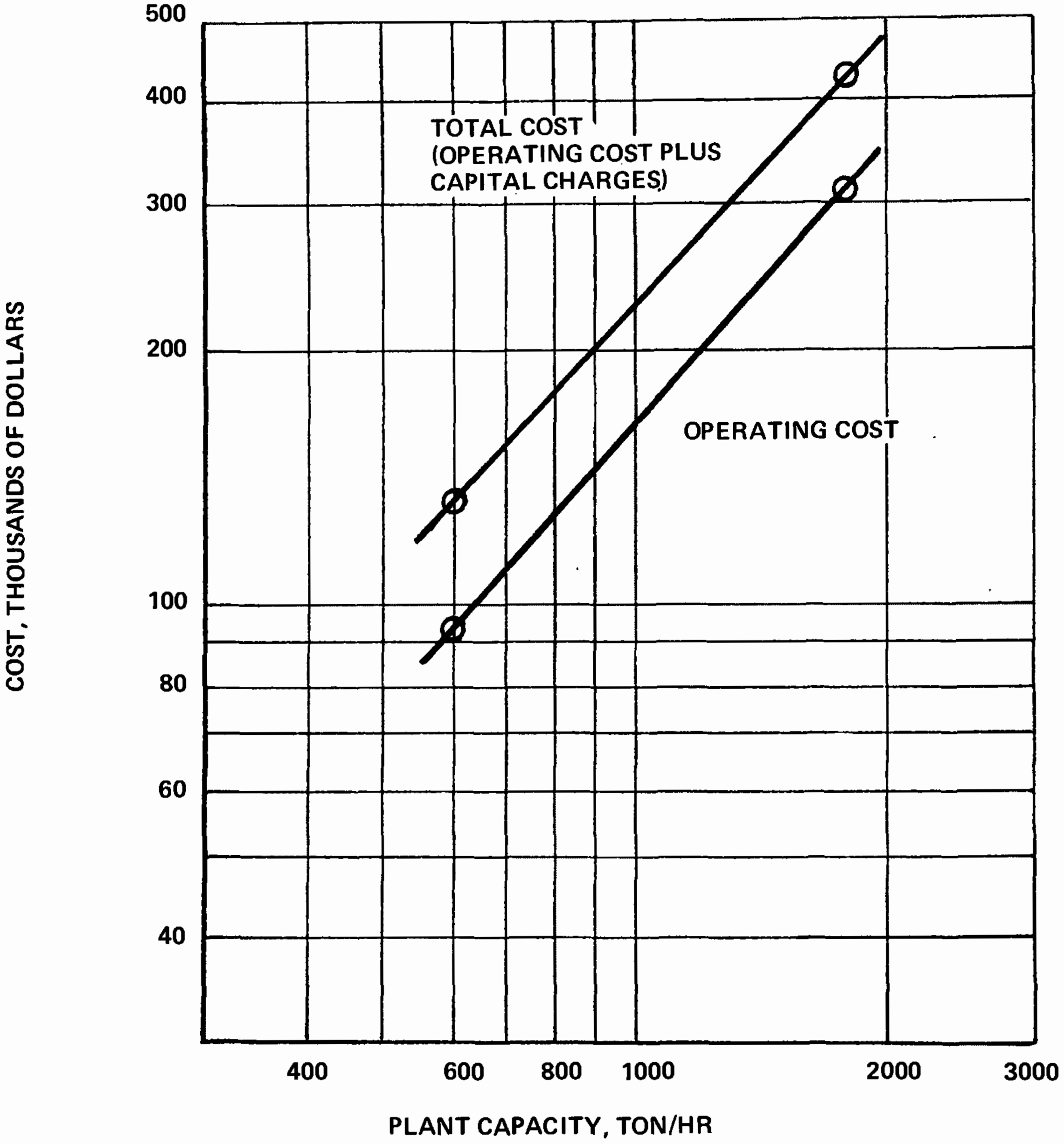


FIGURE 137

ANNUAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS (HIGH EFFICIENCY)

(Low Unit Cost)

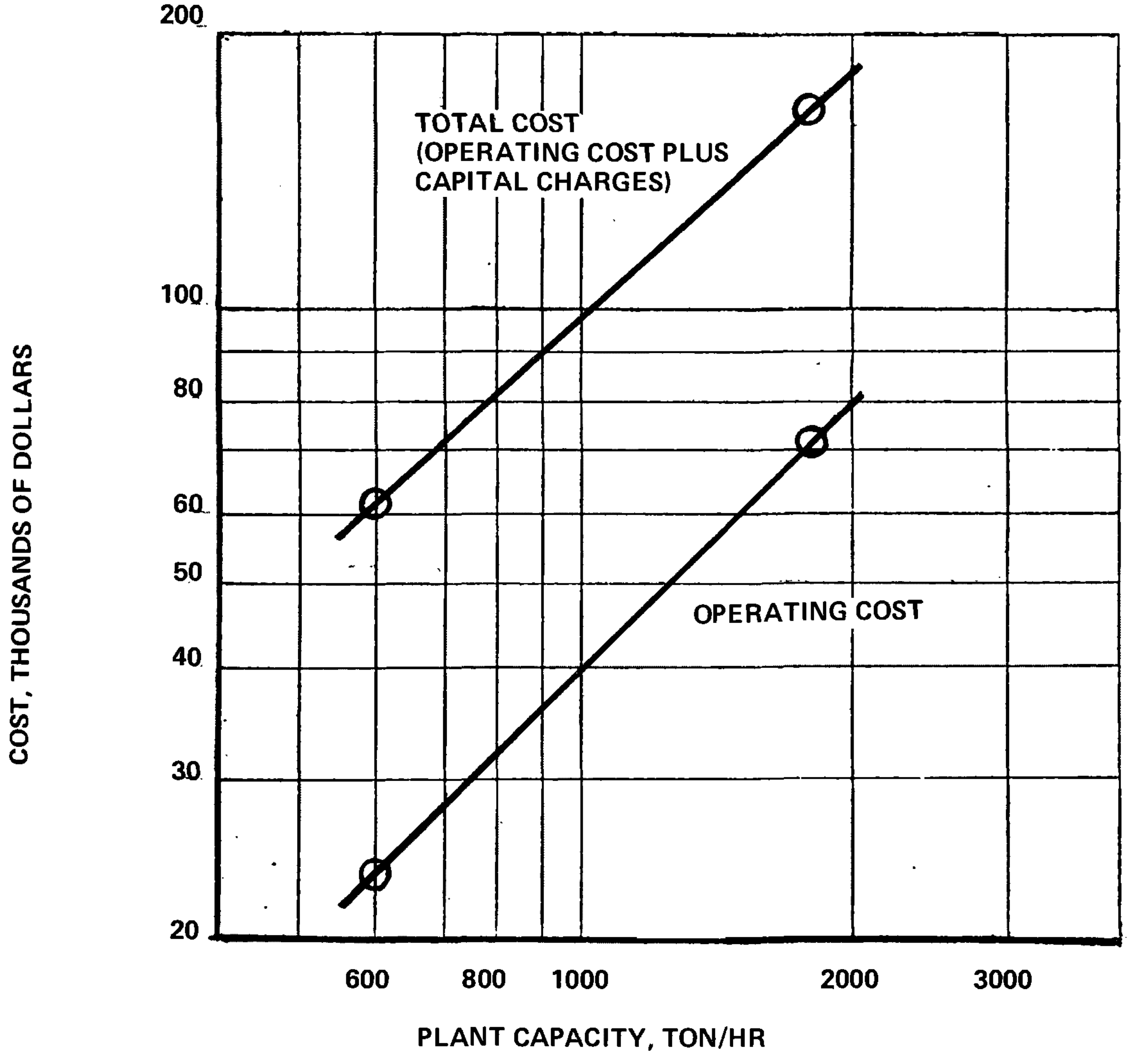


FIGURE 138

ANNUAL COSTS FOR WET SCRUBBERS FOR COAL CLEANING PLANTS

(HIGH EFFICIENCY)

(High Unit Cost)

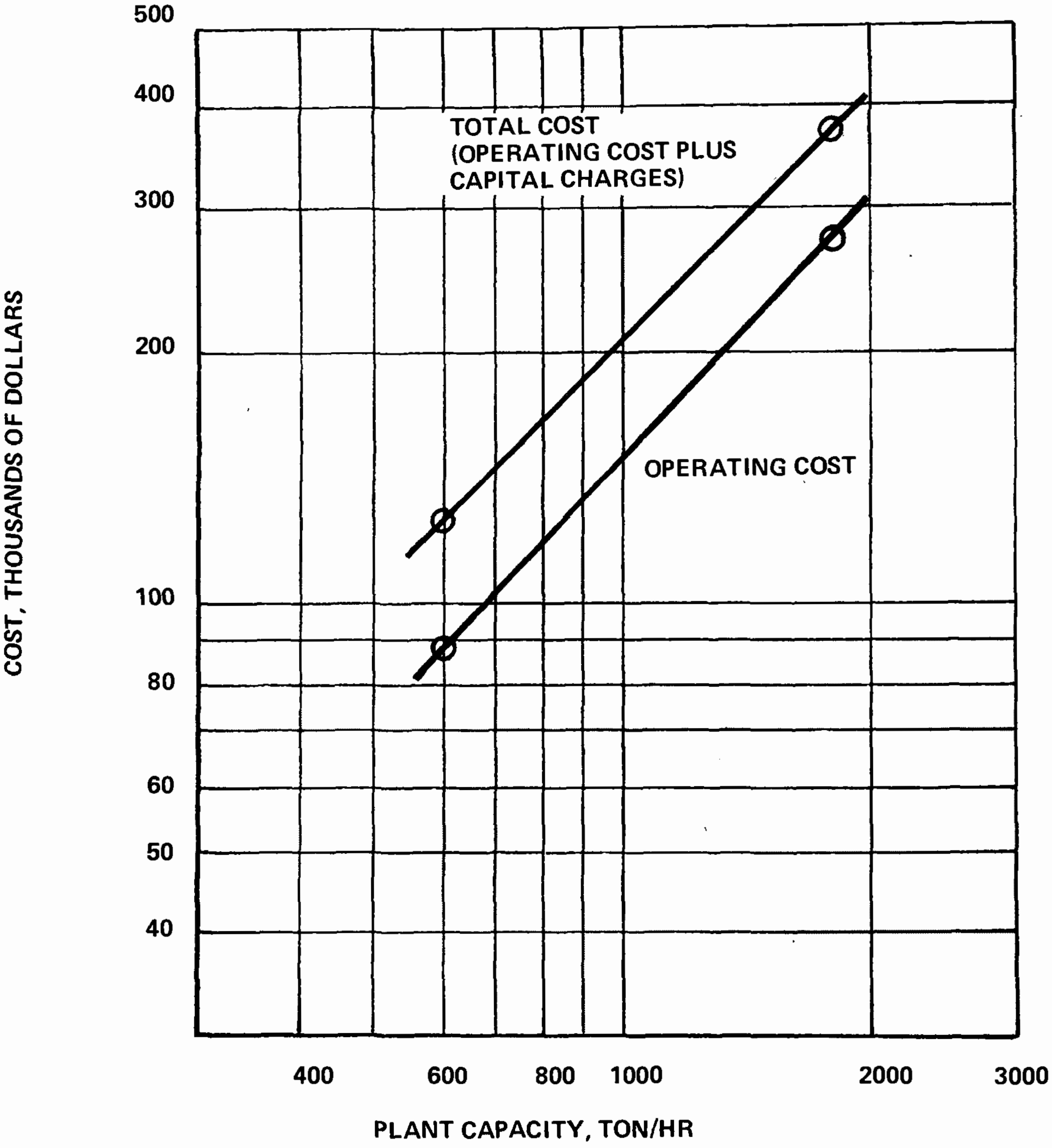


TABLE 231
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR BRICK AND TILE KILNS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$4/hr			400	400
Supervisor	$6/hr			-	-
Total Operating Labor				400	400
Maintenance					
Labor					
Materials					
Total Maintenance				2,520	2,659
Replacement Parts					
Total Replacement Parts				1,007	2,216
Utilities					
Electric Power	$.005/kw-hr			1,770	4,290
Fuel				-	-
Water (Process)	$0.10/M gal.			289	660
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				2,059	4,950
Total Direct Cost				5,986	10,225
Annualized Capital Charges				8,831	11,571
Total Annual Cost				14,817	21,796

TABLE 232
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR BRICK AND TILE KILNS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year					
Operating Labor (if any)					
Operator	$9/hr			900	900
Supervisor	$12/hr			-	-
Total Operating Labor				900	900
Maintenance					
Labor					
Materials					
Total Maintenance				2,520	2,659
Replacement Parts					
Total Replacement Parts				1,007	2,216
Utilities					
Electric Power	$0.20/kw-hr			7,080	17,160
Fuel				-	-
Water (Process)	$0.50/M gal			1,444	3,302
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				8,524	20,462
Total Direct Cost				12,951	26,237
Annualized Capital Charges				8,831	11,571
Total Annual Cost				21,782	37,808

FIGURE 139

ANNUAL COSTS FOR WET SCRUBBERS FOR BRICK AND TILE KILNS

(Low Unit Cost)

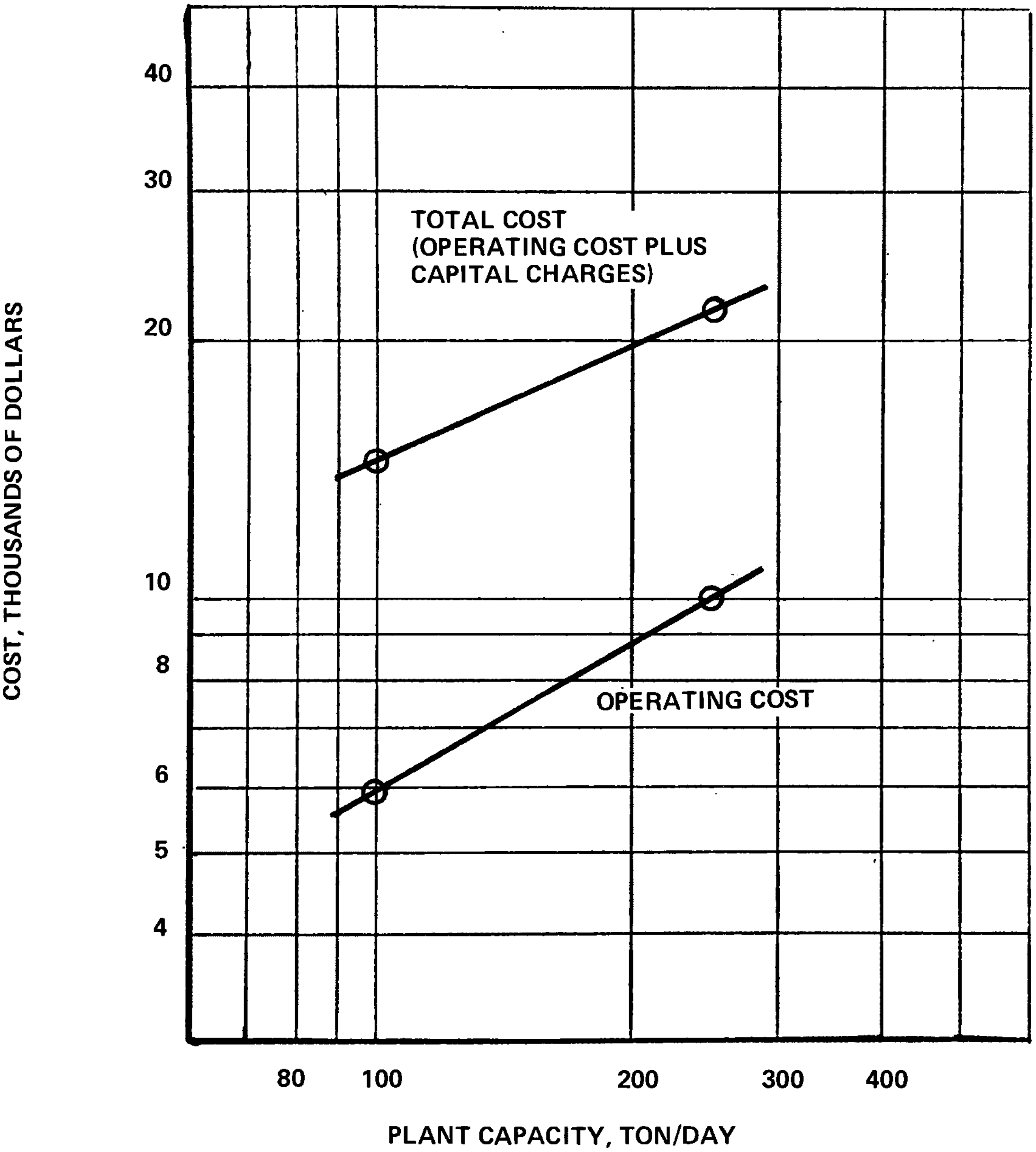


FIGURE 140

ANNUAL COSTS FOR WET SCRUBBERS FOR BRICK AND TILE KILNS

(High Unit Cost)

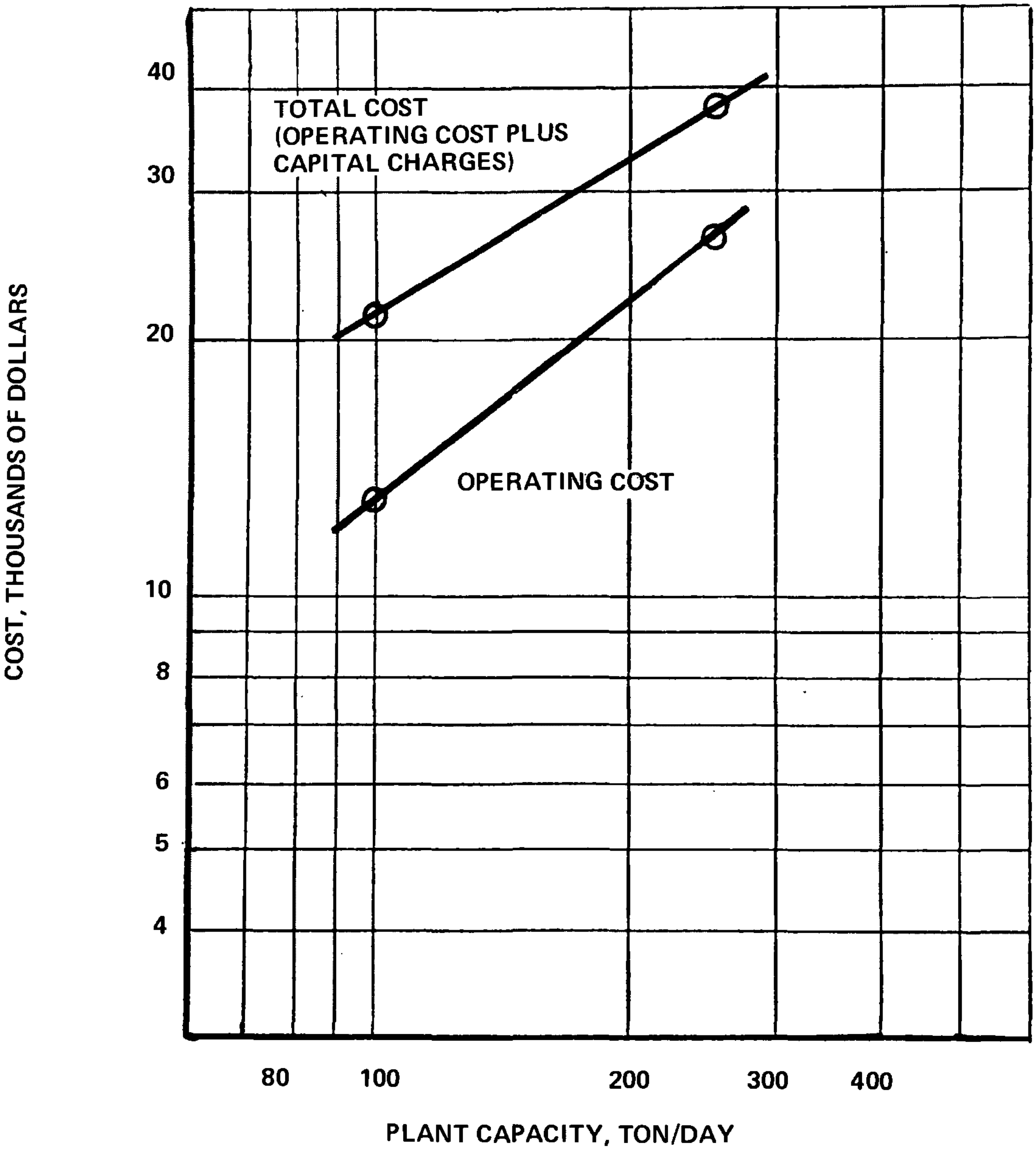


TABLE 233
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$4/hr			1,000	1,000
Supervisor	$6/hr			-	-
Total Operating Labor				1,000	1,000
Maintenance					
Labor	$4/hr			640	640
Materials				40	40
Total Maintenance				680	680
Replacement Parts					
Total Replacement Parts				300	300
Utilities					
Electric Power				-	-
Fuel	$0.50/MM BTU			27,950	64,500
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				27,950	64,500
Total Direct Cost				29,930	66,480
Annualized Capital Charges				16,700	27,003
Total Annual Cost				46,630	93,483

TABLE 234
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$9/hr			2,250	2,250
Supervisor	$12/hr			-	-
Total Operating Labor				2,250	2,250
Maintenance					
Labor	$9/hr			1,440	1,440
Materials				40	40
Total Maintenance				1,480	1,480
Replacement Parts					
Total Replacement Parts				300	300
Utilities					
Electric Power				-	-
Fuel	$1.25/MM BTU			69,875	161,250
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				69,875	161,250
Total Direct Cost				73,905	165,280
Annualized Capital Charges				16,700	27,003
Total Annual Cost				90,605	192,283

FIGURE 141

ANNUAL COSTS FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS

(Low Unit Cost)

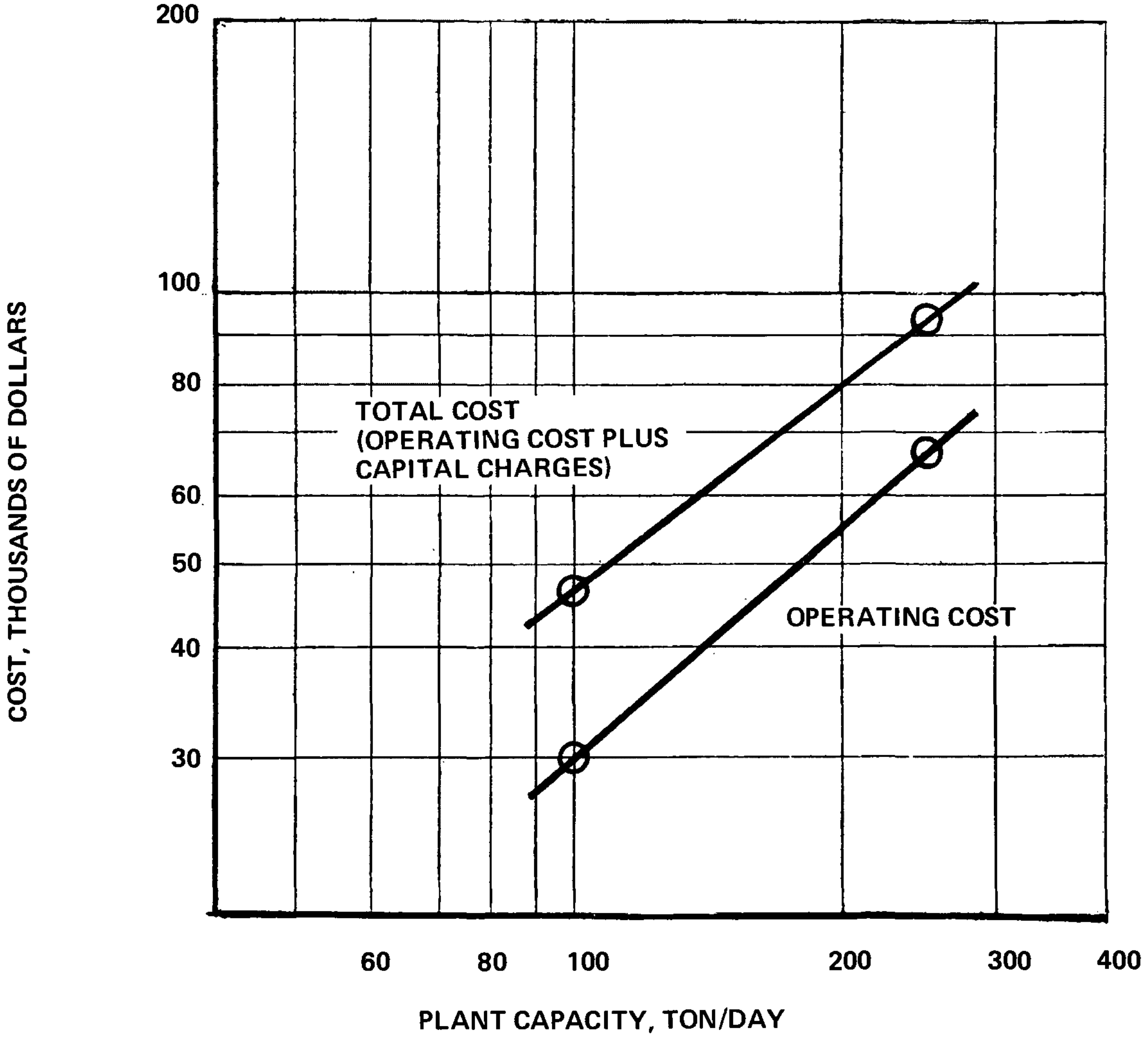


FIGURE 142

ANNUAL COSTS FOR THERMAL INCINERATORS FOR BRICK AND TILE KILNS

(High Unit Cost)

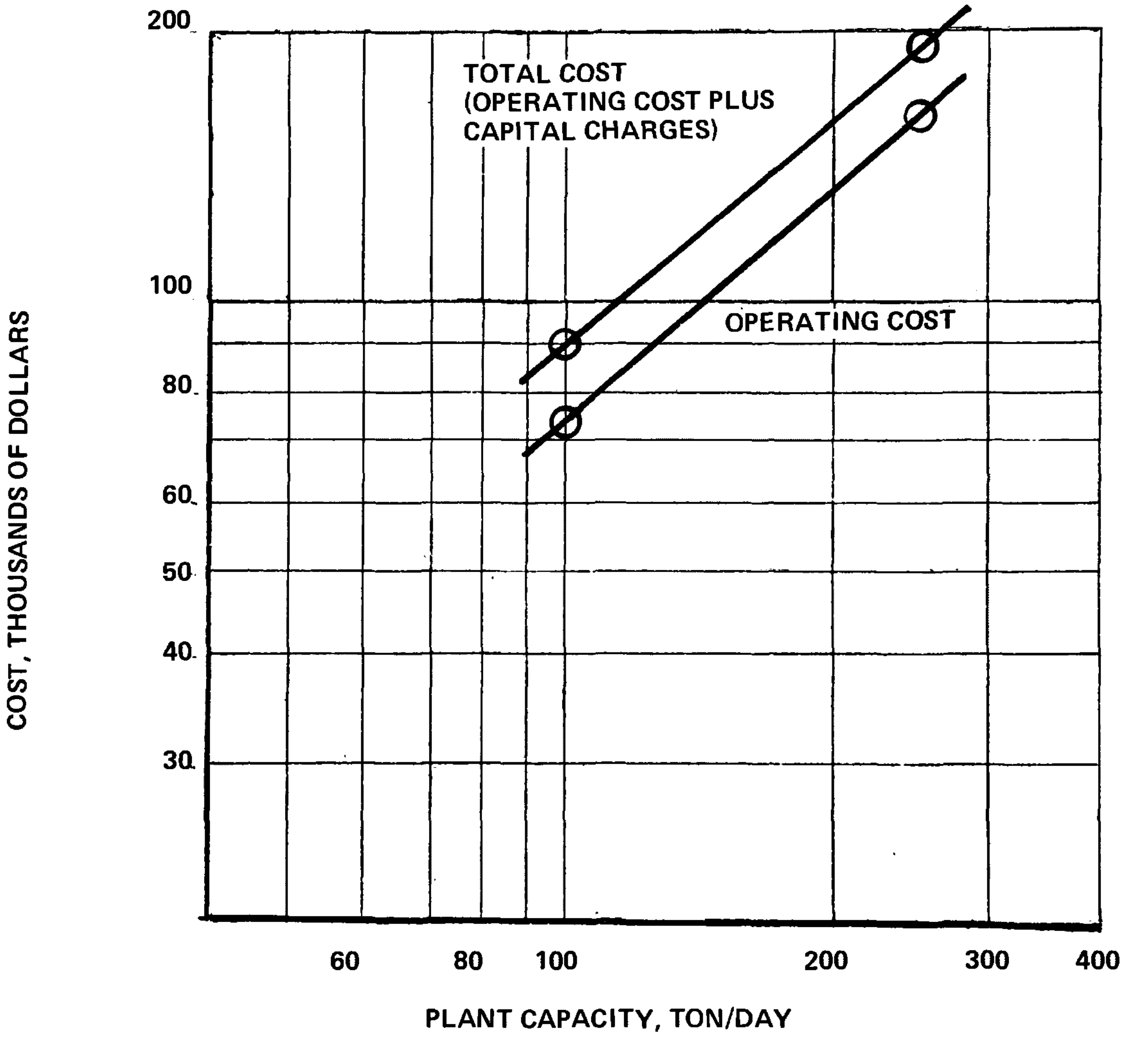


TABLE 235

ANNUAL OPERATING COST DATA

(COST IN $/YEAR)

FOR COMBINED GAS CLEANING SYSTEMS FOR COPPER ROASTING FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$4/hr			-	-
Supervisor	$6/hr			-	-
Total Operating Labor					
Maintenance					
Labor	$4/hr			780	780
Materials					
Total Maintenance				780	780
Replacement Parts					
Total Replacement Parts				1,750	2,450
Utilities					
Electric Power	$.005/kw-hr			4,862	10,224
Fuel				-	-
Water (Process)	$0.10/M gal.			1,752	4,438
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				6,614	14,662
Total Direct Cost				9,144	17,892
Annualized Capital Charges				32,966	65,830
Total Annual Cost				42,110	83,722

TABLE 236
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR COMBINED GAS CLEANING SYSTEMS FOR COPPER ROASTING FURNACES

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$9/hr			-	-
Supervisor	$12/hr			-	-
Total Operating Labor					
Maintenance					
Labor	$9/hr			780	780
Materials					
Total Maintenance				780	780
Replacement Parts					
Total Replacement Parts				1,750	2,450
Utilities					
Electric Power	$.020/kw-hr			19,449	40,896
Fuel				-	-
Water (Process)	$0.50/M gal			8,758	22,182
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				28,207	63,078
Total Direct Cost				30,737	66,308
Annualized Capital Charges				32,966	65,830
Total Annual Cost				63,703	132,138

FIGURE 143

ANNUAL COSTS FOR COMBINED GAS CLEANING SYSTEMS FOR COPPER ROASTING FURNACES

(Low Unit Cost)

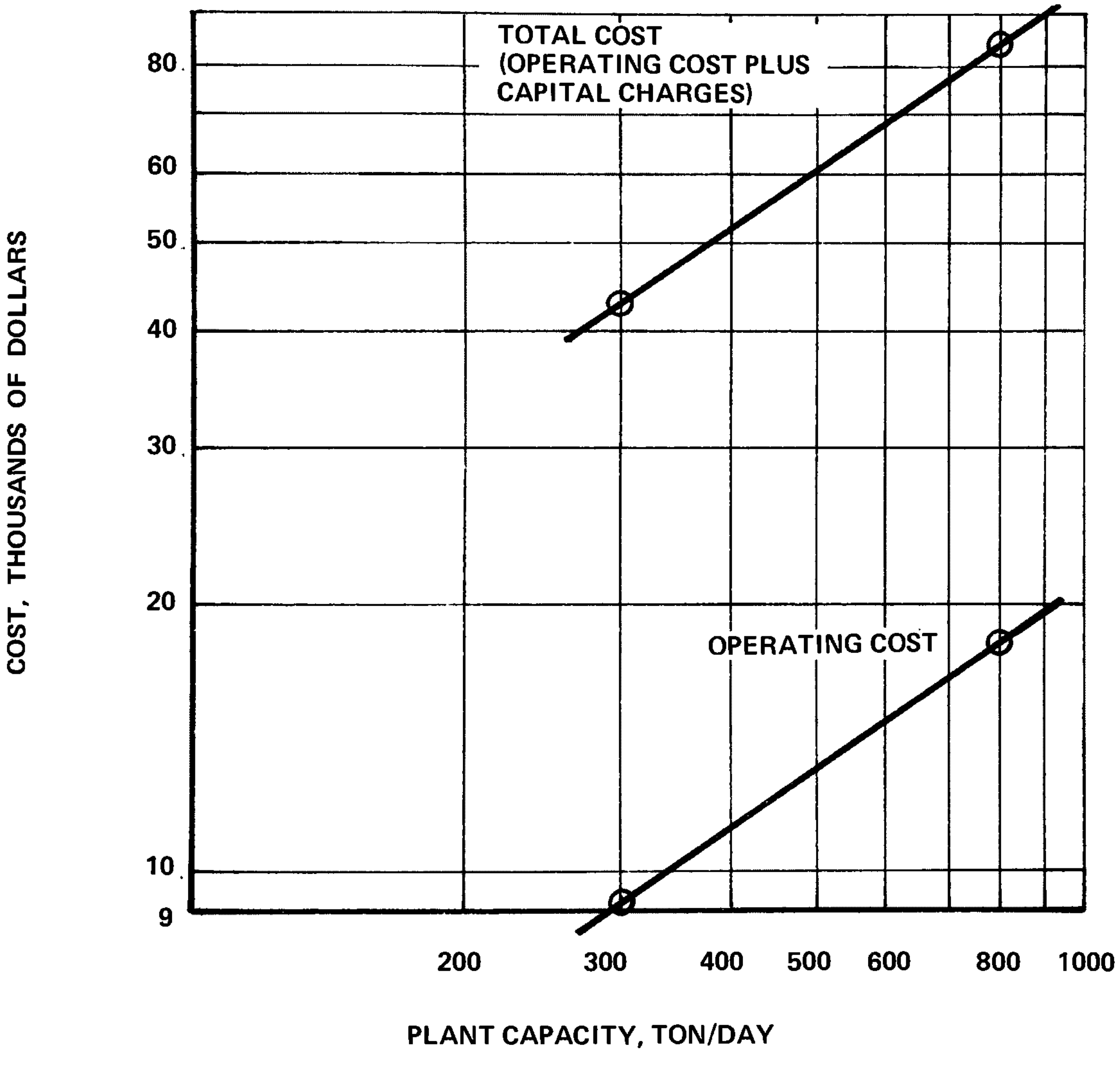


FIGURE 144

ANNUAL COSTS FOR COMBINED GAS CLEANING SYSTEMS FOR COPPER ROASTING FURNACES

(High Unit Cost)

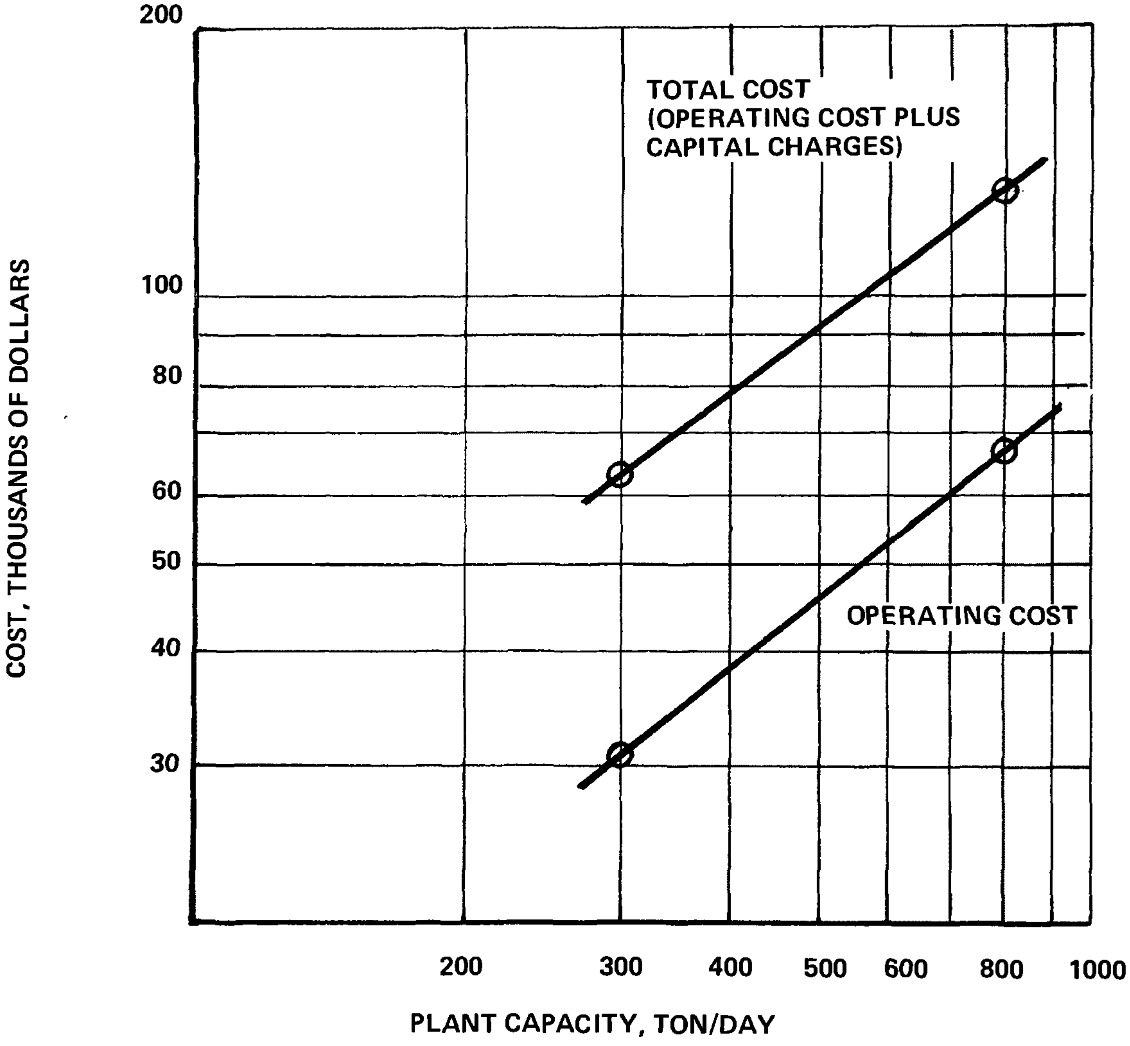


TABLE 237
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$4/hr	700	700	700	700
Supervisor	$6/hr	70	70	70	70
Total Operating Labor		770	770	770	770
Maintenance					
Labor	$4/hr	383	383	383	383
Materials		500	500	500	500
Total Maintenance		883	883	883	883
Replacement Parts					
Total Replacement Parts		4,250	7,500	5,250	7,500
Utilities					
Electric Power	$.005/kw-hr	1,565	3,105	1,565	3,105
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		1,565	3,105	1,565	3,105
Total Direct Cost		7,468	12,258	8,468	12,258
Annualized Capital Charges		43,487	87,281	54,659	90,461
Total Annual Cost		50,955	99,539	63,127	102,719

TABLE 238
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$9/hr	1,575	1,575	1,575	1,575
Supervisor	$12/hr	157	157	157	157
Total Operating Labor		1,732	1,732	1,732	1,732
Maintenance					
Labor	$9/hr	863	863	863	863
Materials		500	500	500	500
Total Maintenance		1,363	1,363	1,363	1,363
Replacement Parts					
Total Replacement Parts		4,250	7,500	5,250	7,500
Utilities					
Electric Power	$.020/kw-hr	6,260	12,420	6,260	12,420
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		6,260	12,420	6,260	12,420
Total Direct Cost		13,605	23,015	14,605	23,015
Annualized Capital Charges		43,487	87,281	54,659	90,461
Total Annual Cost		57,092	110,296	69,264	113,476

FIGURE 145

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES (HIGH EFFICIENCY)

(Low Unit Cost)

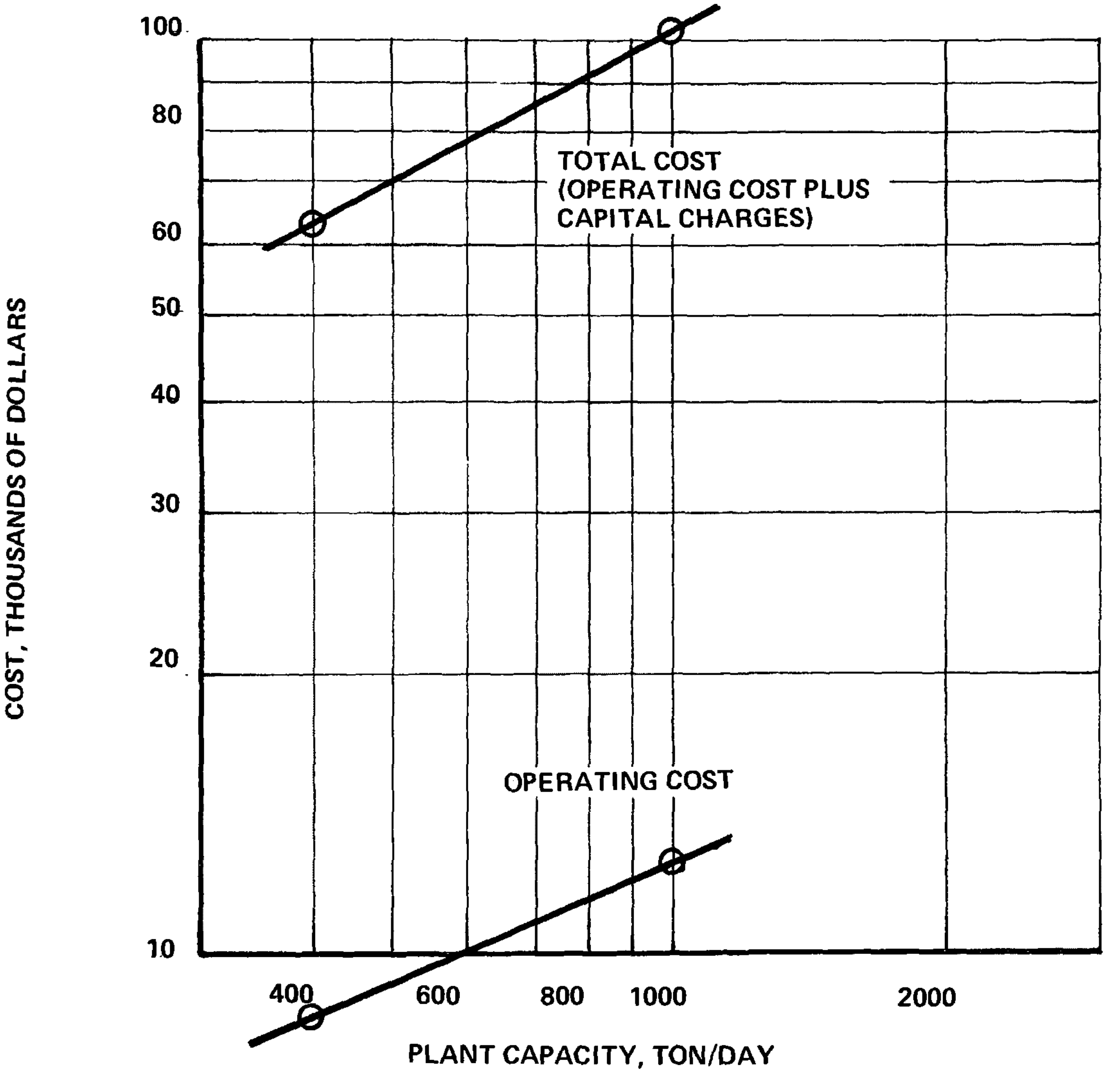


FIGURE 146

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR COPPER REVERBERATORY FURNACES (HIGH EFFICIENCY)

(High Unit Cost)

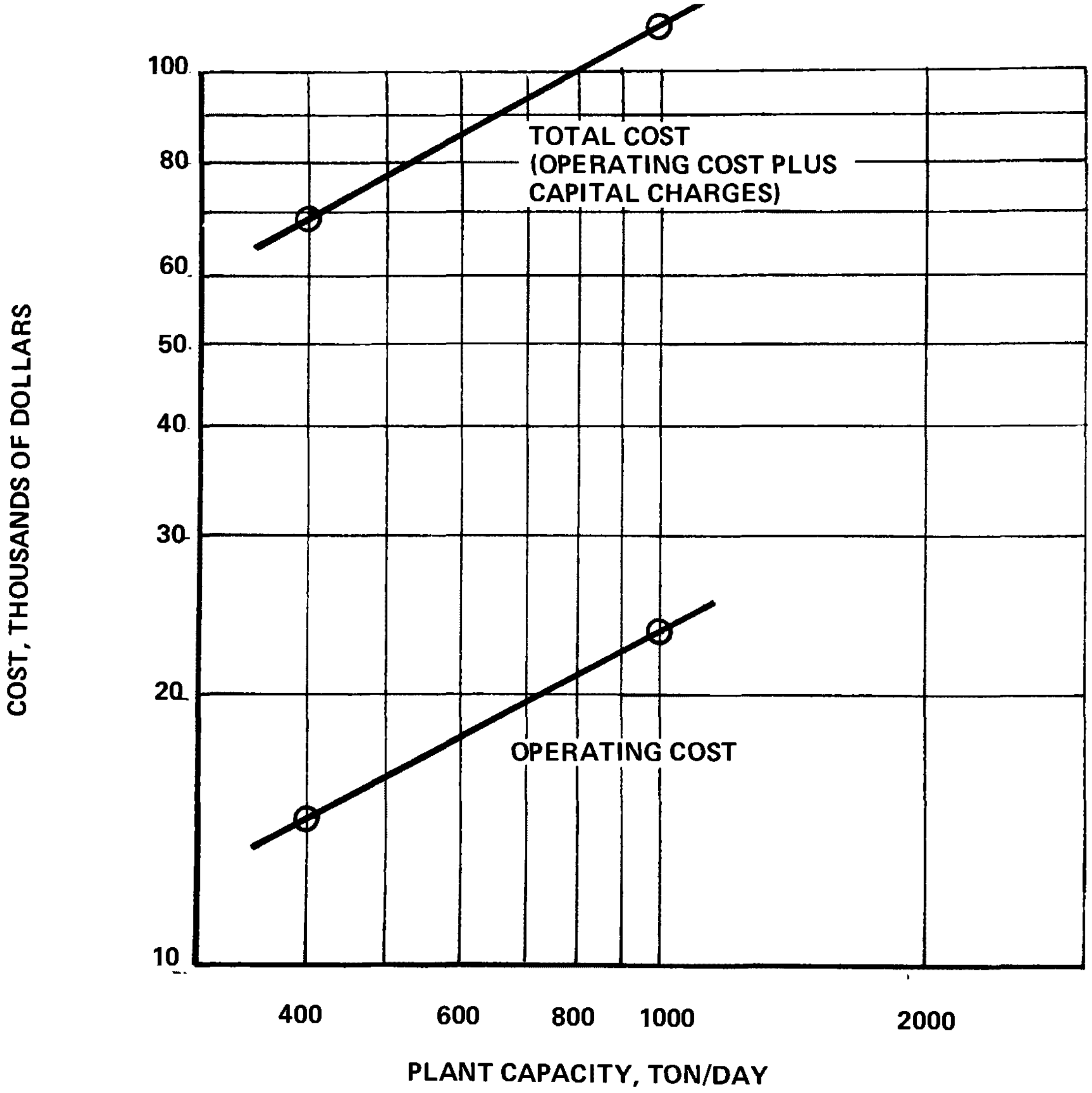


TABLE 239
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR COPPER REVERBERATORY FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance					
Replacement Parts					
Total Replacement Parts					
Utilities					
Electric Power	$.005 kw-hr	27,000	40,500	90,000	110,000
Fuel	$0.50/MM BTU	25,250	62,000	25,250	62,000
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		52,250	102,500	115,250	172,000
Total Direct Cost		52,250	102,500	115,250	172,000
Annualized Capital Charges		20,615	44,250	20,015	51,150
Total Annual Cost		72,865	146,750	135,265	223,150

TABLE 240
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR COPPER REVERBERATORY FURNACES

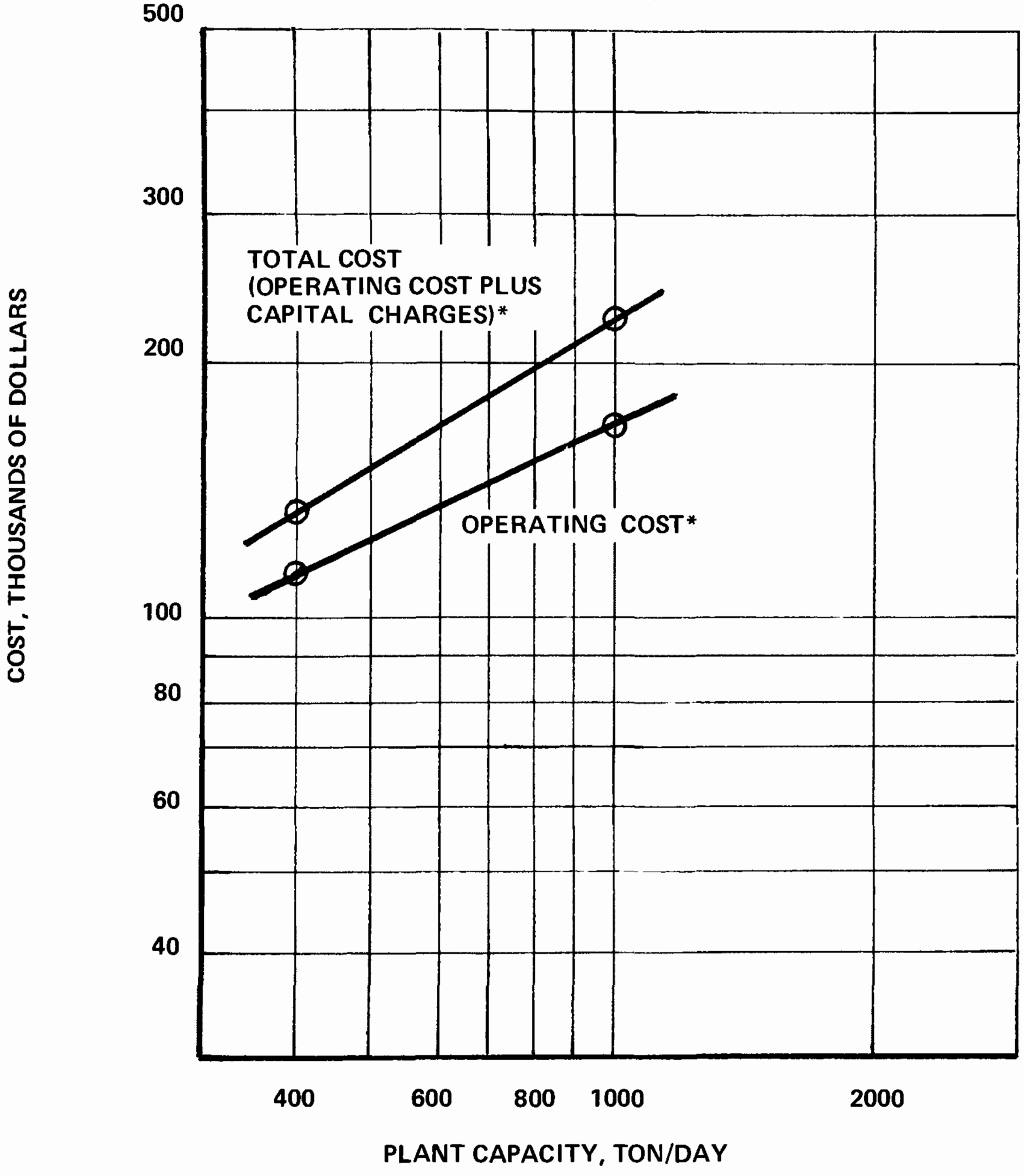
High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance					
Replacement Parts					
Total Replacement Parts					
Utilities					
Electric Power	$.020/kw-Hr	108,000	162,000	360,000	440,000
Fuel	$1.25/MM BTU	63,125	155,000	63,125	155,000
Water (Process)		-	-	-	-
Water (Cooling)		-	-	-	-
Chemicals, Specify		-	-	-	-
Total Utilities		171,125	317,000	423,125	595,000
Total Direct Cost		171,125	317,000	423,125	595,000
Annualized Capital Charges		20,615	44,250	24,015	51,150
Total Annual Cost		191,740	361,250	447,140	646,150

FIGURE 147

ANNUAL COSTS FOR WET SCRUBBERS FOR COPPER REVERBERATORY FURNACES (HIGH EFFICIENCY)

(Low Unit Cost)

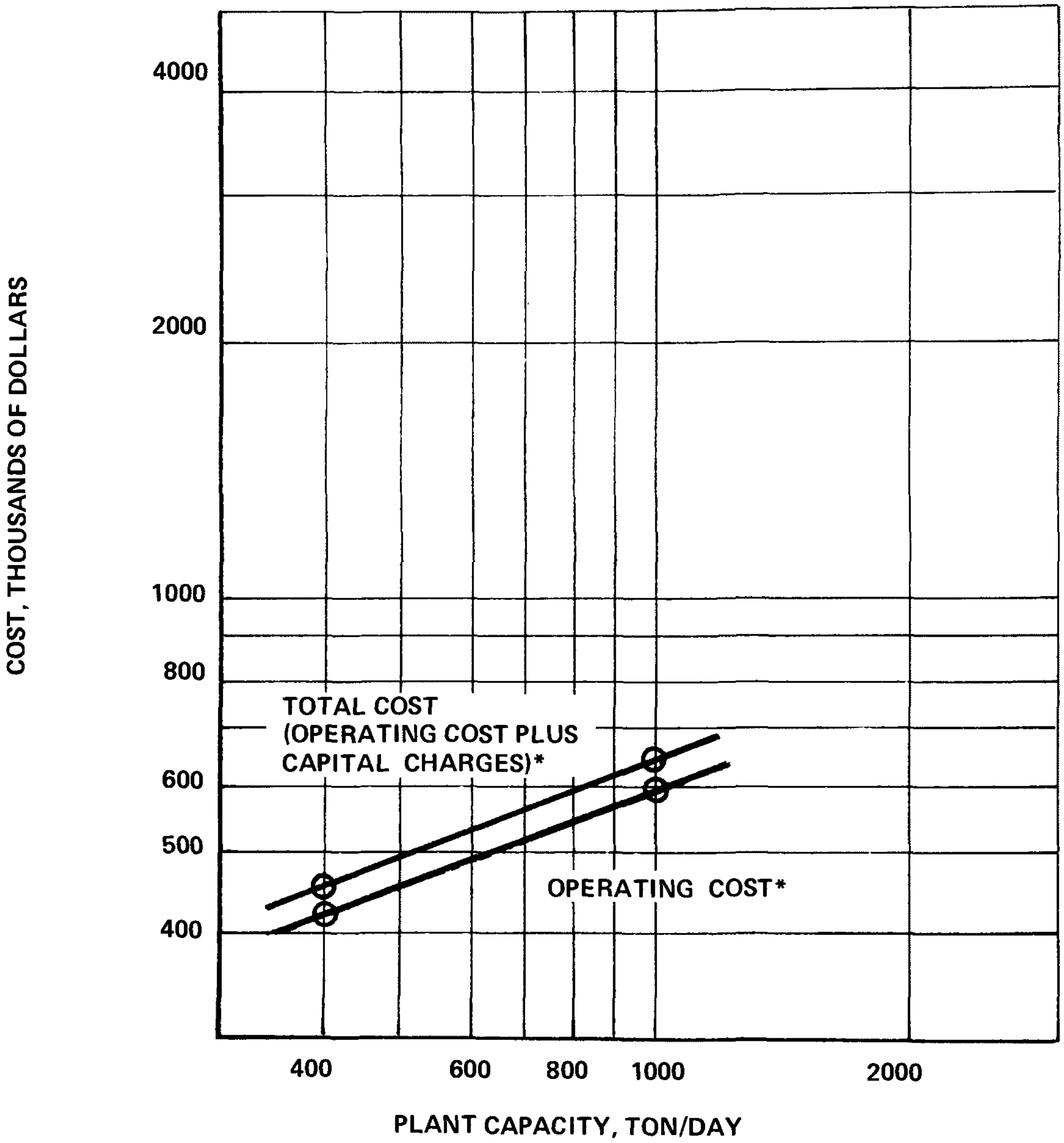


*This does not include operating labor, maintenance labor, or repair parts costs.

FIGURE 148

ANNUAL COSTS FOR WET SCRUBBERS FOR COPPER REVERBERATORY FURNACES (HIGH EFFICIENCY)

(High Unit Cost)



*This does not include operating labor, maintenance labor, or repair parts costs.

TABLE 241
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR BARK BOILERS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance				480	480
Replacement Parts					
Total Replacement Parts				500	1,000
Utilities					
Electric Power	$.005/kw-hr			1,195	3,268
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				1,195	3,268
Total Direct Cost				2,175	4,748
Annualized Capital Charges				29,043	59,907
Total Annual Cost				31,218	64,655

TABLE 242
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR ELECTROSTATIC PRECIPITATORS FOR BARK BOILERS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator					
Supervisor					
Total Operating Labor					
Maintenance					
Labor					
Materials					
Total Maintenance				480	480
Replacement Parts					
Total Replacement Parts				500	1,000
Utilities					
Electric Power	$.020/kw-hr			4,780	13,073
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				4,780	13,073
Total Direct Cost				5,760	14,553
Annualized Capital Charges				29,043	59,907
Total Annual Cost				34,803	74,460

FIGURE 149

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR KRAFT MILL BARK BOILERS

(Low Unit Cost)

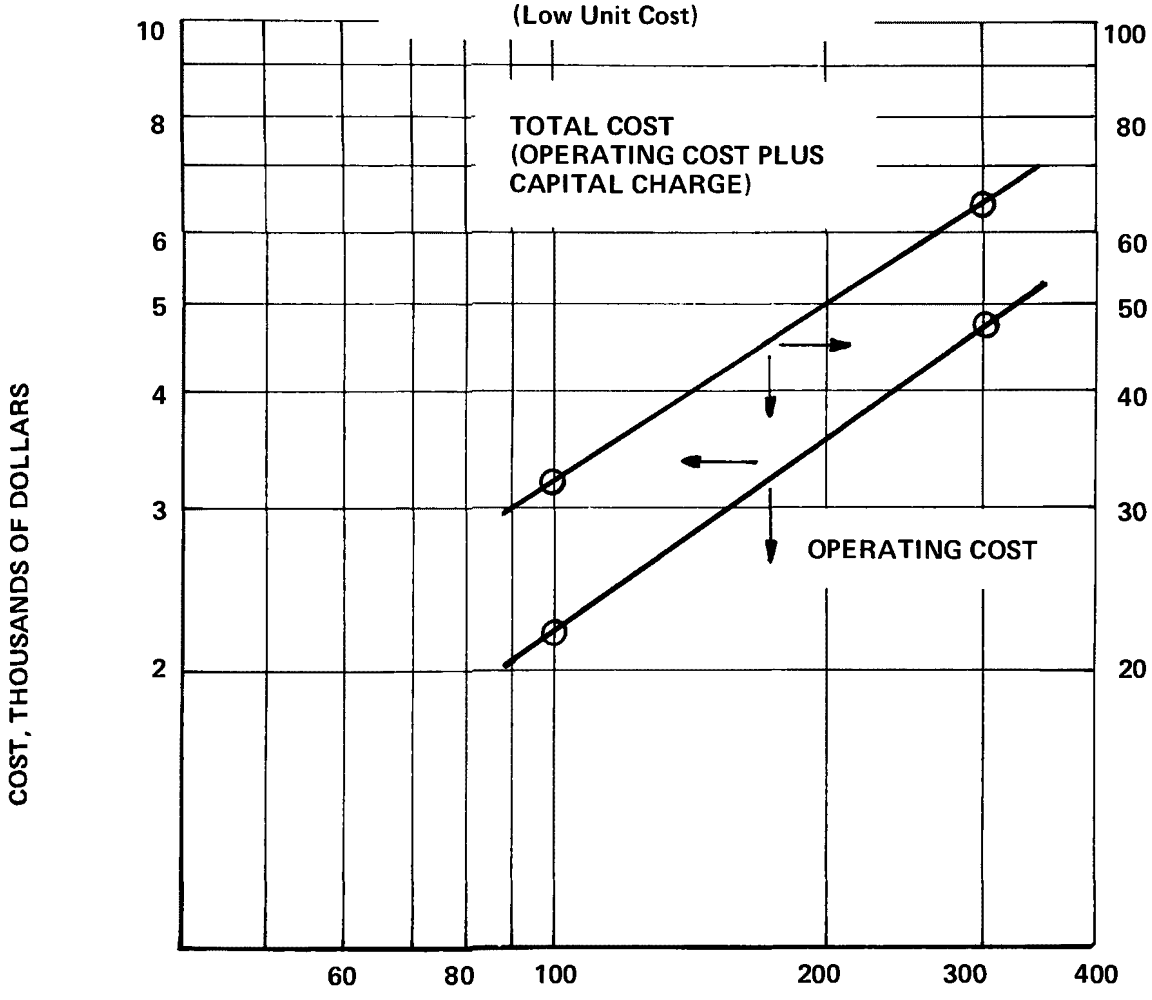


FIGURE 150

ANNUAL COSTS FOR ELECTROSTATIC PRECIPITATORS FOR KRAFT MILL BARK BOILERS

(High Unit Cost)

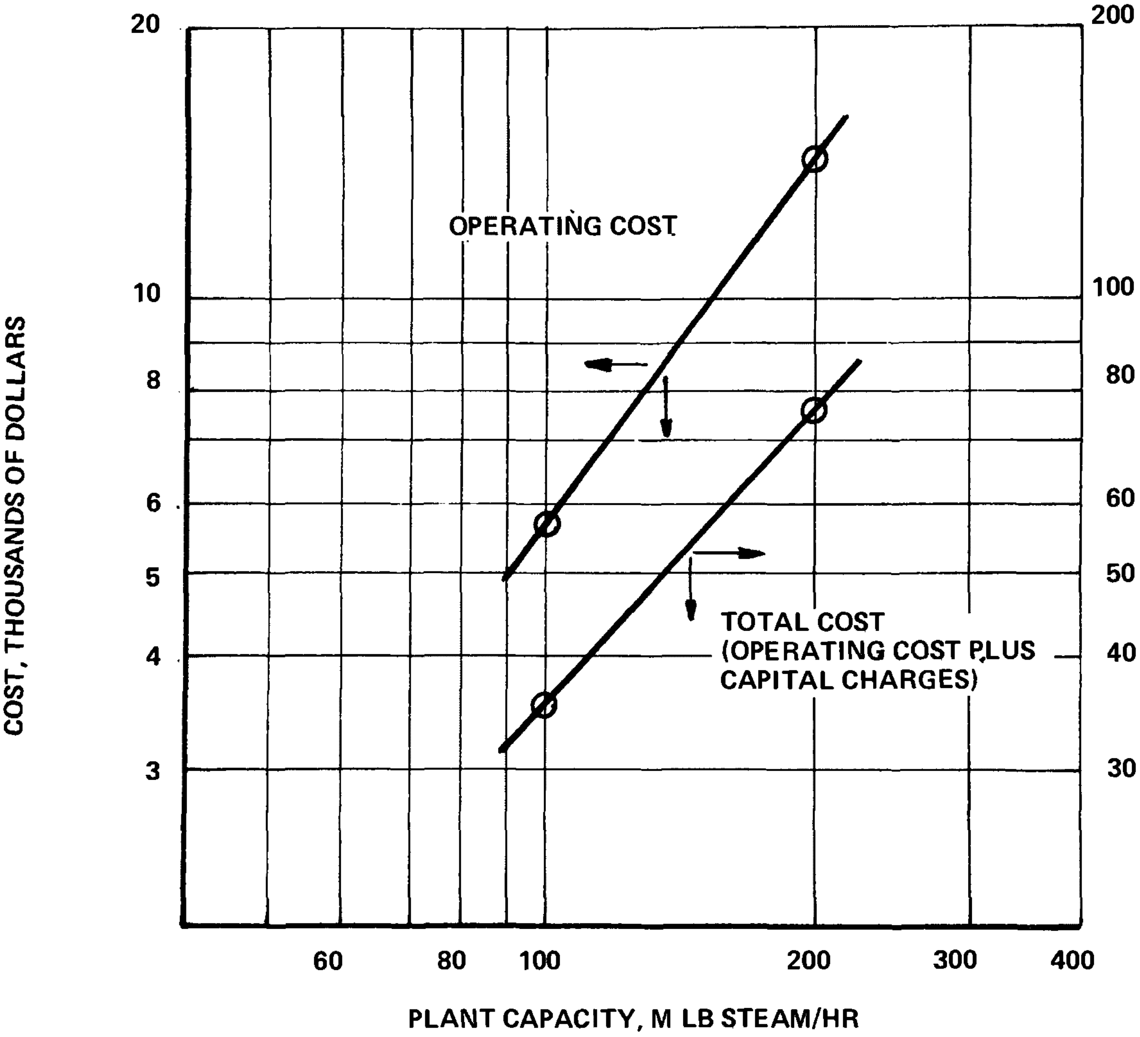


TABLE 243
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR BARK BOILERS

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$4/hr			800	800
Supervisor				-	-
Total Operating Labor				800	800
Maintenance					
Labor					
Materials					
Total Maintenance				5,200	12,483
Replacement Parts					
Total Replacement Parts				6,200	13,843
Utilities					
Electric Power	$.005/kw-hr			11,085	38,440
Fuel				-	-
Water (Process)	$0.10/M gal			2,180	5,970
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				13,265	44,410
Total Direct Cost				25,465	71,536
Annualized Capital Charges				18,499	45,453
Total Annual Cost				43,964	116,989

TABLE 244
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR BARK BOILERS

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	8,600				
Operating Labor (if any)					
Operator	$9/hr			1,800	1,800
Supervisor				-	-
Total Operating Labor				1,800	1,800
Maintenance					
Labor					
Materials					
Total Maintenance				5,200	12,483
Replacement Parts					
Total Replacement Parts				6,200	13,843
Utilities					
Electric Power	$.020/kw-hr			44,340	153,760
Fuel				-	-
Water (Process)	$0.50/M gal			10,900	29,850
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				55,240	183,610
Total Direct Cost				68,440	211,736
Annualized Capital Charges				18,499	45,453
Total Annual Cost				86,939	257,189

FIGURE 151

ANNUAL COSTS FOR WET SCRUBBERS FOR BARK BOILERS

(Low Unit Cost)

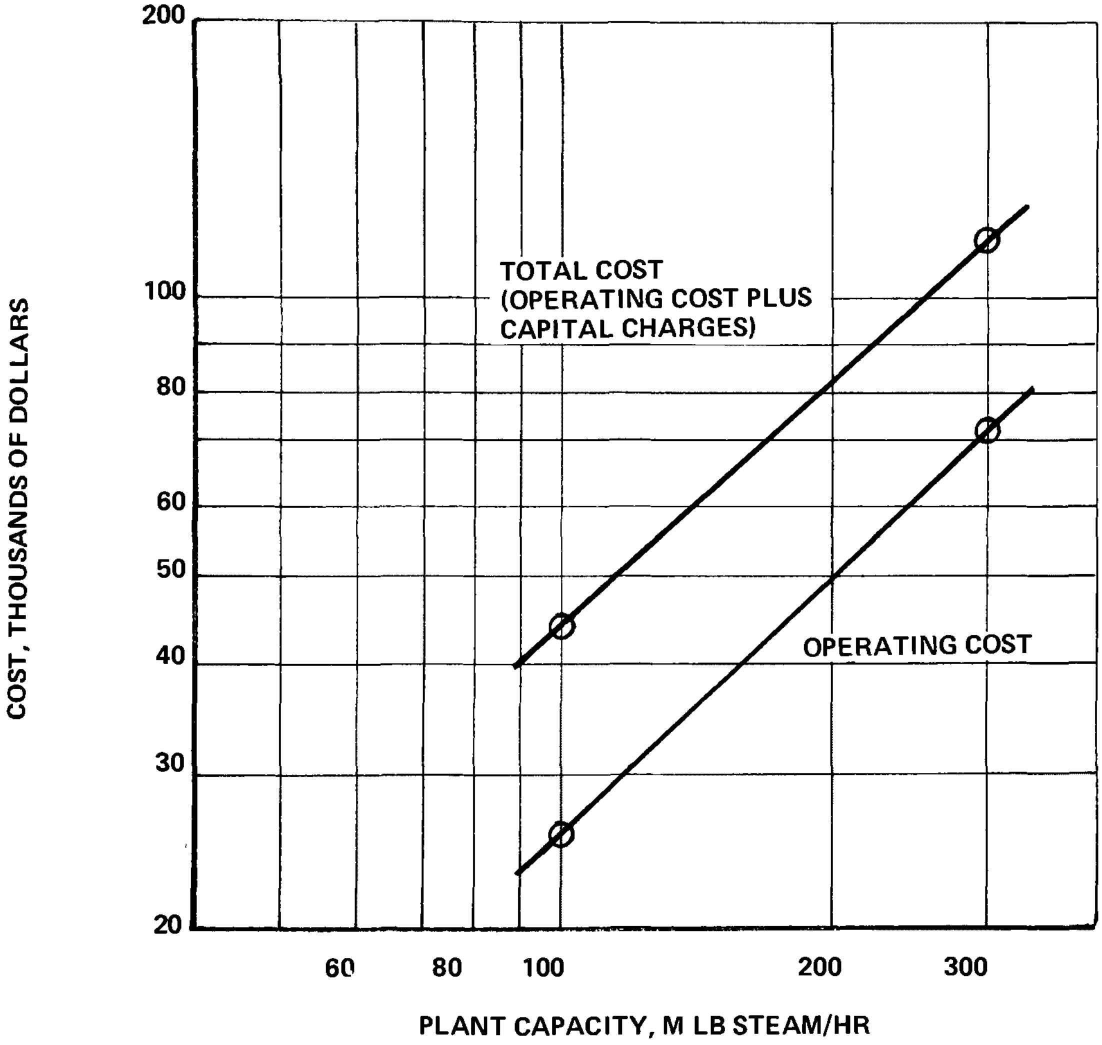


FIGURE 152

ANNUAL COSTS FOR WET SCRUBBERS FOR BARK BOILERS

(High Unit Cost)

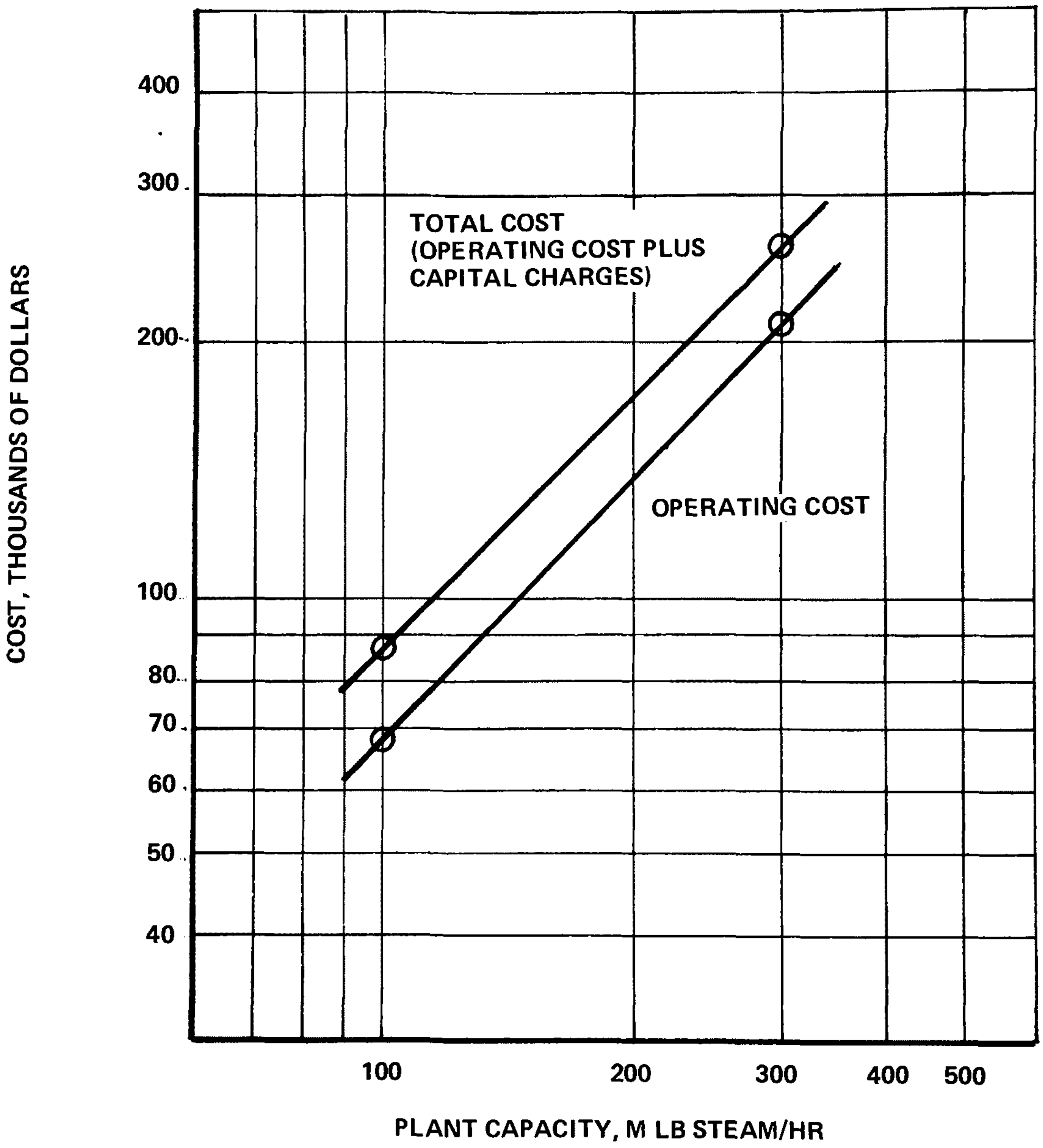


TABLE 245

ANNUAL OPERATING COST DATA

(COSTS IN $/YEAR)

FOR FABRIC FILTERS FOR FERROSILICON FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$4/hr			12,000	12,000
Supervisor	$6/hr			800	800
Total Operating Labor				12,800	12,800
Maintenance					
Labor					
Materials					
Total Maintenance				4,560	11,800
Replacement Parts					
Total Replacement Parts				7,500	31,640
Utilities					
Electric Power	$.005/kw-hr			8,059	28,318
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				8,059	28,318
Total Direct Cost				32,919	84,558
Annualized Capital Charges				47,300	147,100
Total Annual Cost				80,219	231,658

TABLE 246
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS FOR FERROSILICON FURNACES

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$9/hr			27,000	27,000
Supervisor	$12/hr			1,800	1,800
Total Operating Labor				28,800	28,800
Maintenance					
Labor					
Materials					
Total Maintenance				4,560	11,800
Replacement Parts					
Total Replacement Parts				7,500	31,640
Utilities					
Electric Power	$0.020/kw-hr			32,236	113,273
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				32,236	113,273
Total Direct Cost				73,096	185,513
Annualized Capital Charges				47,300	147,100
Total Annual Cost				120,396	332,613

FIGURE 153

ANNUAL COSTS FOR FABRIC FILTERS FOR FERROSILICON FURNACES

(Low Unit Cost)

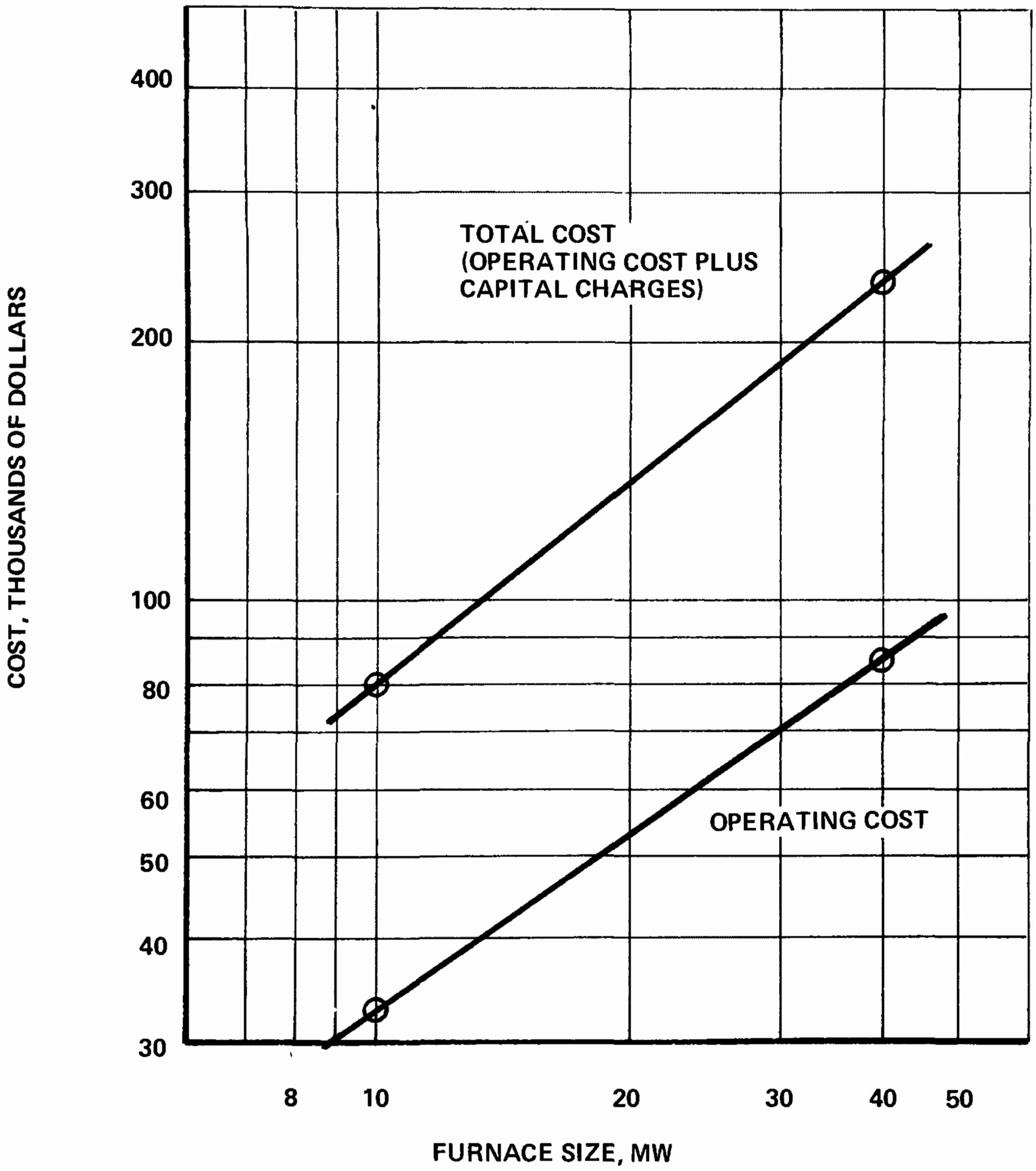


FIGURE 154

ANNUAL COSTS FOR FABRIC FILTERS FOR FERROSILICON FURNACES

(High Unit Cost)

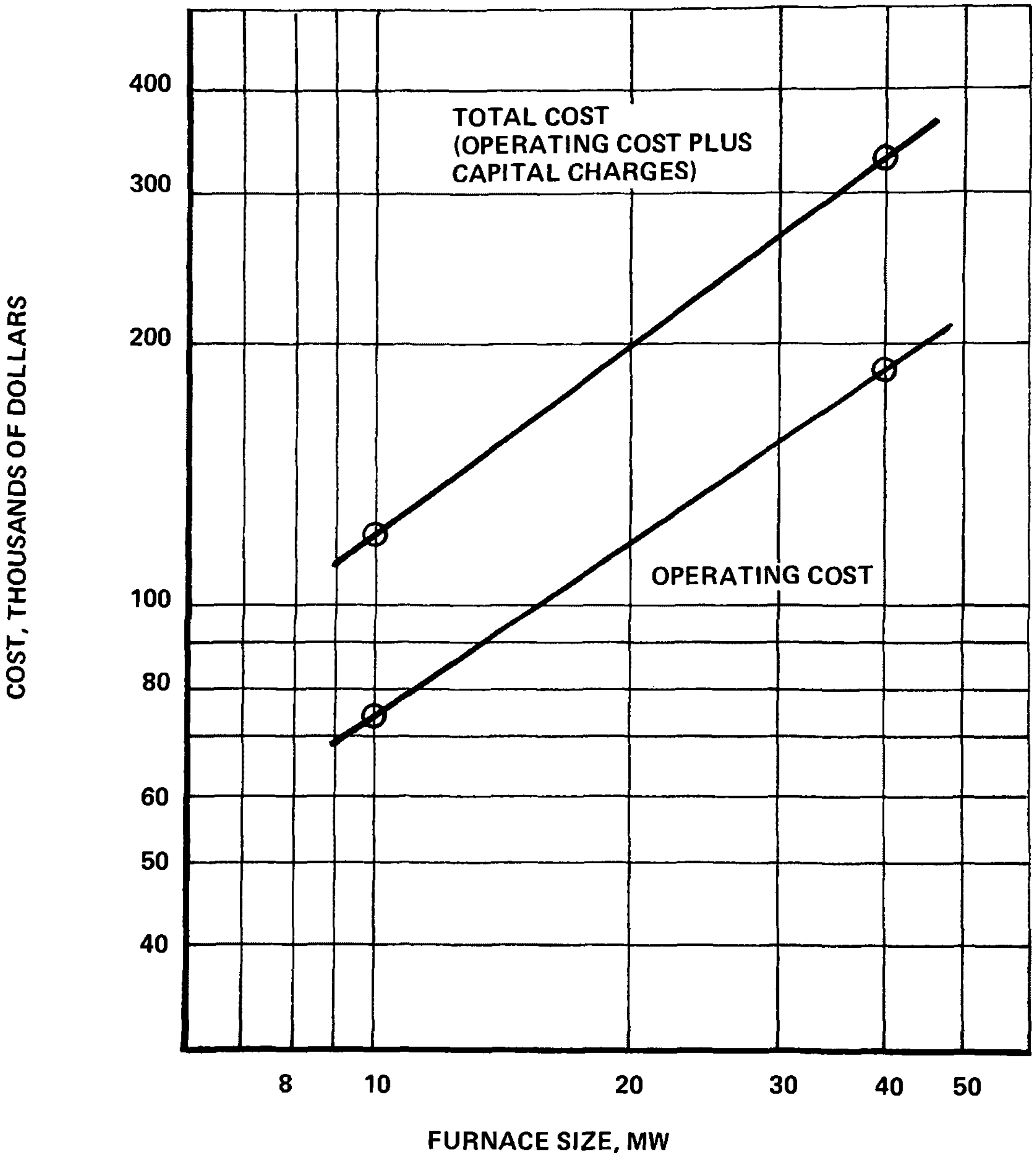


TABLE 247
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS FOR FERROCHROME FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$4/hr			12,000	12,000
Supervisor	$6/hr			800	800
Total Operating Labor				12,800	12,800
Maintenance					
Labor					
Materials					
Total Maintenance				4,400	6,600
Replacement Parts					
Total Replacement Parts				6,540	17,840
Utilities					
Electric Power	$.005/kw-hr			4,818	14,636
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				4,818	14,636
Total Direct Cost				28,558	51,876
Annualized Capital Charges				39,700	82,300
Total Annual Cost				68,258	134,176

TABLE 248
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR FABRIC FILTERS FOR FERROCHROME FURNACES

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$9/hr			27,000	27,000
Supervisor	$12/hr			1,800	1,800
Total Operating Labor				28,800	28,800
Maintenance					
Labor					
Materials					
Total Maintenance				4,400	6,600
Replacement Parts					
Total Replacement Parts				6,540	17,840
Utilities					
Electric Power	$0.020 kw-hr			19,273	58,545
Fuel				-	-
Water (Process)				-	-
Water (Cooling)				-	-
Chemicals, Specify				-	-
Total Utilities				19,273	58,545
Total Direct Cost				59,013	111,785
Annualized Capital Charges				39,700	82,300
Total Annual Cost				98,713	194,085

FIGURE 155

ANNUAL COSTS FOR FABRIC FILTERS FOR FERROCHROME FURNACES

(Low Unit Cost)

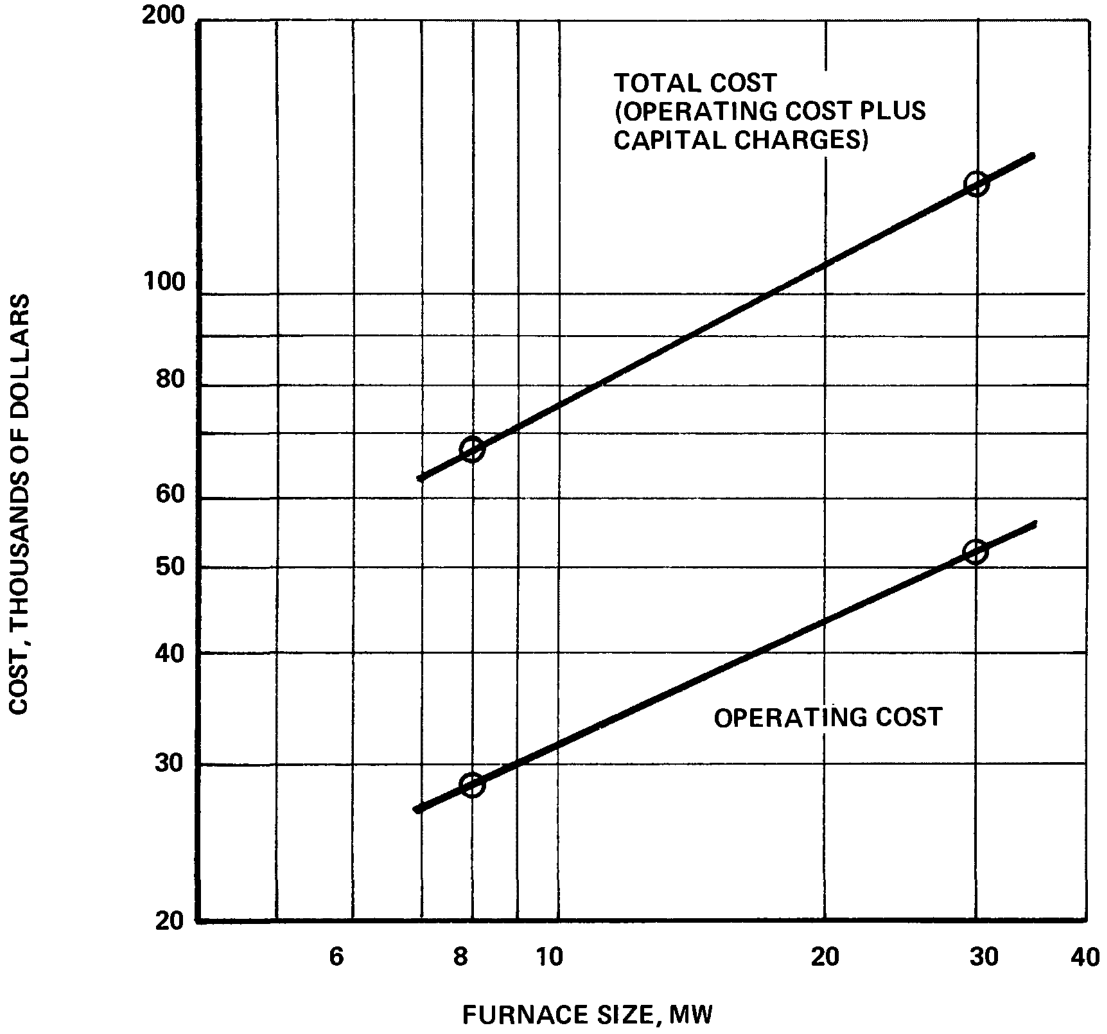


FIGURE 156

ANNUAL COSTS FOR FABRIC FILTERS FOR FERROCHROME FURNACES

(High Unit Cost)

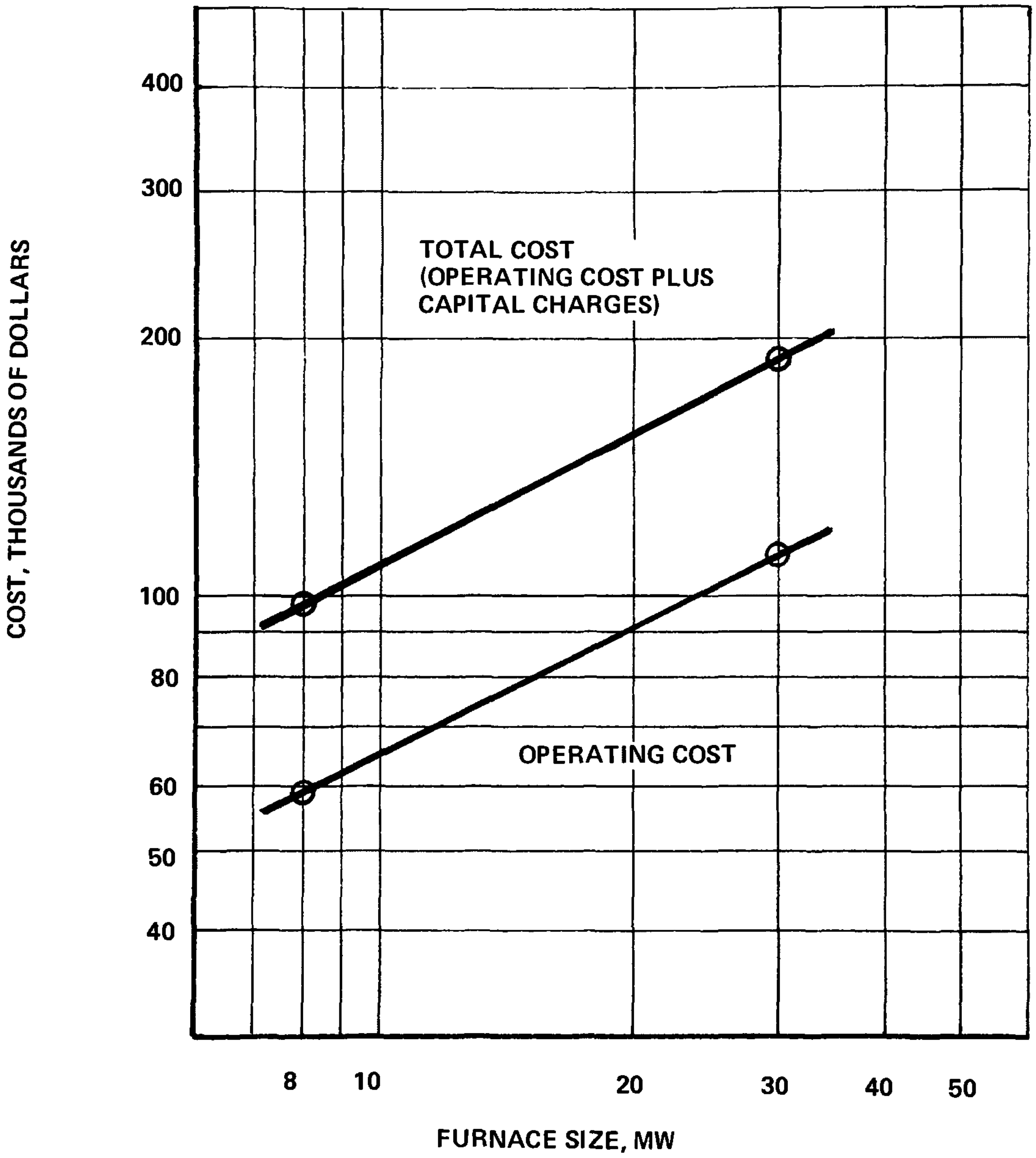


TABLE 249
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR FERROSILICON FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$4/hr				
Supervisor					
Total Operating Labor		2,400	2,400	2,400	2,400
Maintenance					
Labor					
Materials					
Total Maintenance		38,000	65,500	42,000	74,000
Replacement Parts					
Total Replacement Parts		23,000	39,000	25,000	44,500
Utilities					
Electric Power	$.005/kw-hr	14,227	33,773	28,955	80,091
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)	$0.02/M gal	6,920	25,080	8,000	29,100
Chemicals, Specify		-	-	-	-
Total Utilities		21,147	58,853	36,955	109,191
Total Direct Cost		84,547	165,753	106,355	230,091
Annualized Capital Charges		104,400	218,500	115,100	241,300
Total Annual Cost		188,947	384,253	221,455	471,391

TABLE 250
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR FERROSILICON FURNACES

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$9/hr				
Supervisor					
Total Operating Labor		5,400	5,400	5,400	5,400
Maintenance					
Labor					
Materials					
Total Maintenance		38,000	65,500	42,000	74,000
Replacement Parts					
Total Replacement Parts		23,000	39,000	25,000	44,500
Utilities					
Electric Power	$.020/kw-hr	56,909	135,091	115,818	320,364
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)	$0.09/M gal	31,140	112,860	36,000	130,950
Chemicals, Specify		-	-	-	-
Total Utilities		88,049	247,951	151,818	451,314
Total Direct Cost		154,449	357,851	224,218	575,214
Annualized Capital Charges		104,400	218,500	115,100	241,300
Total Annual Cost		258,849	576,351	339,318	816,514

FIGURE 157

ANNUAL COSTS FOR WET SCRUBBERS FOR FERROSILICON FURNACES (HIGH EFFICIENCY)

(Low Unit Cost)

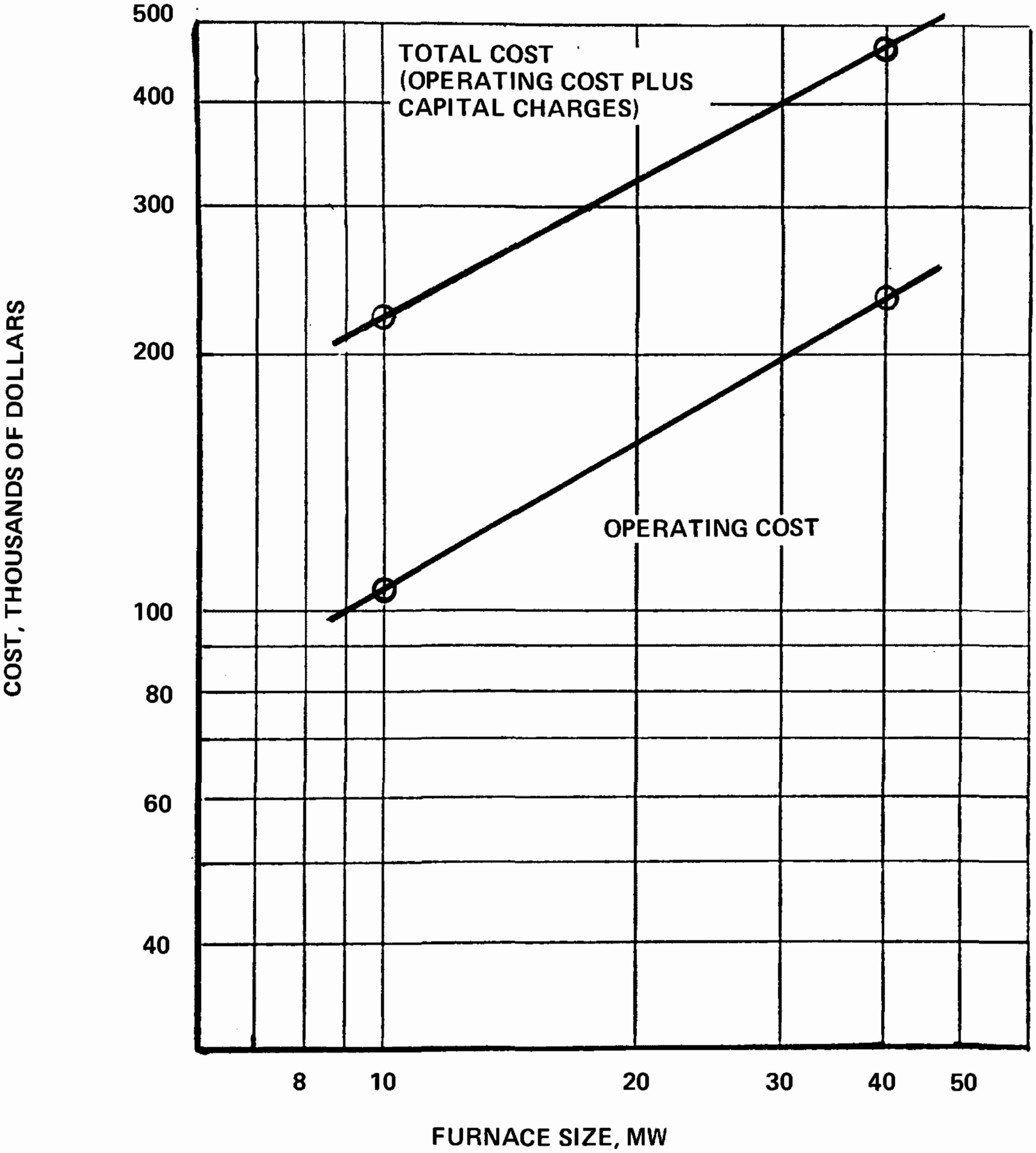


FIGURE 158

ANNUAL COSTS FOR WET SCRUBBERS FOR FERROSILICON FURNACES (HIGH EFFICIENCY)

(High Unit Cost)

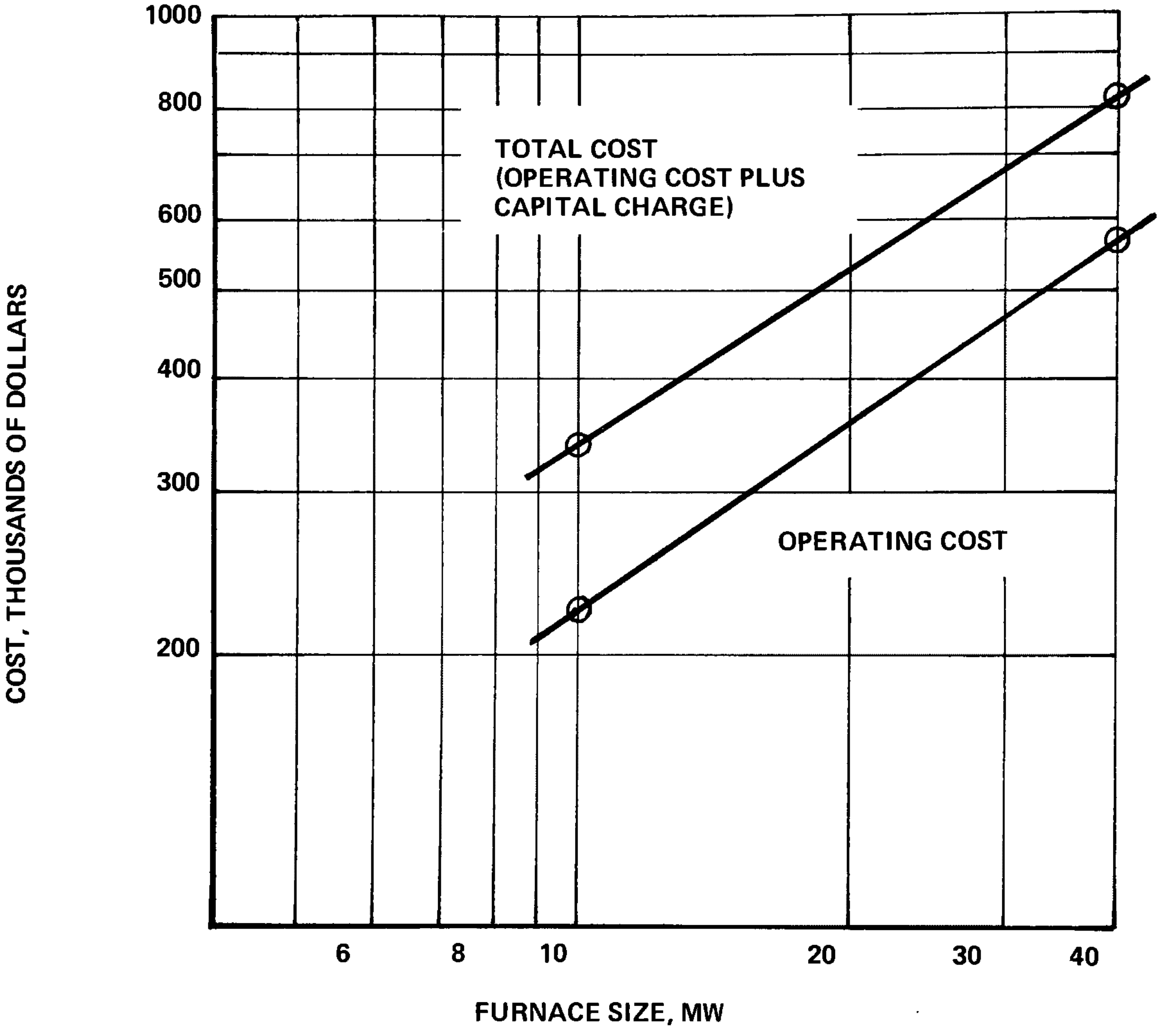


TABLE 251
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR FERROCHROME FURNACES

Low Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$4/hr				
Supervisor					
Total Operating Labor		9,934	9,934	9,934	9,934
Maintenance					
Labor					
Materials					
Total Maintenance		27,700	50,800	42,000	74,000
Replacement Parts					
Total Replacement Parts		11,700	20,500	25,000	44,500
Utilities					
Electric Power	$.005/kw-hr	12,273	43,409	28,955	80,091
Fuel		-	-	-	-
Water (Process)		-	-	-	-
Water (Cooling)	$0.02/M gal	5,160	18,960	8,000	29,100
Chemicals, Specify		-	-	-	-
Total Utilities		17,433	62,369	36,955	109,191
Total Direct Cost		66,767	143,603	113,889	237,625
Annualized Capital Charges		55,300	101,500	83,300	148,300
Total Annual Cost		122,067	245,103	197,189	385,925

TABLE 252
ANNUAL OPERATING COST DATA
(COSTS IN $/YEAR)
FOR WET SCRUBBERS FOR FERROCHROME FURNACES

High Unit Cost

Operating Cost Item	Unit Cost	LA Process Wt.		High Efficiency	
		Small	Large	Small	Large
Operating Factor, Hr/Year	7,700				
Operating Labor (if any)					
Operator	$9/hr				
Supervisor					
Total Operating Labor		22,350	22,350	22,350	22,350
Maintenance					
Labor					
Materials					
Total Maintenance		27,700	50,800	42,000	74,000
Replacement Parts					
Total Replacement Parts		11,700	20,500	25,000	44,500
Utilities					
Electric Power	$.020/kw-hr	49,091	173,636	115,818	320,364
Fuel		-	-	-	-
Water (Process) Water (Cooling)	$0.09/M gal	23,220	85,320	36,000	130,950
Chemicals, Specify		-	-	-	-
Total Utilities		72,311	258,956	151,818	451,314
Total Direct Cost		134,061	352,606	241,168	592,164
Annualized Capital Charges		55,300	101,500	83,300	148,300
Total Annual Cost		189,361	454,106	324,468	740,464

FIGURE 159

ANNUAL COSTS FOR WET SCRUBBERS FOR FERROCHROME FURNACES (HIGH EFFICIENCY)

(Low Unit Cost)

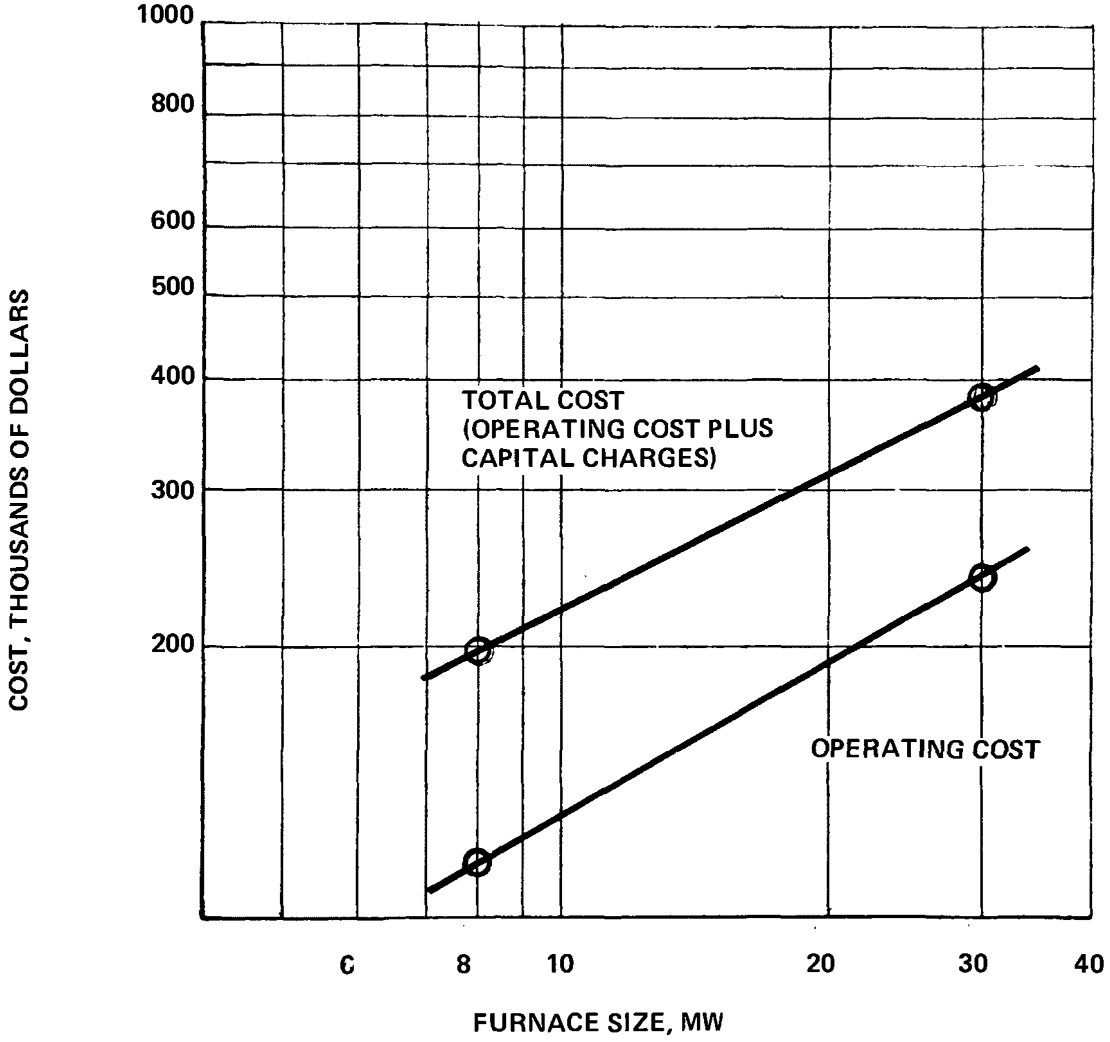
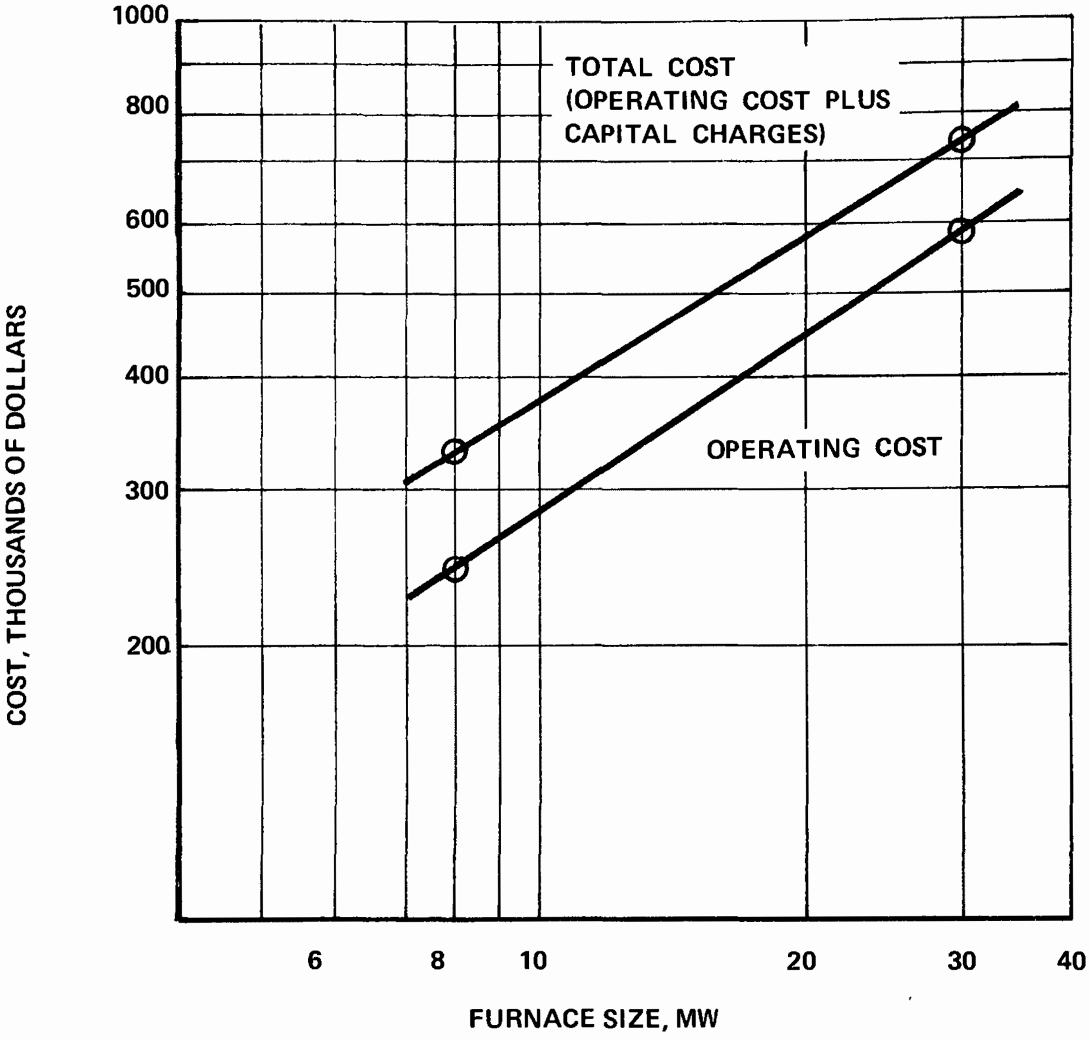


FIGURE 160

ANNUAL COSTS FOR WET SCRUBBERS FOR FERROCHROME FURNACES (HIGH EFFICIENCY)

(High Unit Cost)



4. GENERALIZED COST DATA

A series of correlations were made relating the cost of equipment to the gas flow rate. Here, as in the rest of this report, costs are reported in 1971 dollars.

SCRUBBERS

Correlations for scrubbers were made both for the scrubber cost and for the total installed cost of the scrubber system. Figure 161 shows the cost of the scrubber alone. Although there is a little scatter in the data, the results can be well represented by one curve. Scrubbers for all applications studied appear to have the same cost basis. This is not true for the installed scrubber system costs as shown on Figure 162. Here the data fall into three groups. These groups are not differentiated by operating efficiency. Instead, they group by the complexity of the system involved. Scurbbers for steelmaking and ferroalloys fall on the upper curves. These are complex systems for which the total system cost is quite large relative to the scrubber cost.

Scrubbing systems for rendering and asphalt batching fall on the lower line. These systems have very little extra equipment and are simple in scope. The remaining four applications fall on the center line.

An attempt was made to correlate direct operating costs in a similar way. Although a positive relationship was shown to exist, the data was widely scattered. This occurred because of wide variations in the amount of maintenance and operating labor required from system to system. The principle operating cost common to all scrubbing systems is power cost which is directly related to the system pressure drop. Power cost correlates well with gas rate using parameters of system pressure drop. Maintenance and operating labor requirements have very little to do with gas throughput, however, and this fact prevents adequate correlation.

PRECIPITATORS

Similar correlations were made for electrostatic precipitators. Figure 163 shows the cost of the precipitator alone. As opposed to the scrubber correlation, the equipment costs fall into three groups. The groups are characterized by the required level of performance. Costs for total installed cost, shown on Figure 164, do not relate to the required efficiency. Instead, like scrubbers, they relate to the complexity of the system. Systems operating on BOF steelmaking furnaces are expensive relative to others.

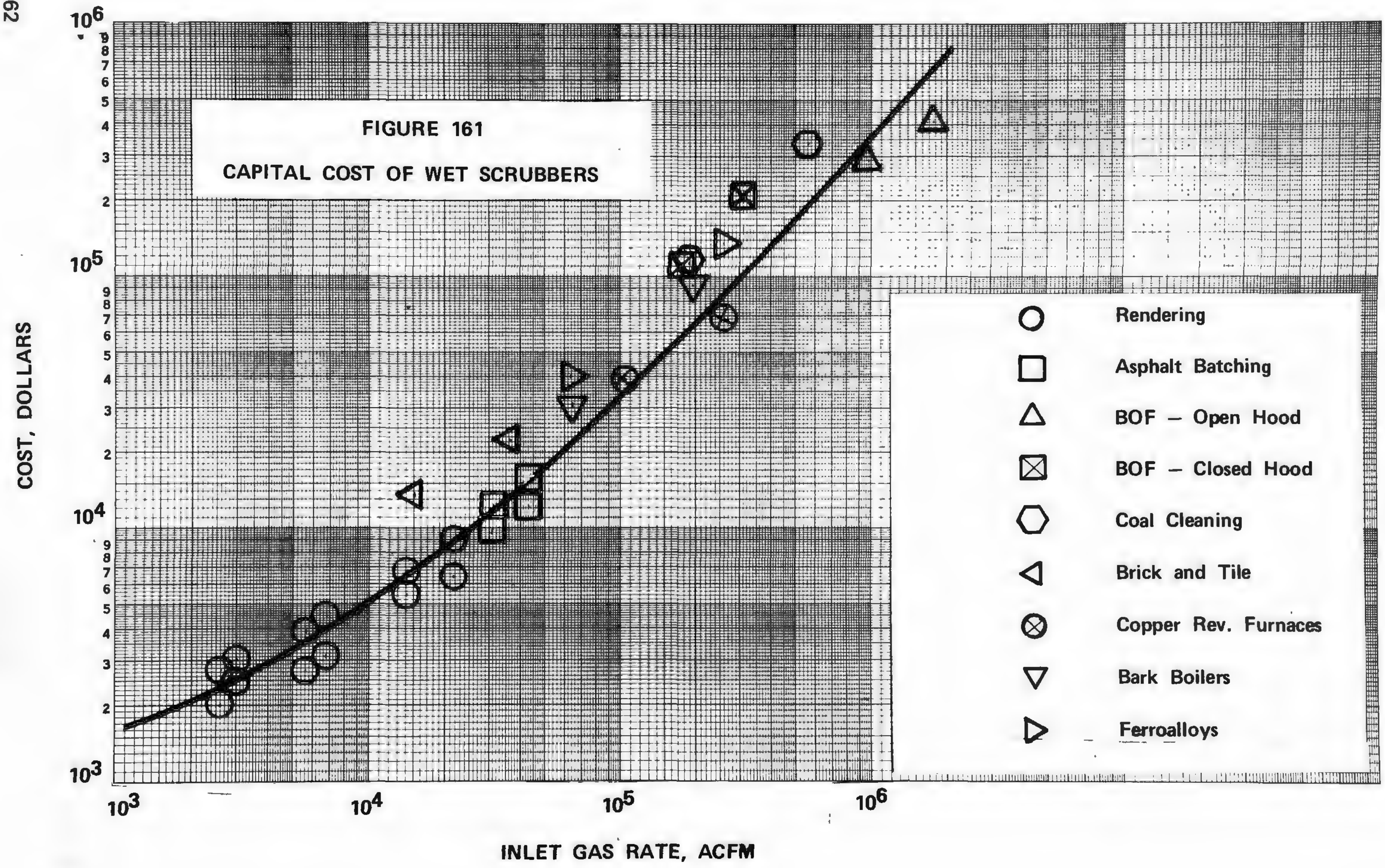


FIGURE 161

CAPITAL COST OF WET SCRUBBERS

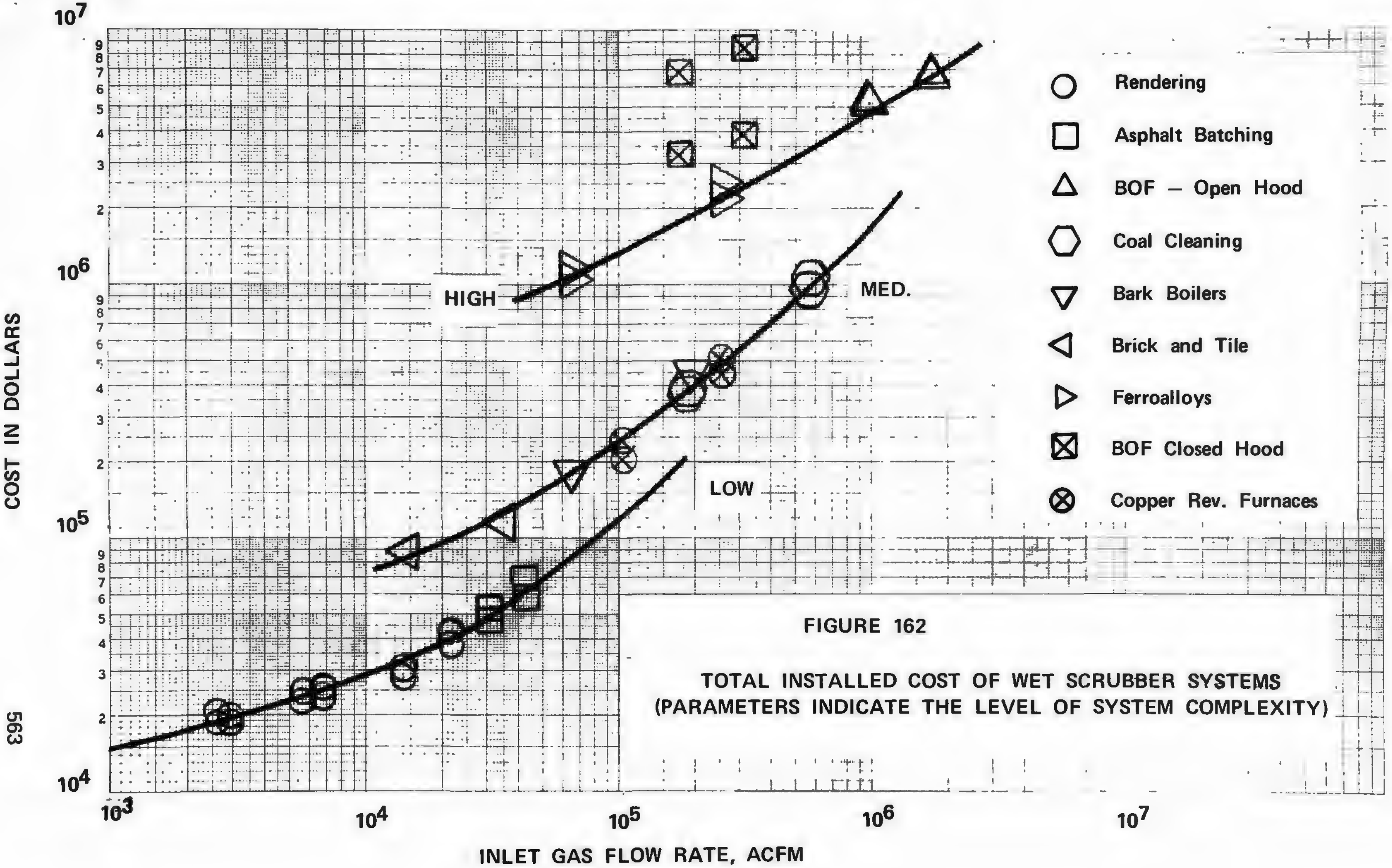


FIGURE 162

TOTAL INSTALLED COST OF WET SCRUBBER SYSTEMS
(PARAMETERS INDICATE THE LEVEL OF SYSTEM COMPLEXITY)

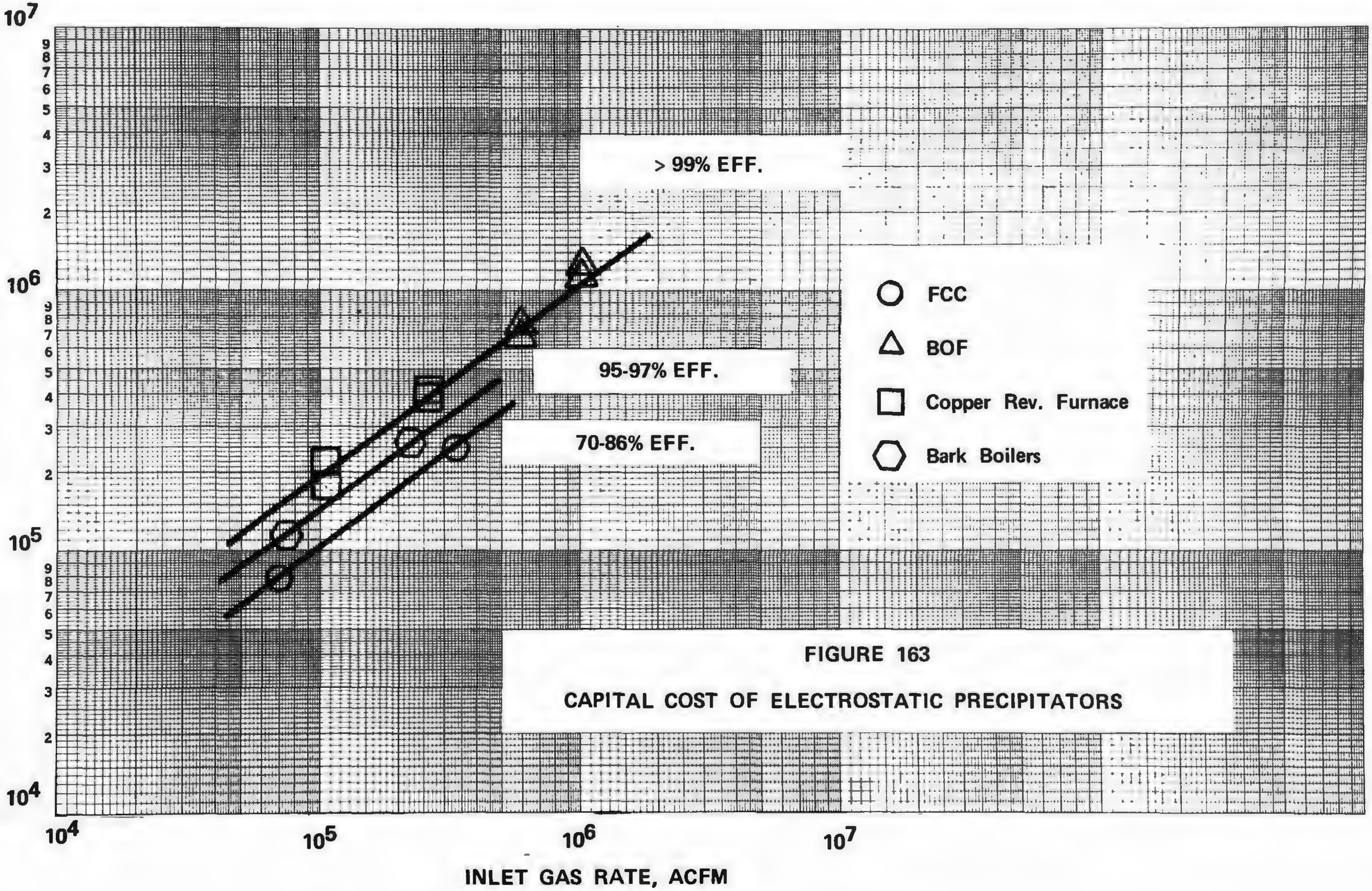


FIGURE 163

CAPITAL COST OF ELECTROSTATIC PRECIPITATORS

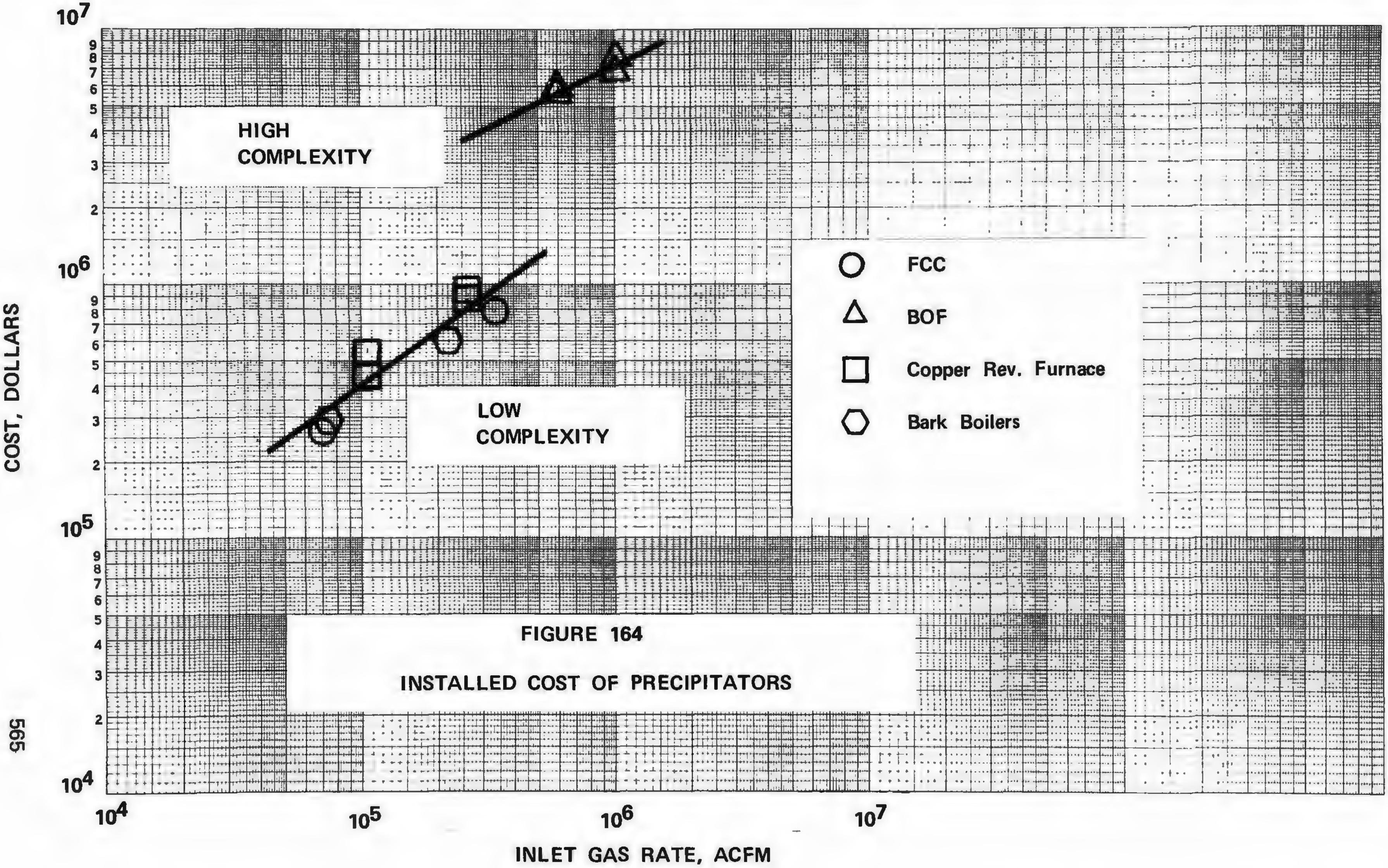


FIGURE 164

INSTALLED COST OF PRECIPITATORS

An attempt was made to show a similar correlation for operating costs. The result is presented in Figure 165. Correlation exists only for equipment grouped by process application. No general relationship appears to exist.

INCINERATORS

Data were collected for only two incinerator systems. One of these, rendering, had no heat exchange. The other, brick and tile kilns, had 65% heat recovery. The cost relationship between these two kinds of systems is clearly shown in Figures 166 - 168. Figure 166 shows the purchase cost of the incinerators. Incinerators with heat recovery are more expensive, by a factor of three, on the range shown on the plot. Cost of the total system is shown on Figure 167. Again, systems with 65% heat recovery cost about four times those without heat recovery. Direct hourly operating costs are presented in Figure 168. The major component of operating cost for these systems is fuel cost. Operating cost is therefore nearly inversely proportional to heat recovery. This relationship is apparent in Figure 168.

FABRIC FILTERS

Only two fabric filter applications were included in the nine process areas studied; asphalt batching and ferroalloys. The purchased cost of the fabric filters is shown on Figure 169. Installed costs for those two types of systems are shown correlated with size on Figure 170. Costs for the two applications are quite different. Although the performance of the systems are comparable, the difficulty of accomplishing that performance differs widely. Requirements for particle size, temperature, and air to cloth ratio all cause ferroalloy systems to cost most. The relationship of operating cost to size shown on Figure 171 is similar. For asphalt batching, roughly two-thirds of the operating cost goes for bag replacement. While ferroalloys have high bag replacement costs, they also have significant labor costs which total to much greater operating cost per cubic foot of flow.

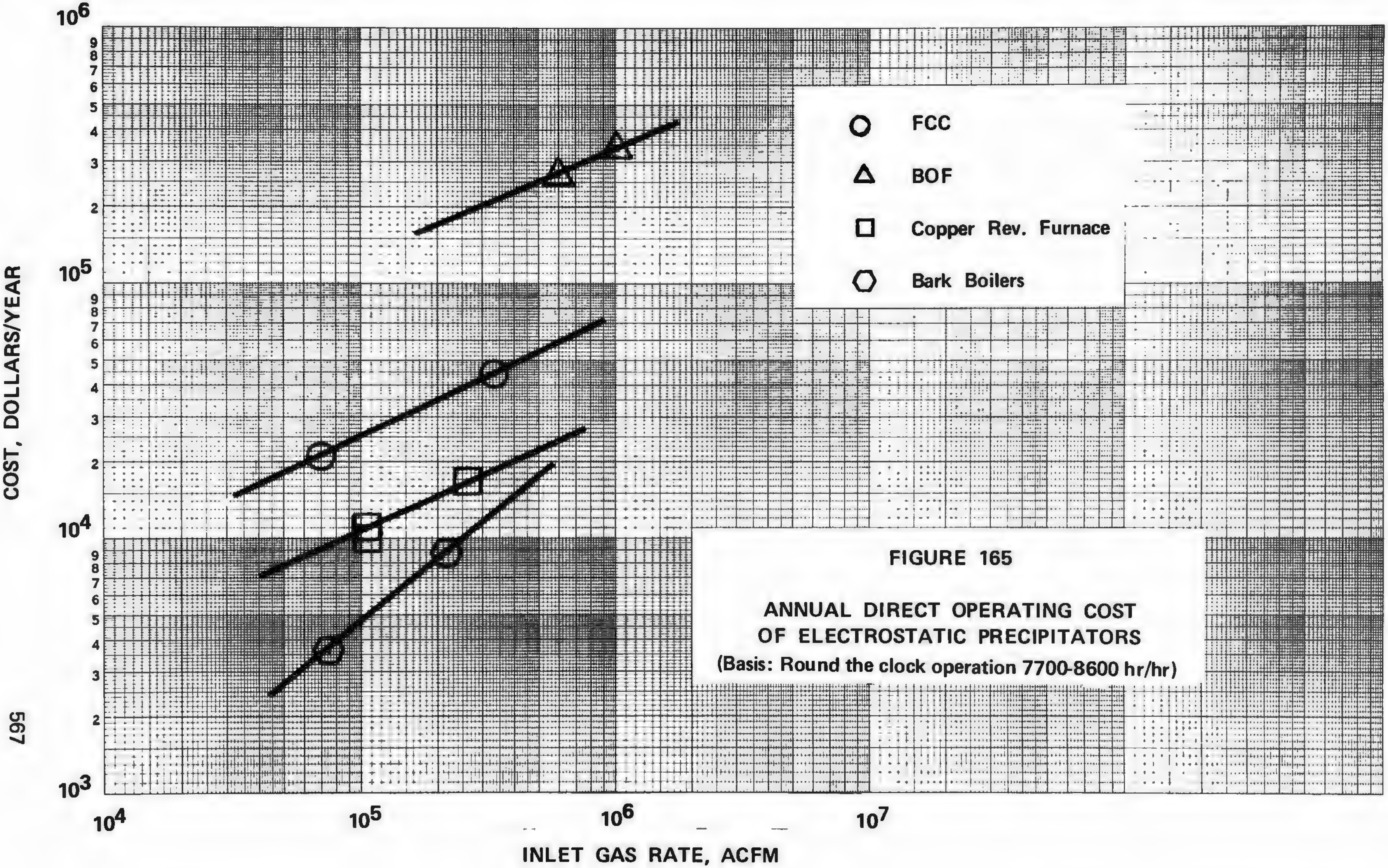


FIGURE 165

ANNUAL DIRECT OPERATING COST
OF ELECTROSTATIC PRECIPITATORS
(Basis: Round the clock operation 7700-8600 hr/hr)

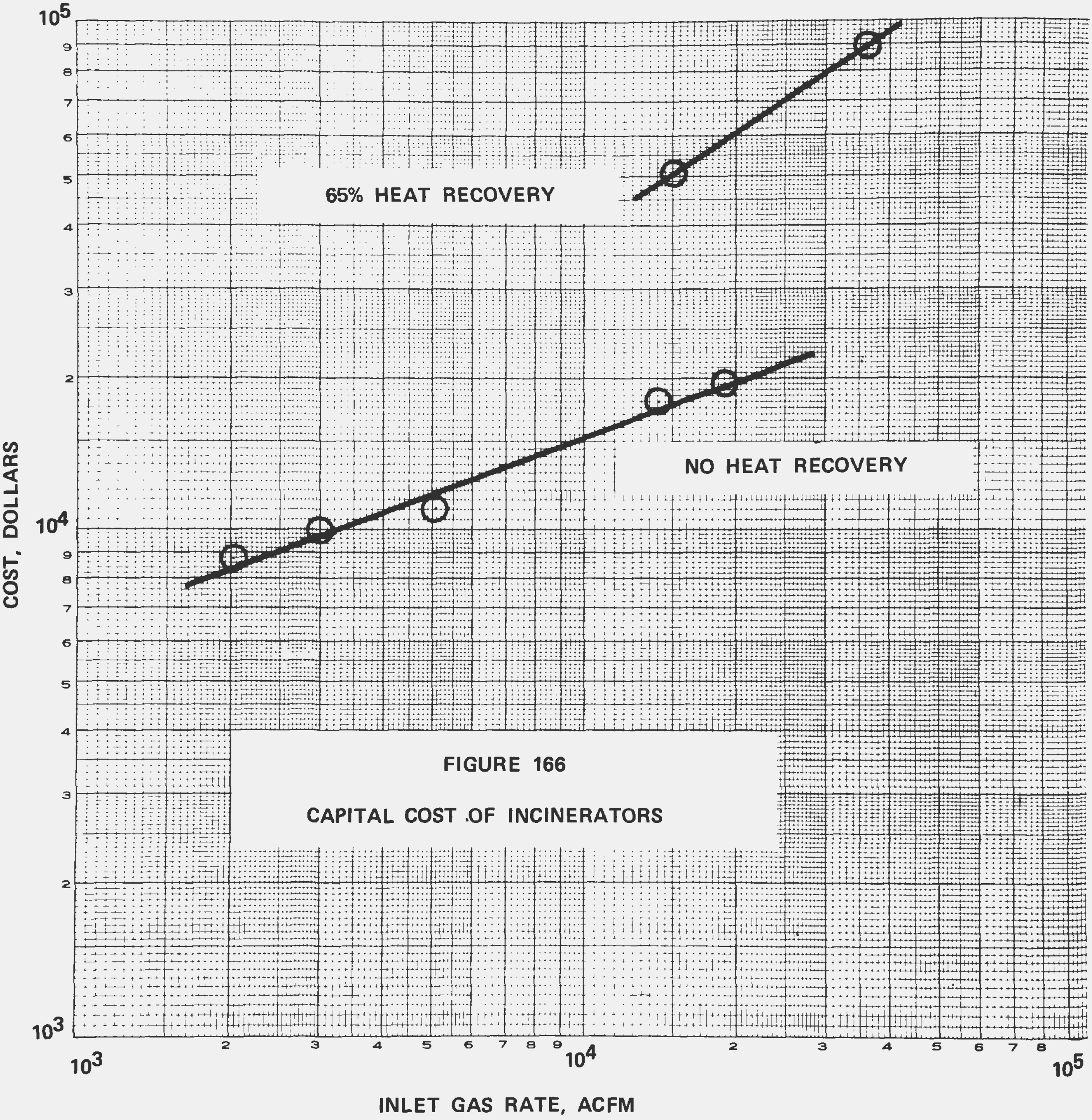
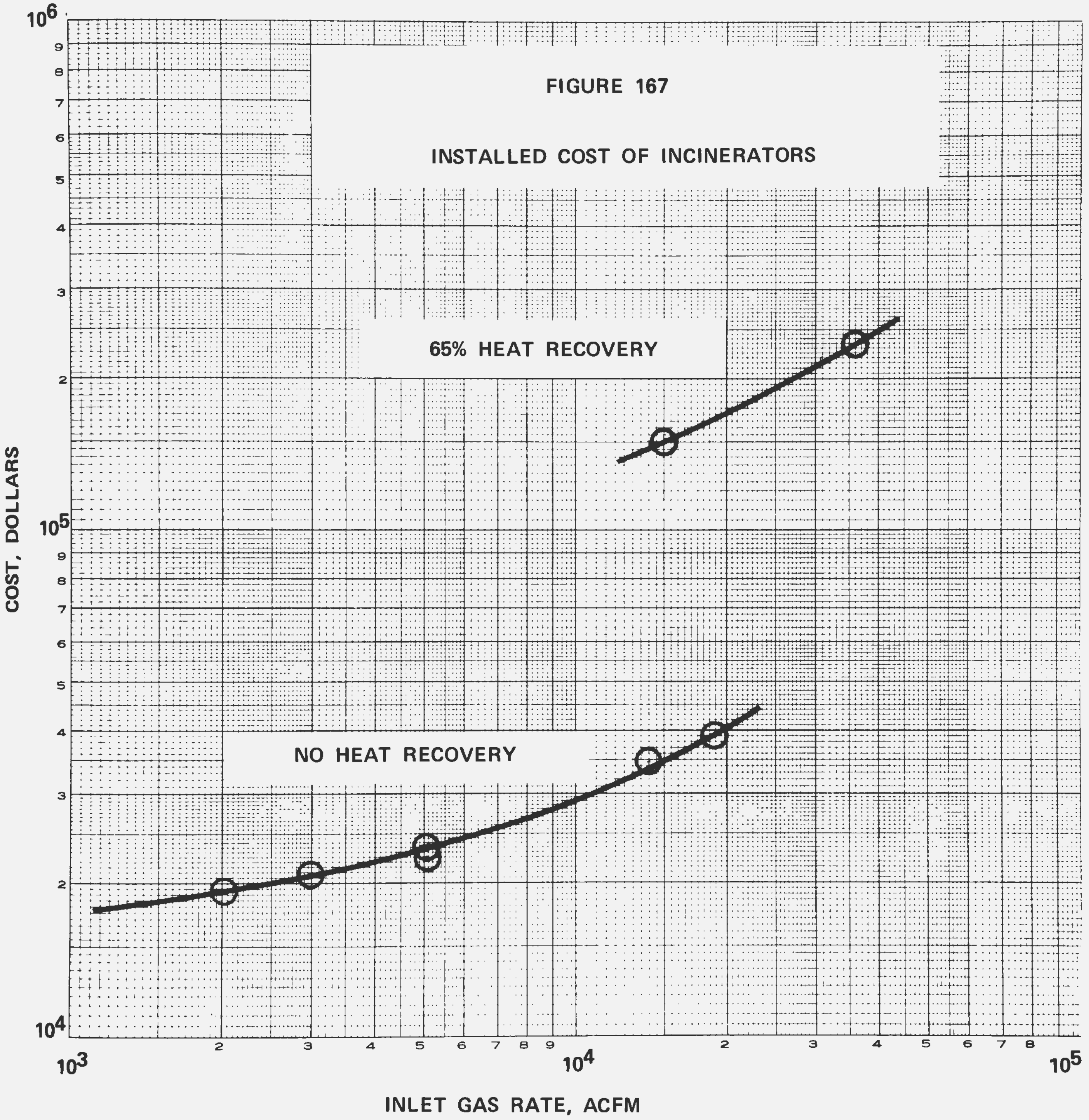


FIGURE 166

CAPITAL COST OF INCINERATORS

FIGURE 167

INSTALLED COST OF INCINERATORS



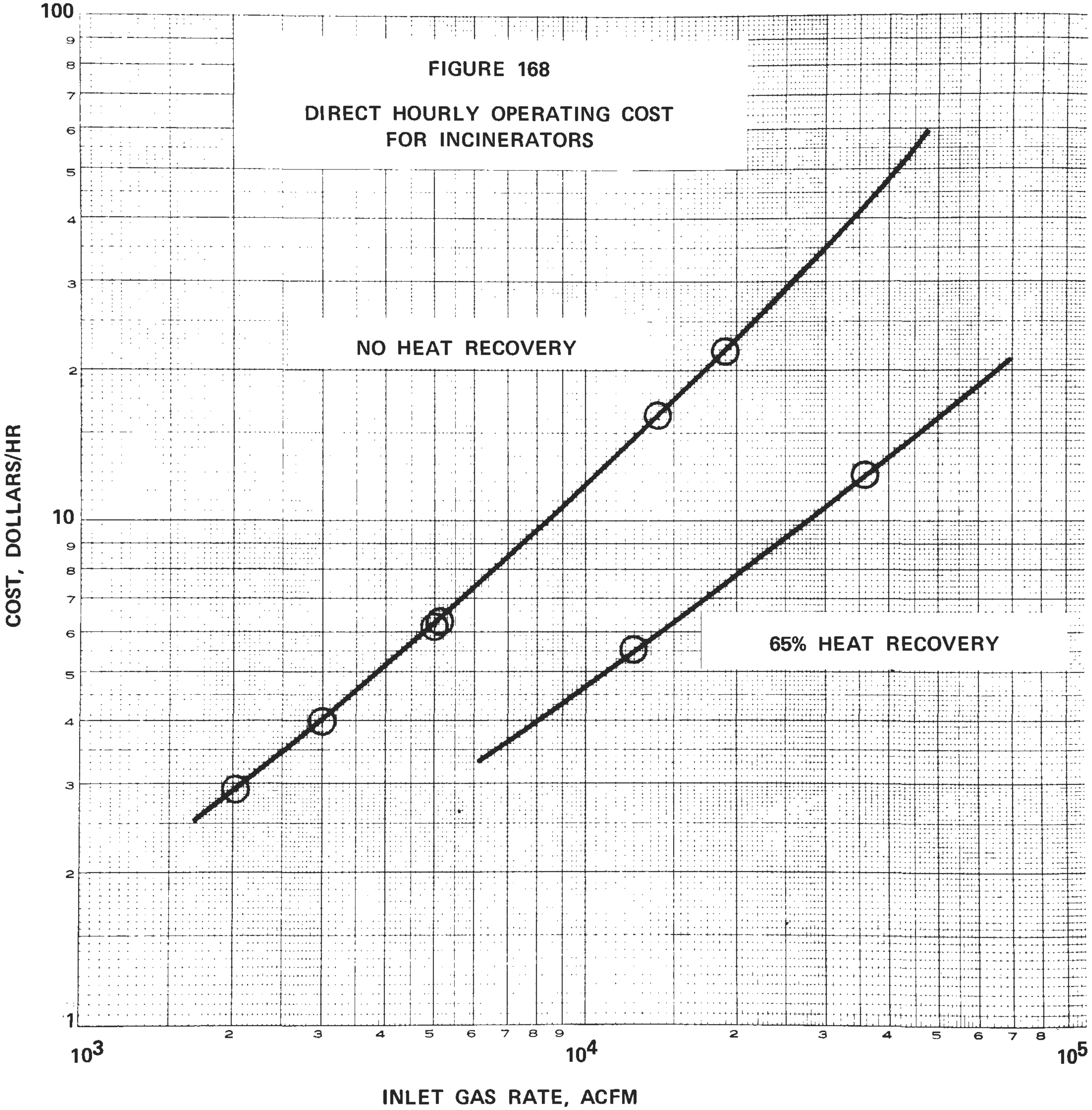


FIGURE 168
DIRECT HOURLY OPERATING COST
FOR INCINERATORS
NO HEAT RECOVERY
65% HEAT RECOVERY
COST, DOLLARS/HR
100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1
10^3
2
3
4
5
6
7
8
9
10^4
2
3
4
5
6
7
8
10^5
INLET GAS RATE, ACFM

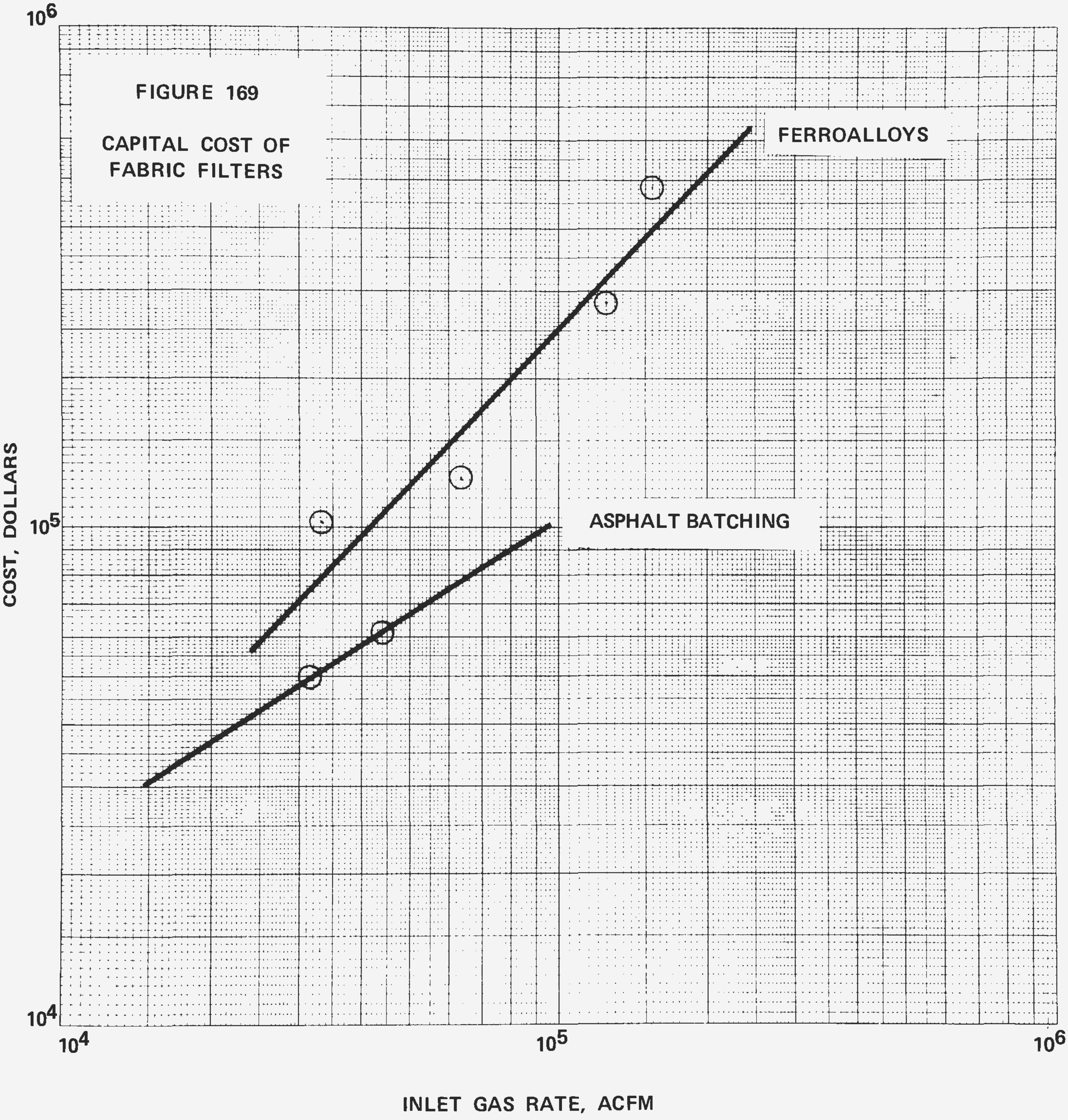


FIGURE 169

CAPITAL COST OF FABRIC FILTERS

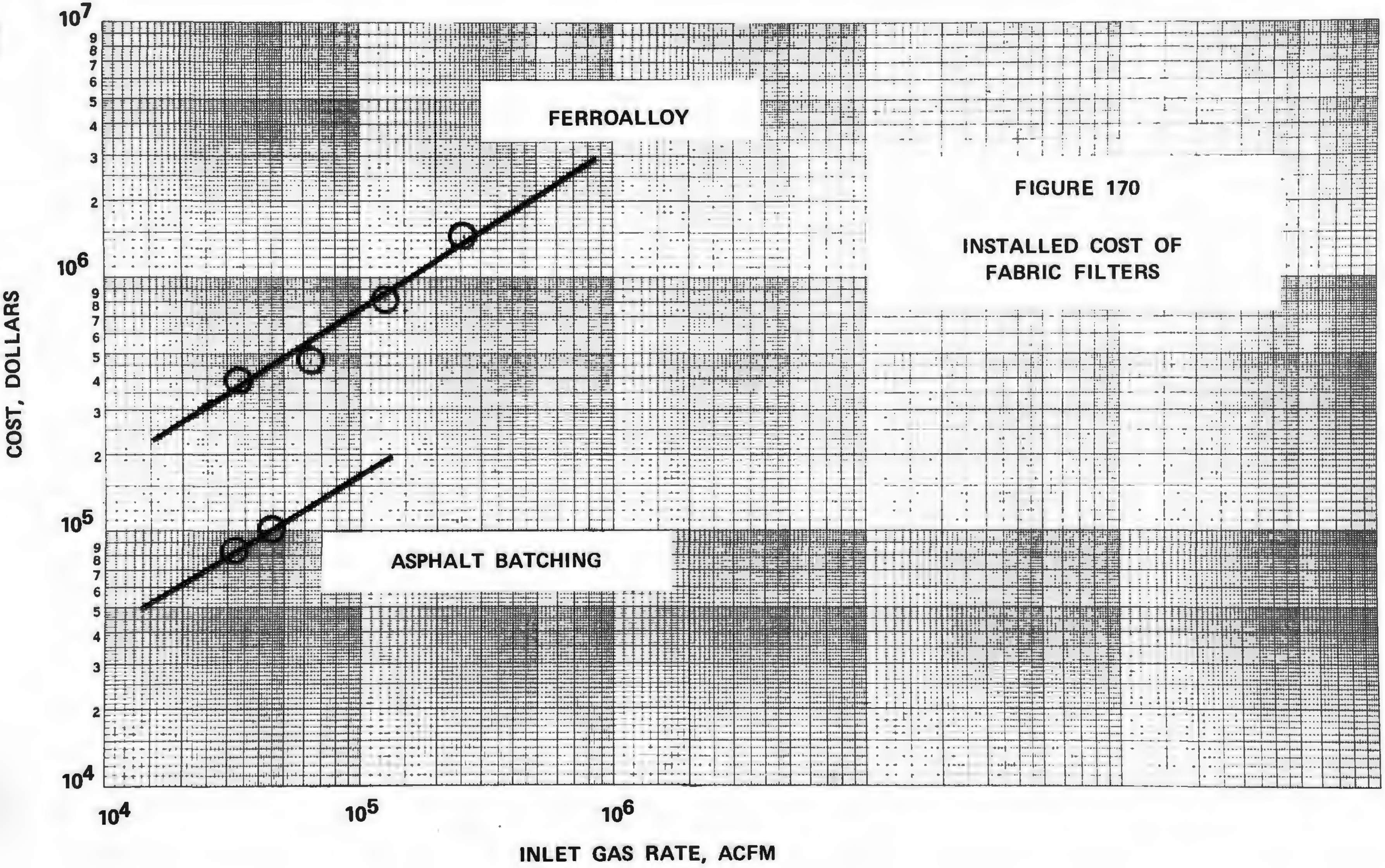


FIGURE 170

INSTALLED COST OF FABRIC FILTERS

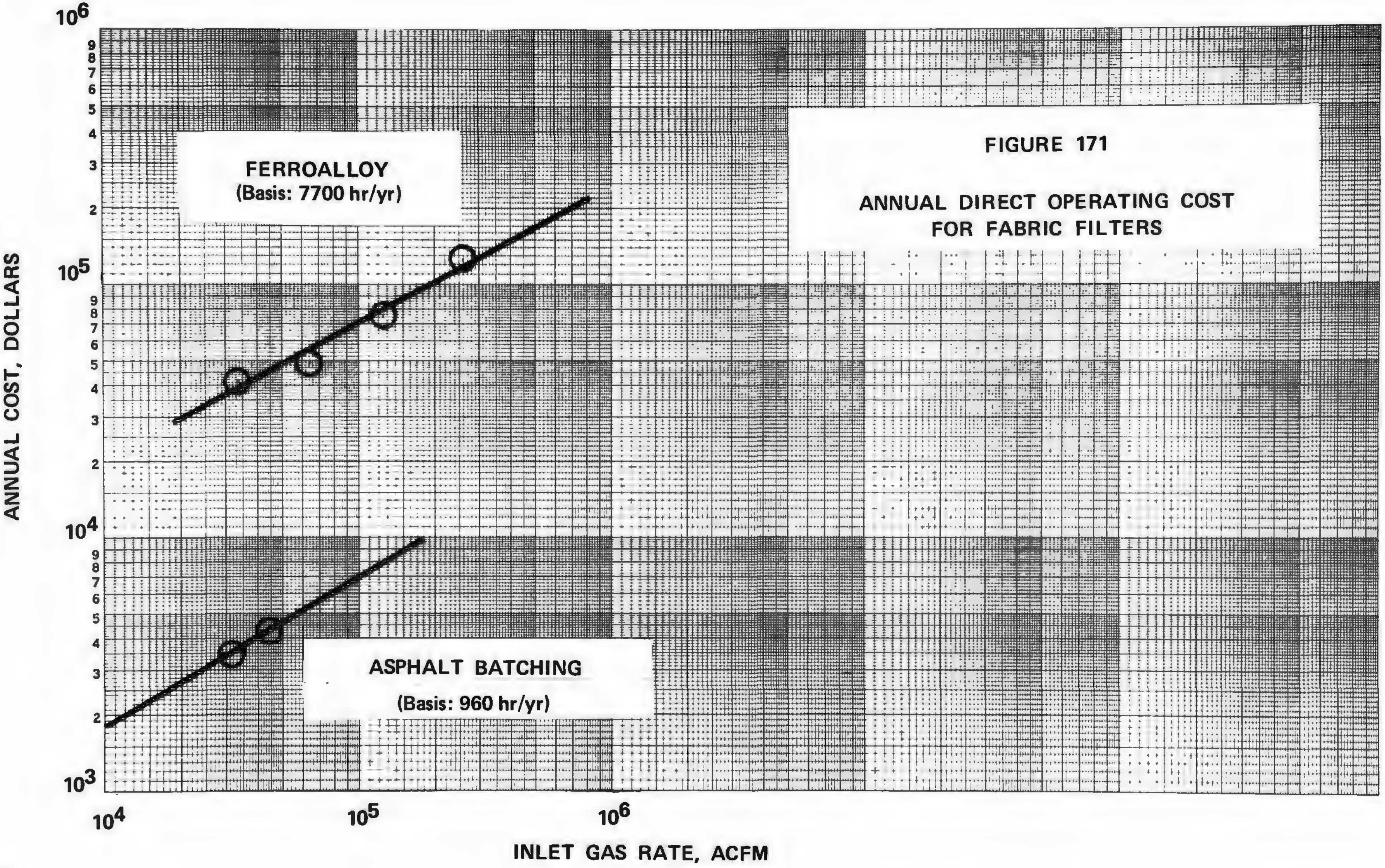


FIGURE 171

ANNUAL DIRECT OPERATING COST FOR FABRIC FILTERS

III. CONCLUSIONS AND RECOMMENDATIONS

The data collected during the course of this program substantiate several major conclusions with regard to the application areas covered:

A. *Rendering* odors can be controlled by thermal incineration at reasonable cost if the gas flow from odor-containing sources is limited severely by proper use of condensers, enclosures around equipment, etc. The cost is nearly proportional to the air flow rate treated. Scrubbing with permanganate or other oxidizing chemicals costs a great deal to operate, if all of the organics are reacted out of the gas stream by the oxidation chemicals.

B. *Fluidized Bed Catalytic Cracking* units in petroleum refineries may be equipped with electrostatic precipitators which are adequate for control of particulate emissions in all of the cases considered. For small units or those with relatively low catalyst losses, the addition of an external cyclone may be sufficient for good particulate control. On units with very low rates of attrition of catalyst, it may be possible to meet existing regulations without external particulate control devices.

C. *Asphalt Batch Plants* are adequately treated by both wet scrubbers and fabric collectors, with economic factors likely to influence the installation of one system over the other. Electrostatic precipitators have also been applied with some degree of success in the past.

D. *Basic Oxygen Furnace* steelmaking processes have been treated by both scrubbers and precipitators. The scrubbing systems can be designed in such a way as to minimize or eliminate infiltration of ambient air (closed hood system) and thereby minimize the system size. However, the complexity of this approach tends to increase the system cost in comparison with the larger open hood systems with either scrubbers or precipitators as the primary abatement device. Precipitator systems have no upper limit on efficiency during most of the cycle, but have potential resistivity problems at the beginning and end of the blow. The open hood scrubbers require high head fans (two fans in series, or positive displacement blowers) to hold particulate losses as low as those for the closed hood system.

E. *Coal Cleaning Processes* are treated exclusively by scrubbers, which have no unusual problems or performance limitations.

F. *Brick and Tile Kilns* normally produce no significant emissions. However, hydrocarbons, fluorine and/or sulfur oxides may be emitted if precursor impurities are present in the raw material or fuel. The hydrocarbon emissions may require incineration to eliminate visible smoke, and fluorine or sulfur oxides may require treatment by wet scrubbers.

G. *Copper Smelting* by roasting and reverberatory furnaces of conventional design were covered in this study. Smelting technology is changing rapidly in this area and may eliminate these processes as separate steps. However, the two types of gas cleaning processes covered should be appropriate to combined smelting processes as they emerge. One process deals with the cleaning of a gas stream used as feed to a sulfuric acid plant. This involves cooling, acid mist precipitation and particulate scrubbing. The other approach deals with wet scrubbing of gases vented to the atmosphere with a significant concentration of SO_2, or use of electrostatic precipitators on this gas stream.

H. *Bark Boilers* produce a carbonaceous ash which is easily removed from the flue gas by mechanical collectors, and a fine flyash which requires precipitation or scrubbing. Both methods are employed in plants where recycle of carbonaceous ash to the furnace is practiced.

I. *Ferrochrome and Ferrosilicon Furnaces* present difficult particulate control problems which have been handled adequately only by fabric collectors. Wet scrubbers of very high pressure drop are capable of satisfactory operation, but are unlikely to be competitive, whereas precipitators have not functioned satisfactorily because of resistivity problems.

Several additional conclusions can be drawn relative to the equipment types covered by generalizing data from all of the areas:

A. Thermal incinerators were quoted for two applications. Data relating cost to size is relatively consistent between the two if the presence or absence of heat exchange is taken into account. The main variable in both capital and operating cost is gas flow, not process unit capacity.

B. Electrostatic precipitator costs can be generalized well using gas flow as a primary variable and system complexity as a coarse parameter. Efficiency level was not as critical in installed cost as was the nature and complexity of the overall system in which the precipitator was used. This study covered a wide range of complexity.

C. Scrubber costs varied largely with gas flow and only slightly with efficiency. However, the fan cost increased sharply as particulate collection efficiency or complexity of the system increased.

D. Fabric collector costs varied nearly linearly with gas flow, as expected, and did not include efficiency as a parameter. However, the cost of the system was influenced sharply by temperature and the necessity for protecting the fabric. Here again, "difficulty" of the service is the best coarse correlation parameter.

APPENDIX

APPENDIX I

Rule 54 of the Air Pollution Control District of Los Angeles County

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.

(1). 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 II

INSTRUCTIONS FOR SUBMITTING COST DATA

Two forms (two copies each) are enclosed with each specification. These are for submitting:

(A) Estimated Capital Cost Data

(B) Annual Operating Cost Data

These forms will also be used to exhibit averages of the three cost estimates for each process and equipment type. Because your costs will be averaged with those of other IGCI members, it is necessary to prepare them in accordance with instructions given in the following paragraphs.

(A) Estimated Capital Cost Data

The upper part of this form should already be filled out for the particular application when you receive it. This information on operating conditions should be identical to that in the specification and is repeated here only for the convenience of those reading the form.

You should fill in the dollar amounts estimated in the appropriate spaces on the bottom half of the form. It should not be necessary to add any information other than the dollar amounts. If you wish to provide a description of the equipment proposed, please do so on one or more separate sheets of paper, and attach it to the form. If any item is not involved in the equipment you are proposing, please indicate this by writing "none" in the space rather than leaving it blank or using a zero.

(1) *The "gas cleaning device"* cost should be reported just as you would report a flange-to-flange equipment sale to the IGCI. That is, a complete device including necessary auxiliaries such as power supplies, mist eliminators, etc. Do NOT include such items as fans, solids handling equipment, etc., unless these are an *integral part of your gas cleaning device*.

(2) *"Auxiliaries"* are those items of equipment which are frequently supplied with the gas cleaning device. There is a purely arbitrary definition of those items included here and those included in the "Installation" Costs. Do NOT include any of the cost of erecting or installing auxiliaries in this category.

(3) *"Installation Cost"* should include all of the material not in (1) or (2) and the field labor required to complete a turnkey installation. In cases where the equipment supplier ordinarily erects the equipment but does not supply labor for foundations, etc., it is necessary to include an estimated cost for these items.

The installation should be estimated for a new plant, or one in which there are no limitations imposed by the arrangement of existing equipment. Installation labor should be estimated on the basis that the erection will take place in an area where labor rates are near the U.S. average, and the distance from your plant is no more than 500 miles. Milwaukee, Wisconsin is an example of a city with near-average labor rates.

(B) Annual Operating Cost Data

Some of the information will be supplied by Air Resources, such as unit costs for labor and utilities, and annualized capital charges. You should fill in the usage figures for the complete abatement system units indicated below:

Labor	hrs/year
Maintenance Materials	Dollars/year
Replacement Parts	Dollars/year
Electric Power	kw-hr/year
Fuel	MMBTU/year
Water (Process)	MM gal/year
Water (Cooling)	MM gal/year
Chemicals	Dollars/year

Air Resources will average the consumption figures reported, and convert them to dollar values for inclusion in the final report.

APPENDIX III

SPECIFICATIONS FOR ABATEMENT EQUIPMENT

1. SCOPE

A. This specification covers vendor requirements for air pollution control equipment for the subject 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 in sections 2 and 3. The vendor should specify any of the performance characteristics which cannot be guaranteed without samples of process effluent.

B. The vendor shall submit a bid showing three separate prices as described below.

1. *All labor, materials, equipment, and services to furnish one pollution abatement device together with the following:*

    a. *All ladders, platforms and other accessways to provide convenient access to all points requiring observation or maintenance.*

    b. *Foundation bolts as required.*

    c. *Six (6) sets of drawings, instructions, spare parts list, etc., pertinent to the above.*

2. *Auxiliaries including*

    (a) Fan(s)

    (b) Pump(s)

    (c) Damper(s)

    (d) Conditioning Equipment

    (e) Dust Disposal Equipment

3. *A turnkey installation of the entire system including the following installation costs:*

    (a) Engineering

    (b) Foundations & Support

    (c) Ductwork

    (d) Stack

    (e) Electrical

    (f) Piping

    (g) Insulation

(h) Painting

(i) Startup

(k) Performance Test

(l) Other

C. For the "pollution abatement device only" quotation, 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 operating parameters such as gas flow.

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 in Section 5, and to good engineering practice.

**This is a typical request. The member companies are NOT to furnish this material under the present project.*

2. PROCESS DESCRIPTION

A single wet scrubber is to treat the effluent from a typical asphalt batching plant operation. All of the air required to ventilate the following items of equipment must be treated so as to conform to the specified particulate emission limits.

1. *Cold aggregate elevator*
2. *Rock dryer*
3. *Hot aggregate elevator*
4. *Vibrating screens*
5. *Sorted hot aggregate storage bins*
6. *Weigh hopper*
7. *Mixer*

The necessary enclosures to minimize escapement of dust from conveyors, elevators, etc. will be provided by others. The vendor is to furnish all interconnecting ductwork, primary collector, wet scrubber, fan, slurry pumps, settler and clarified water return pumps. Dust from the primary cyclone is to be returned to the bottom of the hot elevator, whereas dust collected in the scrubber is to be settled to approximately 60% solids content by weight and removed by truck.

The plant is located outside, adjacent to a public highway, and with little likelihood of interferences of roadways, buildings, etc. with the location of pollution control equipment. The plant is considered temporary (2-4 years expected life in this location) and may be moved. Ability of the pollution abatement equipment to be dismantled and reloacted is of prime importance.

3. OPERATING CONDITIONS

Two sizes of wet scrubbers are to be quoted for each of two efficiency levels. Vendors quotation should consist of four separate and independent quotations.

	Small	Large
Plant Capacity, ton/hr	100	200
Process Weight, lb/hr	204,000	408,000
Gas to Primary Collector		
Flow, ACFM	31,400	44,000
Temp., ^oF	370	370
% Moisture	17	21
Primary Collector Inlet Loading, lb/hr	4,000	8,000
Primary Collector Outlet Loading, lb/hr	1,000	2,000
Primary Collector Efficiency, %	75	75
Gas to Secondary Collector (Scrubber)		
Flow, ACFM	30,600	42,900
Temp., ^oF	350	350
% Moisture	17	21
Outlet from Secondary Collector		
Flow, ACFM	25,000	35,200
Temp., ^oF	147	152
Moisture Content, Vol. %	23	26.2

Case 1 — Medium Efficiency

Outlet Loading, lb/hr	40	40
Outlet Loading, gr/ACF	0.187	0.133
Efficiency, Wt. %	96	98

Case 2 — High Efficiency

Outlet Loading, lb/hr	6.43	9.06
Outlet Loading, gr/ACF	0.03	0.03
Efficiency	99.68	99.77

4. PROCESS PERFORMANCE GUARANTEE

A. The equipment 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 turnkey proposal.

E. In the event the equipment 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

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.

APPENDIX IV

STATISTICAL BASIS FOR DATA PRESENTATION

The cost quotations received from member companies have in every case been averaged and the resulting values presented graphically in the body of the report. Provided there is no more than a reasonable spread between the quotations, it is helpful to treat the data received as a random selection from among a "population" of twenty or so potential bidders. Statistical values for the confidence limits of the mean cost have been calculated.

Calculation Method – The calculations performed by ***CONLIM are based on the following formulas:

$$\text{Confidence limits} = \bar{X} \pm st_{n-1;\,\gamma}$$

where

$\bar{X}$ = the sample mean, based on three bids in most cases

s = the sample standard deviation

$t_{n-1;\,\gamma}$ the (γX 100) percentage point of the student-t distribution with n-1 degrees of freedom

Size of sample - n, usually three

$$\text{Sample mean value} = \frac{1}{n} \sum_{i=1}^{n} X_i$$

$$\text{Variance of sample} = \frac{1}{n} \sum_{i=1}^{n} (X_i - \bar{X})^2$$

$$\text{Standard deviation of sample} = \sqrt{\frac{\Sigma (X_i \;\; \bar{X})^2}{n}}$$

$$\text{Estimated population standard deviation} = \sqrt{\frac{\Sigma (X_i - \bar{X})^2}{n - 1}}$$

$$\text{Standard error of mean} = \frac{S}{\sqrt{n}}$$

where

S - sample standard deviation

When the population is finite, a correction factor of $\left(\frac{N-n}{N}\right)$ is included in both the variance and the standard deviation computations, as follows:

$$S_f^2 = S^2\left(\frac{N - n}{N}\right)$$

where

S_f^2 = the corrected variance for finite populations

S^2 - the non-corrected variance for infinite populations

N - the population size, usually taken as 20

n - the sample size, usually three

The results are presented graphically using a solid line on log-log paper for the mean cost vs. equipment size, and dotted lines for the 75% and 90% confidence intervals based on three bids (or the actual number of bids received) out to an approximate population of 20 possible bidders.