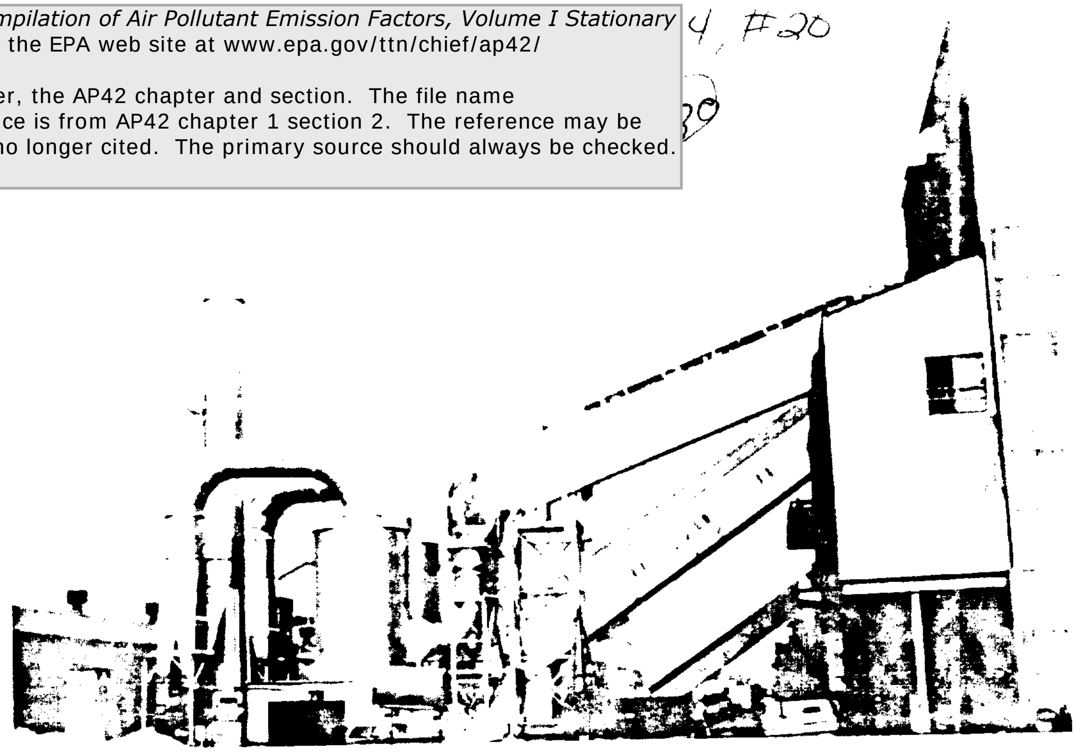

Fig. 1—High energy wet scrubber installation on 30-mw H.C FeCr furnace

1970 ELECTRIC FURNACE AWARD PAPER

Control of emissions from ferroalloy furnace processing

by R. A. Person

INTRODUCTION

Recently stepped-up activity by regulatory agencies and an increased awareness by politicians and the public at large of air pollution issues will require a more intensive effort by the ferroalloy industry to control its process emissions. While air pollution control has been a matter of prime concern, the results thus far have been somewhat inadequate, largely because of technical difficulties and high costs associated with this control. A chronological account of typical problems encountered in achieving control was recently given by Dr. Ferrari.[1]

This paper strives to summarize the current status of the problem from an engineering viewpoint and point out possible methods of solution. In view of the large scope of the subject, a complete detailed analysis has not been made in this paper, and many specific cases are covered by general statements. To our knowledge, aside from a general survey of the problems in the French ferroalloy industry,[2] the available literature is concerned with specific installations or products.

Because of the wide variety of products and processing equipment, it is difficult to generalize, but many basic principles apply to the majority of operations.

Calcium carbide furnaces, because they represent the same basic type of furnace as a ferroalloy unit and because they can be a major contributor to air pollution, are also mentioned.

The optimum long-range solution is not only the provision of fume collection equipment, but also the adoption of different furnace design and alternate metallurgical processes and operating practices. The optimum economic solution is also dependent on the growth pattern of the industry. Unfortunately, pressure for quick results may force short-term action which is not necessarily in conformity with the best long-range solution.

In the discussion to follow, the term "dust" will be taken to mean solid particles that have resulted from comminution of larger solids (dust would generally be greater than 2 microns in size); fume will be taken to mean solids that have resulted from condensation out of a gas phase, gas phase reaction, or atomization of liquid (fume would generally be less than 2 microns in size). However, occasionally the terms are used interchangeably.

GENERAL DISCUSSION OF PROBLEM

Type of Emission

The production of ferroalloys has many dust- or fume-producing steps. The dust resulting from raw material handling, mix delivery, and crushing and sizing of the solidified product can be har[illegible]

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conventional techniques and is ordinarily not a pollution problem. This dust, resulting from solids handling, accordingly will not be discussed further.

By far the major pollution problem arises from the ferroalloy furnaces themselves. The conventional submerged arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of CO, in many cases in larger amounts than the metallic product. Other sources of primary gas are moisture in the charge materials, reducing agent volatile matter, thermal decomposition products of the raw ore, and intermediate products of reaction. Normally these other sources do not amount to more than 30% of the CO production. The CO rising out the top of the furnace carries fume or fume precursors from higher temperature regions of the furnace and also entrains the finer size constituents of the mix or charge. Because of the steady state operation of the submerged arc furnace, this gas generation is continuous.

In an open furnace, all the CO burns with induced air at the top of the charge, resulting in a large volume of high temperature gas. In a closed furnace most or all of the CO is withdrawn from the furnace without combustion with air.

Even if no gas is produced by the process, as in a melting operation in an open arc furnace, pollution occurs as a result of thermally induced air flow. The heat source of the furnace transfers heat to a column of air and a chimney effect ensues, with the induced air carrying fume from the heat source.

Additional generation of fume occurs at the furnace tapholes. In some cases gas issues from the taphole, but usually the fume results from air flow induced by heat transfer from the molten metal or slag. Because most furnaces are tapped intermittently, taphole fumes occur only about 10 to 20% of the furnace operating time.

Table II—Typical properties of silica fume from bag collector on silicon metal furnace

	I	II
SiO_2	96.09%	94.39%
Fe_2O_3	0.34	0.46
MnO	0.09	—
Al_2O_3	0.21	0.67
CaO	0.35	0.16
MgO	0.23	0.37
K_2O	0.59	—
Na_2O	0.07	0.12
SO_3	0.35	—
LOI	1.68	3.22

Surface area	25.9 M^2/g
Particle size range	0.25–0.02 microns
Average particle size	0.12 microns
Bulk density as generated	4–6 lb/ft^3
Bulk density (packed)	12–14 lb/ft^3
Color	Gray
pH	6.7
Oil absorption	85–95 lb of oil/100 lb
LOI 105°C, one hour	0.46%
LOI 1000°C, one hour	1.22%

Still another source of fume occurs in handling the metal after the taphole. Conveying the ladle, pouring, and casting give rise to additional heat-source-induced flow. Again this fume generation is intermittent.

Some processes conduct additional reactions in the ladle, such as chlorination, oxidation, gas mixing, and slag-metal reactions. In these cases there may be actual gas generation in addition to the treatment gas, and possibly gross ejection of a portion of the ladle contents. These ladle treatment reactions are batch processes with intermittent fume generation.

A minor source of pollution on furnaces with self-baking electrodes is the fume resulting from the electrode paste during heating and baking. This fume is usually directly vented.

Except for ejected mix particles, the fume size is generally below 2 microns; in the case of silicon furnaces, 80% by count is reported to be below 0.1 micron. In some cases, however, agglomeration does

Table I—Typical furnace fume characterizations

Furnace Product	50% FeSi	SMZ*	SiMn†	SiMn†	FeMn	H.C. FeCr	Chrome Ore Lime Melt	Mn Ore†–Lime Melt
Furnace type	Open	Open	Covered	Covered	Open	Covered	Open	Open
Fume shape	Spherical, sometimes in chains	Spherical, sometimes in chains	Spherical	Spherical	Spherical	Spherical	Spherical and irregular	Spherical and irregular
Fume size characteristics (microns)								
Maximum	0.75	0.8	0.75	0.75	0.75	1.0	0.50	2.0
Most particles	0.05–0.3	0.05–0.3	0.2–0.4	0.2–0.4	0.05–0.4	0.1–0.4	0.05–0.2	0.2–0.5
X-ray diffraction								
Primary	← All fumes were primarily amorphous →							
Trace constituents	FeSi, $FeSi_2$	Fe_3O_4, Fe_2O, Quartz, SiC	Mn_3O_4, MnO, Quartz	Quartz, SiMn, Spinel	Mn_3O_4, MnO, Quartz	Spinel, Quartz	Spinel	CaO
Chemical analysis (%)								
SiO_2	63–88[3]	61.12	15.68	24.60	25.48	20.96	10.86	3.28
FeO		14.08	6.75	4.60	5.8[illegible]	10.92	7.48	1.22
MgO		1.08	1.12	3.78	1.03	15.41	7.43	0.96
CaO		1.01	—	1.58	2.24	—	15.06	34.24
MnO		6.12	31.35	31.92	33.60	2.84	—	12.34
Al_2O_3		2.10	5.55	4.48	8.38	7.12	4.88	1.36
LOI		—	23.25	12.04	—		13.86	11.92
TC: as Cr_2O_3		—	—	—	—	29.27	14.69	—
SiC		1.82	—	—	—	—	—	—
ZrO		1.26	—	—	—	—	—	—
PbO		—	0.47	—	—	—	—	0.98
Na_2O		—	—	2.12	—	—	1.70	2.05
BaO		—	—	—	—	—	—	1.13
K_2O		—	—	—	—	—	—	13.08

* Si = 60–65%; Mn = 5–7%; Zr = 5–7%
[illegible]

occur, and the effective particle size may be much larger. In the dry state, the collected fume is very light, the bulk density varying from 4 to 30 lb per cu ft.

Chemical analyses of the fume correspond to oxides of the product being produced with the addition of carbon from the reducing agent and enrichment of SiO_2, CaO, and MgO, if present in the charge. Typical chemical analyses are given in Tables I and II.

Variation with Process

A. Continuous Operation

The majority of ferroalloy furnaces are termed submerged arc although the mode of energy release is in many cases resistive heating. They operate with continuous power and mix applications, except for periods of power interruption or mechanical breakdown of components. Operating times average 90 to 98%. The electrodes operate 3 to 6 feet above the hearth, and are submerged 3 to 5 feet below the mix level so that some heat exchange and mass transfer can occur between the reaction gas and the mix. The products produced in this type furnace are chiefly: (a) silicon alloys: ferrosilicon (50 to 98% Si) and CaSi; (b) chromium alloys: H.C. FeCr in various grades and FeCrSi; and (c) manganese alloys: standard FeMn and SiMn.

With silicon alloys, the fume produced is gray and contains a high percentage of SiO_2.[3] Some tars and carbon are also present arising from the coal, coke, or wood chips used. The SiO_2 is considered to result from the oxidation and disproportionation of SiO, a gaseous intermediate at reaction temperatures. As the percentage of silicon in the alloy increases, the SiO loss increases, so that a silicon metal furnace produces substantially more fumes than a 50% FeSi furnace at the same load. In addition, the higher ferrosilicon operations (75% Si and above) are known as "hot" operations; i.e., the gas exiting from the mix is at a high temperature and the furnace is subject to blows (frequently jets of gas issue at high velocity directly from the high temperature reaction zone). Higher silicon operations are also subject to hearth buildups of silicon carbide. Under these conditions, electrodes operate in a higher position and more fume can result.

Chromium furnaces also produce a white or light-colored fume. Analyses indicate SiO_2, MgO, and some iron and chromium oxides. Ferrochrome-silicon furnaces produce a SiO_2 fume similar to a ferrosilicon operation with some additional chromium oxides.

Manganese operations are major visual offenders from the emission standpoint since the fume is brown. Analyses indicate the fume to be largely a mixture of SiO_2 and manganese oxides. The latter presumably result from the vaporization of manganese or the production of a volatile intermediate.

Because manganese ores can contain a significant amount of water, as well as higher manganese oxides which release oxygen upon heating at temperatures below 1000°C, a manganese furnace can be subject to "rough" operation. Sudden release of gas can result in substantial mix ejection from the furnace. In furnace with self-baking electrodes, the relatively oxidizing atmosphere can result in "fluting" of the electrodes, furnishing a direct gas passage from the high temperature zone of the furnace, with increased fume emission.

Silicomanganese furnaces are subject to "slag boils," where slag rises up to cover the top surface of the charge, impeding mix delivery and uniform gas ascent.

B. Batch Noncontinuous

There are a smaller number of furnaces which do not operate with deep submergence of the electrodes and produce a melt batch which is usually removed by tilting the furnace. Mix additions and power input would usually be cyclic. Examples of products produced in this type of furnace are: (a) manganese ore-lime melt for subsequent ladle reaction with silicomanganese to produce M.C. and L.C. ferromanganese; (b) chrome ore-lime melt for subsequent ladle reaction with ferrochrome-silicon to produce L.C. ferrochrome; and (c) special alloys, such as aluminum-vanadium, ferrocolumbium.

As a result of sudden addition of mix containing volatile constituents (coal volatiles, moisture, aluminum) to a hot furnace container, substantial violent gas eruptions can occur. This is best exemplified by the manganese ore-lime melt furnace where momentary gas flow following mix addition can be five times the average flow (as contrasted with variation of 20% or less in a well-running submerged arc furnace). Temperature and dust-loading peaks also correspond to the gas flow peak.

In contrast, chromium ore-lime melt furnaces, to which little or no gas-releasing constituents are fed, are not subject to this violent behavior.

In some circumstances, solids or molten material ejected from the furnace continue to burn in the air, giving rise to collection problems.

Some of the special alloys are also produced by aluminothermic reactions without the addition of electrical energy. These reactions, if unconfined, give rise to momentary peaks of gas flow.

C. Raw Materials

It has been mentioned above that volatile materials in the furnace charge give rise to rough operation. Another significant contributor to rough operation is the presence of fines or decrepitating material in the feed. These materials promote bridging and nonuniform descent of the charge, resulting in gas channeling and bypassing. Sudden collapse of a bridge then gives rise to a momentary gas burst.

On some products, economics has dictated the use of raw materials with more fines or with more volatile matter. Each of these has an adverse effect on the smooth operation of the furnace, and consequently pollution may increase.

D. Operating Techniques

Differences in operating techniques can have a significant effect on fume generation. The average rate of furnace gas production is roughly proportional to electrical input, so that a higher load on a given furnace generally results in at least a proportional increase in fume emission. In some circumstances, fume

Table III—Approximate furnace gas generation (without combustion)

Product	(scfm/mw)
Silicon metal	140–150
50% Ferrosilicon	130–140
Standard ferromanganese	160–170
Silicomanganese	120–130
Ferrochrome-silicon	110–120
H.C. ferrochrome	80–90
Calcium carbide	70–80

(Based on gas saturated at 100°F, scf at 30 in. Hg, 60°F)

Table IV—Calculated gas flows

	Closed Furnace	Open Furnace (Low hood)
FeCrSi, 25 mw		
acfm at temp.	8,700 @ 1100°F	230,000 @ 430°F
scfm	2,900	135,000
50% FeSi, 50 mw		
acfm at temp.	20,000 @ 1100°F	410,000 @ 760°F
scfm	6,600	175,000

emission increases at a rate greater than the load increase, as a result of rougher operation and inadequate gas withdrawal capacity.

At a fixed load, even though the gas generation is almost constant, fume concentration and, hence, the weight per hour emitted can vary by a factor of 5 to 1. Operation with insufficient electrode submergence promotes increased fume emission. There is also some evidence that higher voltage operation, in addition to promoting a higher electrode position, alters the mode of energy release beneath the electrodes, increasing locally the energy supplied per unit volume, promoting higher local temperatures, and increasing the fume concentration.[4]

On some operations, silicon metal in particular, where stoking of the charge is necessary to break up crusts and partially agglomerated material and to cover up areas of blows, fume emission can be a function of how well and how often the furnace is stoked.

On other operations, where a mix seal and cover are used to allow collection of most or all of the furnace gas, direct venting and increased fume emission can occur if lack of mix prevents making a seal either because of poor mix placement or insufficient mix delivery. Direct venting can also take place during startup, shutdown, and "burndown" to remove undercover accumulations.

Loads on existing furnaces have been progressively increased as operating techniques improved and as more knowledge of transformer capacity became available. This tendency has taxed the furnace gas collection systems and, in the case of open furnaces, has certainly presented a more concentrated source of fume.

E. Maintenance Practices

Maintenance practices significantly affect fume emission on covered furnaces where accumulation of material under the cover and in gas offtakes and ducts reduces gas withdrawal capacity. Plugging of gas or water passages in cleaning apparatus results in reduced efficiency of gas cleaning.

Water leaks from electrode suspension equipment and other components above the furnace can result in some increase in gas flow (as steam or hydrogen).

Efficient collection of fume and dust in bag collectors is dependent on prompt replacement of broken bags and continued operation of the dust removal conveyors.

F. Design Practices

The design philosophy of dust collector installation also influences fume emission by the degree of weight given such factors as the collection efficiency of particular devices, provision of surge capacity, nature of standby facilities, ease of maintenance, method of fume disposal, method of cooling hot gas, and degree to which fume is intercepted by collecting hoods.

Variation with Furnace Type

A. Magnitude of Gas Flows

The volume of furnace gas generated by a submerged arc furnace smelting process depends on the stoichiometry involved in producing a particular alloy. Very approximate rates are illustrated in Table III.

Peak flows or momentary surges may be 40% higher than the preceding values. The amount collected is reduced due to any inadequacies of the collection system and to any downtime on the furnace.

The gas from a covered furnace normally analyzes 80 to 85% CO, except for manganese products where the CO content may drop to 55% (with an equivalent rise in CO_2 content). Poor cover operation can greatly reduce the gas quality.

When the furnace gas burns with air, as with an open furnace, a significant volume increase occurs, as high as a factor of 50 depending on the amount of induced air, in the volume to be treated for dust collection. Specific examples calculated for average flows at the gas offtakes are given in Table IV.

Without a low hood to restrict air influx, the volumetric rates shown for the open furnace would be increased even more, into the millions of cfm, depending on the building design. Measurements taken at the roof monitor level above an unhooded 16-mw silicon metal furnace showed the flow averages 1,030,000 acfm at 145°F to 160°F, with a fume load of 1500 to 1800 pounds per hour. At 160°F, this flow has a heat content 1,610,000 Btu per minute above the ambient of 62°F, or approximately 100,000 Btu per min. per mw.

Measured dust and fume loadings on the furnace gas from a covered furnace range from 5 to 30 grains per standard cu ft. Measured loadings above open furnaces range from 0.1 to 2 grains per standard cu ft. The measuring techniques have been outlined in a previous paper.[5]

B. Sealed Furnace

By sealing up the top of the furnace, including electrodes, mix spouts and access openings, all of the furnace gas can be collected with no fumes escaping and minimal air inleakage to increase the gas flow. Reliance is made on mechanical seals (stuffing boxes) around the electrodes and on sufficient mix height in the mix spouts to furnish seals.

C. Semi-Covered Furnaces

By placing a water-cooled cover on the furnace and feeding mix through the annulus around the electrode ("inner cone"), the major part of the furnace gas can be collected.* A slight negative pressure is usually maintained beneath the cover by means of the gas withdrawal system. In the 1930's, a sustained program resulted in the development of the semi-covered furnace, with a water-cooled cover and mix introduction around the electrodes. The furnace gas was originally recovered for use in chemical synthesis (methanol).

The use of this cover represented a significant improvement in pollution control. This development was subsequently applied to furnaces producing: CaC_2; FeSi 50%, 65%, 75%: FeCrSi; SiMn; FeMn; and H.C. FeCr.

The chemical use of the CO subsequently proved uneconomical. At Niagara Falls and Ashtabula, the gas is now used as fuel (about 300 Btu per standard cu ft) to calcine limestone. At Niagara Falls, some gas is sold for dry ice production. At Alloy, Marietta, and Sheffield, the gas is merely burnt at flare stacks. Numerous studies have been made on using the gas to generate power, but the investment required has not looked favorable.

The gas is usually cleaned in a Buffalo Forge centrifugal scrubber which is a multistage centrifugal fan with water spray nozzles. These scrubbers do a good job on cleaning the gas (except for some tars), and there is no significant discharge of particulates from the flares. However, existing designs are restricted to a capacity of about 2000 acfm and are higher power and clean water consumers than a venturi scrubber. The dilute liquid discharge can give rise to a water pollution problem or require extensive water treatment facilities and settling ponds.

Over the years, design improvements have been made in the covers; but, for manganese operations, in particular, they have not always proved satisfactory from a pollution standpoint, because enough gas can escape and burn around the electrodes to cause a pollution and maintenance problem. There is also some indication that the actual concentration of fume is greater in this escaping gas than in the collected gas.

On other products, such as ferrosilicon, ferrochromium, and calcium carbide, this approach has met with varying degrees of success from the pollution standpoint. The performance depends on furnace load, raw materials, efficacy of mix delivery and placement, adequacy of gas collection, condition of the cover, and other factors. As pollution regulations have become more stringent, the same performance, which was satisfactory previously, has become marginal.

The semi-covered approach is not entirely consistent with the observed distribution of gas evolution from a submerged arc furnace. Rather than being uniformly distributed across the surface of the charge, most of the gas appears to emanate close to the electrode from "reaction zones" concentric with the electrodes.

On ferroalloys, there can be a reduction in furnace operating time as a result of the cover (due to water leaks, structural failures, electrical arcing, undercover cleanout, scrubber maintenance).

The combination of these various factors has resulted in covers being removed from some existing furnaces. In addition, on some products the flexibility of open furnaces is favored; for example, new furnaces at Alloy and Marietta are open furnaces with dust collectors.

D. Open Furnace

The volume of gas to be treated from an open furnace depends on the specific hood design, if any; the vertical opening required for stoking the charge and the diameter of the furnace substantially fix the minimum capacity of the treatment system.

However, open furnaces, with provision for adding electrode sections under load, require a protected area for this operation normally necessitating a hood with a side withdrawal of combustion gases.

Older open furnaces, without provision for adding electrodes under load or requiring removal of the electrodes (packet type), normally vent directly through roof monitors or a large hole in the roof or stack placed directly above the furnace. The volume of gas in this case is much higher than if a hood were placed at a lower elevation (the temperature, in turn, has been reduced by the additional dilution).

Possible Emission Standards and Effects

From a design engineering standpoint, it would be desirable if specific emission limits (tpd and grains of particulates per standard cu ft) could be set for any pollution source. The current trend, however, as exemplified by the recommendations of the NAPCA, places emphasis on ambient air quality and somewhat subjective visual judgment of the emission appearance. Attempts to attain the ambient air quality desired have resulted in process weight criteria, where the allowable emission is a function of the amount of material being processed.

In this regard, it becomes apparent that the conventional use of collection efficiency (amount collected/amount fed to unit) to judge a particular collector installation is at best of secondary value, since even a 90% collection efficiency may not meet air quality standards. The scale of operation, the operating time of the collector, the fraction of the fume which is picked up by the collector hood, and the characteristics of the uncollected material can be of great significance.

The standards by which process emissions will probably be judged by regulatory agencies are given in items A-D.

A. Fallout

Settleable particulates (in general, material greater in size than 5 microns) should not exceed some specified limit per unit area. In a number of recent cases, the specific recommendation for power plants was for 30 tons per square mile per month for industrial areas and 15 tons per square mile per month for residential areas (each above background).

With regard to furnace process emissions, except for those operations which eject a substantial portion of mix and for calcium carbide operations, fallout is not felt to be a problem except within the plant itself.

B. Suspended Particulates

Keeping suspended particulates (in general, material less than 5 microns in size) in the ambient air below a specified value represents a far more difficult problem. The very fact that it remains suspended means that it is difficult to collect.

Current ambient air criteria are for a maximum concentration of suspended particulates less than 80 to 100 micrograms per cubic meter. To adequately meet this criteria, it is felt that furnace emissions at a given plant should not add more than, say, 60 micrograms per cubic meter, on the average, to the suspended particulates of the ambient.

The Ferroalloys Division design outlet loading for three recent collectors is below 0.035 grain per standard cubic foot (generally only a barely visible exhaust), which corresponds to 80,500 micrograms per cubic meter. Thus a dilution of about 1300 would be required to achieve 60 micrograms per cubic meter from a single source. Ten such sources close together would require a dilution of about 13,000. Under conditions of normal atmospheric turbulence and nominal wind velocity (7 miles per hour), this latter dilution would theoretically be achieved in less than ½ mile. Under inversion or low wind velocity conditions, however, ten barely visible exhausts might not meet the suspended particulate criteria within a mile of the emissions.

In some circumstances, a tall stack may aid in securing dilution and in meeting ambient air criteria.

C. Visual Appearance

An absolutely clear stack which cannot be visually detected is a desirable objective for avoidance of air pollution complaints. In many cases this objective cannot be practically or economically obtained. Because of their small particle size, ferroalloy fumes can be highly visible at weight concentrations where other types of discharge, such as those from power plants, are almost invisible.

The specific recommendation of several interstate conferences was that "pollutant discharges . . . shall not exceed a density of 40% opacity, such opacity being that which obscures an observer's view to a degree equal to an emission designated as No. 2 on the Ringlemann Smoke Chart . . ." This recommendation is basically a subjective shade or color comparison to judge a black smoke such as can emanate from a powerhouse and cannot be objectively applied to nonblack smoke, although a trained observer can obtain consistent results. The No. 2 Ringelmann Smoke Chart is a piece of white paper on which black lines have been drawn to obscure 40% of the white paper. Nominally, the 40% opacity is equivalent to allowing 60% of the transmitted light to pass through.

The visual appearance of a plume is dependent on both reflected and transmitted light and, hence, is affected by the brightness and uniformity of the sky, wind velocity, thickness through which the plume is observed, and moisture content. In specific installations, correlations have been obtained between optical transmission measurements and visual appearance.

Fig. 2—High energy wet scrubber installation on 30-mw SiMn furnace.

Some wet collector installations will give rise to a steam plume, which gives total obscuration at the stack exit. Steam is not likely to be considered a deleterious pollutant, so that it is suggested that as long as any color cannot be distinctly observed the exhaust appearance would be satisfactory. The color

Table V—Allowable discharge from 20-mw open 75% ferrosilicon furnace

	A	B
Mix	21,300 lb/hr	21,300 lb/hr
Electrodes	300	300
Air stoichiometrically required to oxide CO	24,400	
Air stoichiometrically required to oxide SiO	1,800	
Free moisture	−1,500	−1,500
Total	46,300 lb/hr	20,000 lb/hr
Allowable discharge (from formula)	31 lb/hr	18 lb/hr

Table VI—Collector characteristics to satisfy conditions of Table V

	A	B
Avg. inlet loading	1.9 grains/scf	1.9 grains/scf
Avg. outlet loading	0.031 grains/scf	0.018 grains/scf
Min. collection efficiency required	98.4%	99.1%

visibility threshhold for manganese or silicomanganese fume has been judged to be in the range of 0.02 to 0.03 grains per standard cu ft.

For dry exhaust this outlet loading would normally give a barely visible plume (below Ringlemann No. 1, or "20% opacity"), which should be satisfactory from a visual standpoint.

D. Process Weight Criteria

The relative strictness of the application of process weight criteria for air pollution control can be illustrated by calculations based on the current New York State regulations for allowable emissions for Environmental Rating C. For process weight rates of flow up to 100,000 pounds per hour, the following formula applies:

$$E = 0.024P^{0.665}$$

where E = maximum weight discharge of contaminants in pounds per hour,

and P = process weight in pounds per hour.

The process weight comprises all materials introduced into the process, excluding uncombined water and dilution or cooling air. Carbon dioxide and water vapor are not considered contaminants. Some question exists as to whether the process weight should include the air requirements for stoichiometric combination with the carbon monoxide and silicon monoxide arising from the process.

For a 75% ferrosilicon open furnace operation at 20 mw, calculations based on the two interpretations for the process weight are given in Table V.

Using an estimated fume quantity of 1,800 pounds per hour and a gas flow of 110,000 scfm, the characteristics that result for the collector are given in Table VI.

Taphole fumes have not been included in the above discussion because of their intermittent nature. An instantaneous rate of 3 pounds per minute for a 15-minute tapping period every 96 minutes gives an average value of 28 pounds per hour arising from the taphole. While this amount is not significant with respect to the fume emanating from the furnace top, it is of the same order as the emission limit determined by the above criteria.

METHODS OF SOLUTION

Process Changes

Alternate methods of production or modification of existing processes could result in significant fume reduction. Conducting all or part of the reduction reaction outside the smelting furnace may at least result in easier fume collection. Conversion of present batch processing to continuous operation should smooth out gas evolution and result in a smaller collector. Past studies of alternate processes have often failed to show significant economic advantages. However, fuller consideration of the fume collection aspects should stimulate additional work in this regard.

Ultimate collection of taphole and ladle fumes may require different methods of ladle handling, reduced operating flexibility, and specialized mixing equipment.

Raw Material Selection and Treatment

Improved raw material sizing and quality would probably result in some marginal improvement of current operations from the pollution standpoint. Current economics of production do not indicate this approach can be pursued to any degree.

Drying of ore and pretreatment of raw material to remove volatile materials or to agglomerate into a more uniform-sized feed are desirable for improved furnace operation, but have never been justifiable for U.S. ferroalloy operations. The Sauda, Norway, plant of Union Carbide Corp. feeds a mixture of sized and sintered ore to its large manganese operation; this is felt necessary for satisfactory performance of a large covered furnace on standard ferromanganese.

Table VII—Examples of furnace wet scrubbers

Collector	Open Furnace—Low Hood			Semi-closed Furnace
	I	II	III	IV
Original completion date	1967	1968	1968	1965
Furnace rating for collector design	25 mw	30 mw	30 mw	45 mw
Furnace product	FeCrSi	SiMn	H.C. FeCr	50% FeSi
Measured collection efficiency, avg.	92.6%	98.6%	98.2%	98.4% (particulates) 79% (organics)
Inlet loading, grains/scf	1.43	1.31	1.07	4.93
Outlet loading, grains/scf	0.106	0.017	0.019	0.08
Design volume at furnace hood	230,000 acfm	255,000 acfm	210,000 acfm	—
Design temp.	430°F	620°F	590°F	—
Actual duct or offtake temp.	500 to 570°F	490 to 550°F	480°F	1100 to 1200°F
Design volume handled by fans or blowers	194,000 acfm	196,000 acfm	196,000 acfm	6500 scfm
Operating pressure drop across collector, inches water	55	57	57	72 to 80
Installed H.P — fans	2600	2800	2800	600
— auxiliaries	50	50	50	—
Tons/day collected dust	11 to 13	14 to 17	11 to 17	5 to 8
Tons/day uncollected emission	0.75 to 1	0.20	0.26	None
Water circulation	1800 gpm	1800gpm	1800 gpm	75-100 gpm
Water usage	310 gpm	350 gpm	350 gpm	75-100 gpm
Problems	(1) System falls 25% short of design flow. (2) High fan outage (3) Necessity to add lime to neutralize scrubbing liquid	(1) High fan outage.	(1) High fan outage.	(1) Continuous kerosene injection necessary for blowers.

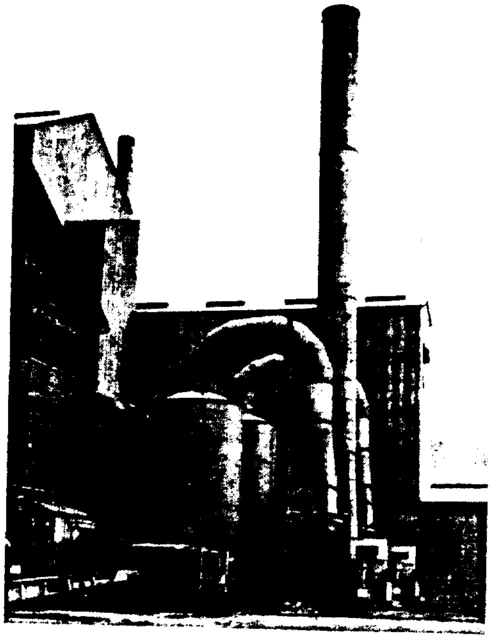

Fig. 3—High energy wet scrubber installation on 25-mw FeCrSi furnace.

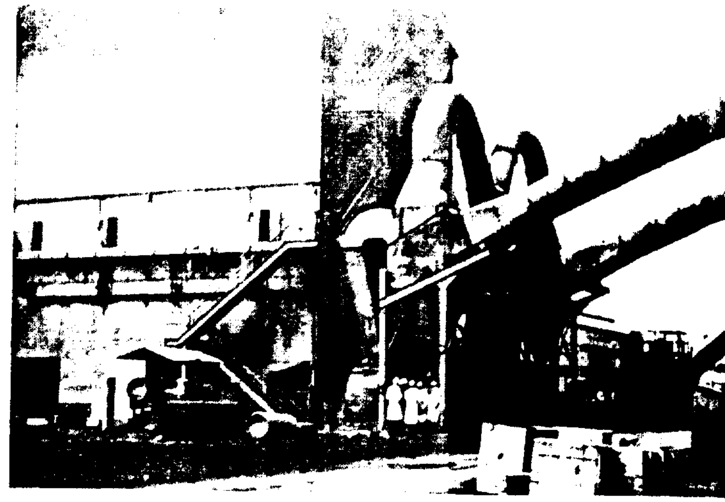

Fig. 4—Bag collector on 12-mw Si metal furnace.

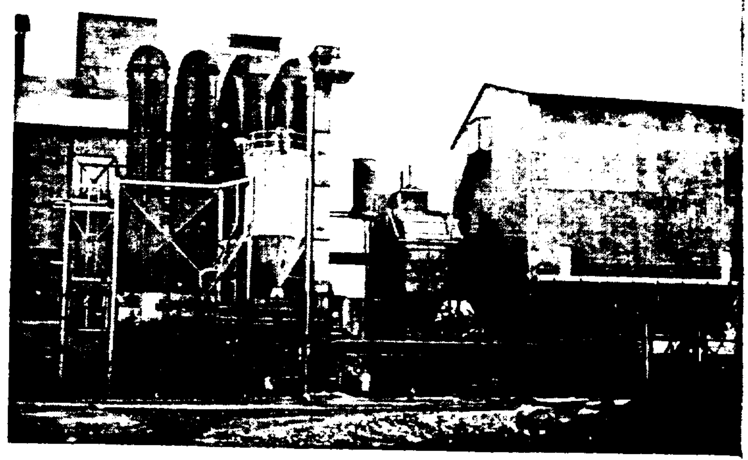

Fig. 5—Bag collector and cooler on 18-mw lime-manganese ore melt furnace

Equipment

A. Open Furnaces

1. Furnace Type

(a) Hooded. Modern open furnaces require a hood to protect the superstructure and the electrode column components. A hood, at least the diameter of the furnace shell, with the minimum opening between the hood and operating or charging floor required for mix placement or stoking, and an air inlet velocity of at least 3 fps, have been the criteria for recent installations. Sufficient hood depth must also be provided to assure that combustion is substantially complete within the hood.

(b) Packet Type. Packet type electrode furnaces need crane access to add new electrode assemblies. Hooding at a low level to minimize gas dilution would require a movable hood of complicated construction, with high maintenance. In addition, the hood, by redistributing the flow of air, may expose components under the hood to higher temperatures than they experienced before hooding.

The alternate of collecting the fume at a higher level above the crane requires greater gas handling capacity and a larger dust collector.

2. Dust Collectors

(a) Wet. The only currently feasible type of wet collector for cleaning the large gas volumes from open furnaces is the high energy or venturi type of scrubber. With required pressure drops on the order of 60 inches water gauge, the power consumption becomes enormous, approaching 10% of the furnace rating (for a low hood design). There are many forms of the venturi or high energy scrubber for this application, but Union Carbide Corp. experience is confined to one type.[1]

Most venturi designs allow recirculation of scrubbing liquor, so that water consumption is reduced to that evaporated into the gas plus that exiting with the concentrated solids steam. Thus, unlike the present Buffalo Forge scrubber with a once-through passage of water, the net liquid outflow is substantially reduced.

The venturi has the advantage of being able to absorb gas temperature peaks by evaporating more water.

The exact size limitations on a venturi depend on the specific design; but ultimately, difficulty in securing adequate water distribution across the throat or restriction is encountered, so that recourse to multiple units is required.

Recent wet scrubber installations are summarized in Table VII. Typical installations are shown in Figs. 1, 2, and 3. Numerous shakedown problems were encountered but will not be enumerated here, other than to mention the required addition of overflow weirs to reduce buildup problems at the dry-wet interface and the addition of sound-suppression devices in the stacks. While satisfactory gas cleaning has been obtained, overall operation has been limited by buildup on fan blades, in turn leading to fan unbalance. The period between fan outages for cleaning has averaged two weeks.

For a ferrosilicon or ferrochrome-silicon operation, substantially all of the sulfur in the reducing agent appears in the gas phase, and a corrosion problem occurs in any liquid recycle system unless neutralizing agents or special materials of construction are used.

The fluid waste from the above installations is fed into previously existing thickeners and settling ponds. Lime additions have proved desirable in order to increase the settling rate.

(b) Dry, (1) Bag. Cloth-type filters* do an effective job of cleaning the combustion gases from open furnaces so long as the filter media remain intact. Power use is usually 1/6 to 1/3 that of a venturi scrubber.

Typical bag collector installations are shown in Figs. 4, 5, and 6. Each of these installations is the pressure-type bag house, with the fan on the dirty gas side, to simplify the collector housing construction and to allow access into the collector during operation. Recent bag collector installations are summarized in Table VIII.

Because of temperature limitations on the cloth (500°F for treated fiberglass), the gas must often be cooled by passing through heat transfer surfaces or by dilution. Cooling by water spray injection is possible, but can lead to control complications and possible blinding of the bags.

To prevent carry-over of burning mix particles, a mechanical collector ahead of the bag house is desirable.

The amount of gas a cloth filter can handle when operating on silica fume without bag blinding is a maximum of about 2 acfm per sq ft of filter area. This limit results in a large number of bags, up into the thousands, in order to treat the combustion gas from an open furnace. The resultant assembly covers a large area and contains a large number of moving parts, since the bags must be flexed or shaken to discharge the dust. Our experience with fiberglass is that gentle bag shaking is preferable. The multiple points of dust discharge give rise to complexities in conveying the collected dust.

The possibility of unequal bag life gives rise to a problem of constant bag replacement. To assure reasonably continuous operation of the collector, it is desirable to divide the collector into compartments and provide some excess capacity so that a portion can be shut down for maintenance.

A significant problem associated with use of fiberglass bags on silica fume collection is the buildup of electrostatic charge, which in turn leads to a high residual pressure drop across the bags.

The application of bag filters to ferroalloy furnaces abroad appears to have been confined to France.*

(b) Dry, (2) Electrostatic Precipitator. The electrostatic precipitator has the theoretical advantage of having the lowest pressure drop of any large volume device capable of removing micron size fume from gas streams, and hence the lowest power and operating costs. It is able to operate at a higher temperature than existing bag filters.

Unfortunately, most ferroalloy fumes at temperatures below 500°F have too high an electrical resistivity, greater than 1 x 10[illegible] ohm-cm, considered the maximum for satisfactory operation. The resistivity is possible in an acceptable range only if the gas temperature is maintained above 500° to 600°F. Another alternate is to humidify the gas to about 20% moisture content and/or add conditioning agents such as ammonia. The order of magnitude of resistivities is illustrated in Table IX. Because of the possibility of operation below the applicable temperature range, either due to normal process conditions or to operation of the furnace below design load, conditioning by humidification would appear to be necessary. Such humidification by water sprays requires good water atomization and sufficient residence time and heat to obtain vaporization, so that a conditioning tower physically bigger than the precipitator might be required. Stainless steel construction would be required for ferrosilicon or ferrochrome-silicon operations. The alternate use of steam is feasible only if low cost steam is available.

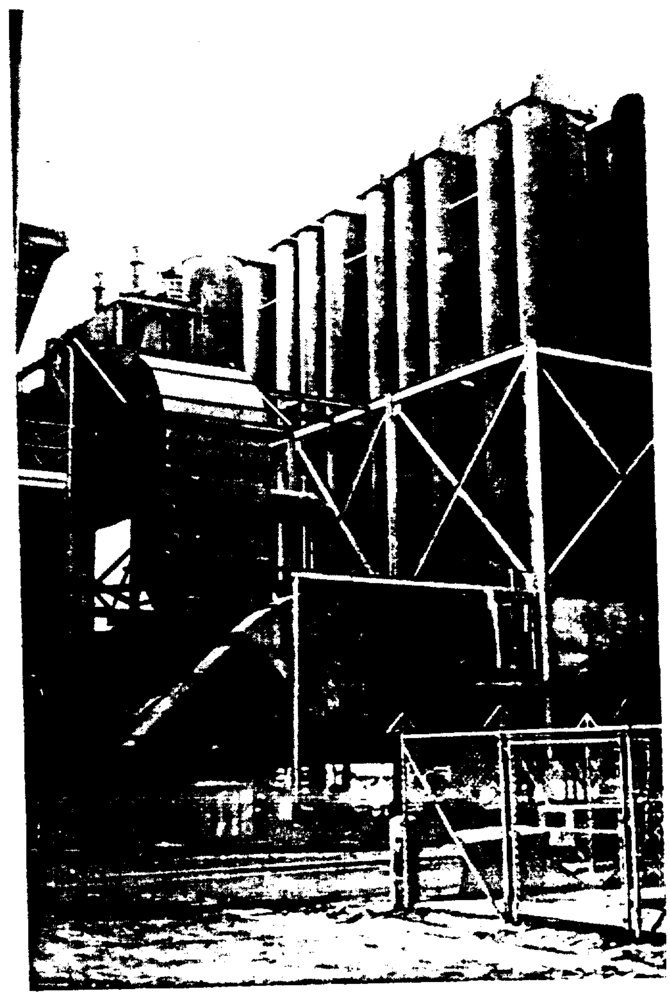

Fig. 6—Cooler and fan installation on 18-mw lime-manganese ore melt furnace.

The resistivity problem can also be overcome by using a wet precipitator, in which the plates are continually washed by a film of water. The water usage for this approach appears to be greater than that for a wet scrubber without recycle.

Table VIII—Examples of furnace bag collectors

Collector	V	VI	VII	VIII
Original completion date	1963	1967	1969	1969
Revisions completed	1965		—	—
Furnace rating for collector design	12 mw	18 mw	20 mw	10.5 mw
Furnace product	Si and FeSi	Lime-manganese ore melt	FeMn-Si	SiMn
Area of radiant tube cooler	None	57,100 sq ft	26,000 sq ft	None
Design volume at furnace	180,000 acfm	630,000 acfm (peak)	254,000 acfm (peak)	100,000 acfm
Design temp. at furnace	450°F	1700°F (peak)	860°F (peak)	400°F
Design volume at collector	180,000 acfm	250,000 acfm	185,000 acfm	125,000 acfm
Design temp. at collector	450°F	400°F (peak)	500°F (peak)	325°F
High temp. bypass set at	500°F	500°F	500°F	450°F (tempering valve)
Average operating temp.	350-450°F	250-350°F	—	—
Operating pressure drop across collector	12-15 in. water	4-8 in. water	—	5-9 in. water
Tons/day collected dust	5-10	15	7 (estimate)	4-6 (estimate)
Bag cleaning	Shaking	Shaking	Shaking	Shaking
Cycle	Continuous	Intermittent	Continuous	Continuous
Cleaning cycle	8 min. every 30 min.	4 min. every 100 min.	—	6 min. every 90 min.
Number of isolatable compartments	1	1	8	6
Installed motor power — fans	900 hp	800 hp	900 hp	500 hp
— auxiliaries	100 hp	100 hp	100 hp	45 hp
Bags, graphite and silicon-treated				
Number	1024	1152	1152	864
Size	← 11.5 in. diam x 30.5 ft long →			
Bag failures	7 per week	None		
Problems	(1) Electrostatic charge. (2) Continuing nature of bag failures. (3) Lack of compartment isolation.	(1) Bypass maintenance. (2) Flow of dust from storage bin.		

Electrostatic precipitators have been installed on open furnaces producing silicon, ferrosilicon, ferrochrome-silicon, and silicomanganese. Definitive information has been reported for Valmoesa[1,10,11] and Weisweiller.

(c) General Comments on Collector Type. There appears to be no fundamental reason why any of the three types of collector—venturi, bag, or electrostatic precipitator—cannot be made to work on open furnace fume collection. It is difficult to make a preeminent case for any one type of collector, and any financial comparisons of operating costs depend on the particular plant circumstances and attitude or preference of the estimator. Within the existing maintenance and operating framework of the Ferroalloys Division, however, it is currently felt that the bag collector will probably function more satisfactorily as an air pollution control device.

B. Covered Furnaces

1. Cover Type

(a) Semi-Covered. The history and general characteristics of the semi-covered furnace as developed by the Ferroalloys Division have been previously discussed. It will only be reiterated here that this approach, while collecting a majority of the fume, in the light of current regulations is satisfactory from a pollution abatement standpoint only in certain specific circumstances.

If immediate improvements must be made in existing semi-covered furnaces, a possible design expedient is the provision of another collection system on a secondary hood placed above the furnace.

(b) Completely Sealed. The sealed furnace, which has a cover including sliding seals around the electrodes and mix spouts, is primarily a European development. It has thus far been applied only to calcium carbide, pig iron, standard ferromanganese, and silicomanganese. (Phosphorus could also be mentioned, but is excluded here because of the marked difference in design and operation.) All inspections of such furnaces have indicated a satisfactory appearance from the pollution viewpoint.

Sealed covers have been designed and manufactured by the major furnace component vendors.[13-14]

A sealed cover has been installed on a 30-mw standard ferromanganese furnace at Sauda, Norway, and is reported to be performing satisfactorily.

Sealed covers are difficult to adapt to existing furnaces because:

1. They are not applicable to unmachined prebaked amorphous carbon electrodes.
2. Sufficient headroom does not exist.
3. Substantial revision of the secondary electrical components is required.
4. A guided electrode column is desirable.
5. Substantial revision of the mix delivery may be necessary.

Thus, application of a sealed cover to an existing furnace involves not only supplying seals, but may also include providing a new superstructure, new electrode columns, and a new mix delivery arrangement, which are almost the equivalent of a new furnace.

(c) Gas Collection Sleeves. A modified cover, incorporating electrode seals, but covering only the "reaction zones" around the electrodes and leaving the outer rim of the furnace open, has been developed.[15] This approach, called gas collection sleeves or smoke rings, has the advantages of collecting gas in the observed region of maximum generation, of allowing partial stoking of the mix, and of being cheaper than a complete cover. Mix feed to the center of the furnace is through a sealed mix spout, while on the outside of the sleeves a head of mix must be maintained to achieve a gas seal.

Initial installations were made at Tenn-Tex, Houston, Texas, on ferromanganese furnaces. These installations suffered from the fact that they were made on existing electrode suspensions on open furnaces which used prebaked electrodes, so that graphite electrodes were necessary to make a seal.

Subsequent installations have been made on calcium carbide[16] and silicomanganese furnaces, for which reported performance has been satisfactory.

Indications are that if a high quality gas (300 Btu per standard cu ft or better) is to be collected only 80 to 90% collection can be attained. Improved fume collection can apparently be obtained at the expense of gas quality, but lack of control of air inspiration could lead to an explosive mixture.

Difficulties in installing gas collection sleeves in existing furnaces, even for an experimental trial, are similar to those noted above for the sealed cover.

2. Gas Cleaners

(a) Wet, (1) Disintegrator Type. The conventional Buffalo Forge or Tiessen scrubber, which has been described previously, does a good gas cleaning job when properly maintained. It has the additional advantage of developing a slight pressure head (about 2 inches water gauge) so that if the furnace gas is to be flared, no additional fan or blower is required. However, the capacity limitation and high water and power consumption make it uneconomical for most new furnace installations.

(a) Wet, (2) Venturi. The high-energy type scrubber[17] has also been installed on CO gas cleaning installations. The required pressure drops are high, but power and water consumption are less than the Buffalo Forge or equivalent mechanical energy scrubber.

The characteristics of a typical installation are included in Table VII.

The venturi itself merely serves to wet and agglomerate the fume. Actual separation from the gas takes place in a mist eliminator or inertial collecting device, which obviously must have a high collection efficiency.

As with any wet scrubbing system, the gas is substantially saturated with water, so that any subsequent cooling of the gas will lead to condensation.

An alternate venturi system is the multiple stage venturi. In addition, the cleaning energy can be added by pumping the liquid phase rather than the gas phase.[18] Such an installation is used on the 30-mw ferromanganese furnace at Sauda.

(b) Dry, (1) Ceramic Tube. A successful dry collector[19] on CO gas from calcium carbide furnaces has been developed in Germany by Suddeutsche Kalkstickstoff-Werke (SKW). It consists of a number of parallel compartments containing multiple ceramic tubes operating at 200° to 600°C (above tar condensation temperatures) on the outside of which the dust collects. The dust is periodically removed by reverse flow of cleaned gas.

It is also necessary to install a tar condenser or scrubber after the SKW collector if the gas is to be used.

Size limitation on the ceramic tubes and the capital cost probably limit application of the SKW collector to cleaning furnace gas from covered furnaces where a dry product is desired.

(b) Dry, (2) Electrostatic Precipitator. The electrostatic precipitator is a possible CO gas cleaning device, but has found limited ferroalloy application, probably because of cost and its unknown performance.

(b) Dry, (3) Bag Collector. It would also be possible to use a bag collector to clean CO gas, but no applications on ferroalloy furnaces are known.

C. Inadequacies of Superficial Solutions

Many relatively simple equipment solutions normally employed for coarse particle collection have been proposed from time to time. Such units include dry and wet cyclones, spray towers, low pressure drop wet scrubbers, mix beds, wet packed beds, and other low energy consuming equipment. The inadequacy of such units on furnace fume has been repeatedly demonstrated.[1,8,10]

These low cost units are primarily inertial collectors; hence, they may do an adequate precleaning job on coarse material. But, unless chemical reaction of the fume with the scrubbing liquor furnishes an additional driving force, collection of micron size material will be poor.

D. Additional Techniques

There are possibilities that new techniques may be developed in addition to the approaches noted above. However, there is no realistic evidence at present to indicate that equipment more economical than the approaches noted above will be commercially available in the near future.

E. Subsidiary Aspects

1. CO Utilization

If the CO produced from the smelting reactions could be regarded as more than a waste product, the incentive for gas collection would be increased. There are basically three factors which have limited its use: (1) the furnace gas must be additionally purified to yield a pure CO, (2) other components for chemical synthesis are not available at specific plant locations, and (3) in the absence of gas storage, several furnaces must be connected up to insure a continuous output equivalent to the average production of one furnace.

Table IX—Measurements of fume resistivity—ohm-cm 200°–300° F temp. range

Product	Without Conditioning	With Conditioning of Gas to 20% Moisture
SMZ	8.7×10^{13}	8.5×10[illegible]
50% FeSi	1.2×10^{13}	9.3×10[illegible]
FeMn	4.7×10^{11}	3.2×10[illegible]
FeCr	9.4×10^{10}	2.1×10[illegible]
SiMn	1.3×10^{10}	2.4 [illegible]

Table X—Total annual costs, $/acfm at furnace hood

	Capital @ 10%	Operating	Total
Venturi	0.24-0.36	0.40-0.60	0.64-0.96
Bag Filter	0.29-0.36	0.30-0.40	0.59-0.76
[illegible]	0.38-0.42	[illegible]	[illegible]

2. **Dust Utilization**

Sale of silica fume recovered from the silicon metal furnace bag collector has partially covered the collector's operating cost (not including depreciation). However, it has not been possible to obtain a market for all of the silica fume collected. Most of the other fumes, because of contamination, probably do not have any sales outlet, but could be at least partially used by recycling to the furnace to the extent that impurity buildup is not deleterious. Agglomeration costs may be excessive, and a promising method of recycle is the hollow electrodes,[8] which can use fine material directly. The hollow electrode, in turn, requires a dependable source of furnace gas or inert gas as a pressurizing medium.

3. **Heat Recovery**

The burning of furnace gas on the surface of the mix in open furnaces or flaring it from stacks in the case of covered furnaces represents an energy loss equivalent to 20 to 35% of the power input to the furnaces. The possibility of economically recovering this energy, even by burning the CO in a power plant, appears remote (except for limestone calcination). A boiler tube-type roof over an open furnace, using the furnace hood to generate steam, might find some application if there were use for low pressure steam.

F. Taphole and Post-Taphole Fumes

An effort is made on present furnaces to remove fumes from the vicinity of the taphole by inducing about 25,000 to 50,000 acfm through a duct and fan system. The actual gathering job can be ineffectual because, if crane access is required at the taphole, the withdrawal is consequently attempted from the side. To adequately remove this fume at the source requires hooding above the ladle, meaning elimination of crane access or provision of a movable hood.

Similar restraints would exist in attempting to collect fumes close to the source in casting and in conducting ladle reactions.

An alternate approach would be to leave these operations as they are and use the building monitor to collect these fumes. While this approach may be significantly more expensive, it may be the only practical way to achieve cleanup of these sources. Care must be taken to assure sufficient volume is treated so that dissipation of heat from solidifying metal and other sources is satisfactorily handled.

G. Disposal of Dust

Barring possible reuse or sale of the collected fume, additional costs must be incurred in its disposal. If dry, it must be wet down and trucked away; if in a slurry, pumped to a settling pond or thickened and filtered to produce a cake, which latter would be trucked away.

ECONOMICS OF DUST COLLECTION

Capital Costs

The cost of a fume collection system is ordinarily proportional to the volumetric rate of gas handled and is relatively insensitive to fume loading. To secure a minimum cost installation, therefore, the general principle of collecting the fume as close to the source as possible has usually been followed. This principle at times may be in conflict with desired operating flexibility.

Particularly with open furnaces, the fume collectors are already so large that there is only marginal saving in dollars per cubic feet per minute in going to large collectors. Additional capacity is obtained by adding more bags in the case of a cloth filter, more plates in the case of a precipitator, and more or longer venturis in the case of a wet scrubber, each addition being directly proportional to the added capacity. Space requirements are likewise almost directly proportional to gas handling capacity. However, some savings may occur in fans, power supplies, and auxiliaries.

Installation of a dust collector on an existing furnace also may require improvements on the furnace itself. Under these circumstances, additional expenditures on the furnace itself may often accompany the dust collector expenditure. In many cases, present furnace hoods are inadequate or nonexistent, and a new hood must be part of any collector installation. Restriction and redirection of air flow as a result of adding a collector may require modification or replacement of certain furnace components.

The possibility of obtaining savings by manifolding furnace hoods into one collector does not appear good. Because of the continuous operation of the majority of furnaces, the same total collector capacity and space requirements would have to be provided and, as noted above, the cost would not be significantly reduced. Standby capacity would be necessary to avoid simultaneous shutdown of several furnaces due to failure of the one collector. Balancing of flows and maintenance of expensive large diameter valves are additional problems associated with manifolding furnace hoods. If any use is ultimately found for the collected fume, mixing of the gases from different products would be a disadvantage.

A better possibility of savings by manifolding would occur in the cleaning of intermittent gas loads such as taphole fumes. In the infrequent case of furnaces which have low scheduled operating time and can definitely be scheduled to operate alternately, manifolding results in lower capital investment.

Any collector installation, because of space requirements, may require relocation or abandonment of existing facilities such as tracks, utility ducts, and storage areas. In locations where space is a premium, significant additional cost may be involved. The structure of existing buildings is generally not sufficient to allow overhead placement of collectors of the size required.

Comparison of collector costs for different new furnace alternates, such as sealed versus open, is not meaningful unless the total installation cost is compared. The comparison is not necessarily in favor of one type or another, but depends on the particular installation.

Installed costs of fume collectors depend on the particular installation and the degree to which utility services are available. In general, the capital cost of the venturi scrubber (excluding effluent treatment) is least and that of the precipitator the greatest. Estimated costs, in terms of dollars per acfm for units recently (1969) installed or planned on open furnaces, excluding the furnace hood and interior ductwork, have been: venturi scrubber: $2.40–3.60; bag filter: $2.90–3.60; electrostatic precipitator (with conditioning): $3.80–4.20.

The purchase or quoted price of the collecting equipment has been about one half of the installed cost. The above comparison does not include consideration of tube-type coolers for the bag filter; it also does not include the liquid waste disposal system for the wet scrubber.

Obviously, the accuracy of the estimated costs depends on the degree to which any proposal has been defined and detailed. Past experience on dust collector installations has indicated that cost has increased as the project developed, and perhaps increased in scope, and more realistic criteria became available.

Operating Costs

Operating costs of dust collectors consist of power, maintenance, supervision and inspection, and dust disposal. It is assumed that all installations will be sufficiently automated so that no operator is required other than on a part-time basis to assure the equipment is functioning. At the present time only the fume from silicon metal furnaces has a partial sales outlet so that, on an overall basis, prospects for a credit from sale or reuse of dust are minimal.

In the case of wet scrubbers, additional costs may be incurred for lime or flocculating agents to secure settling of the liquid waste.

If, to furnish a basis for discussion, a $100,000 to $150,000 per year operating cost is taken for a venturi, handling 250,000 acfm at 500°F at the furnace, the annual operating cost per acfm at the furnace hood becomes $0.40 to $0.60 per acfm. For a precipitator handling the same volume, a $50,000 to $75,000 per year operating cost would correspond to $0.20 to $0.30 per acfm.

For the bag collector, a $75,000 to $100,000 per year operating cost yields $0.30 to $0.40 per acfm. Replacement of bags on a two-year schedule is included in this operating cost.

If invested capital in the collector is taken as being worth 10% annually and if the installed costs per acfm of the preceding section are used, one arrives at the data in Table X.

The analysis in Table X shows no preeminent advantage for any of the three methods. It should be pointed out that maintenance and operating costs for the precipitator are more speculative. It should also be emphasized that individual plant conditions and power costs may tend to favor a particular system.

Application of the costs in Table X to a closely hooded silicon metal furnace (15 mw producing about 10,000 net tons per year, 250,000 acfm dust collector, $0.75 per acfm), yields an equivalent cost of about 1¢ per lb product, which represents about 6% of the current selling price. Application to an unhooded furnace could yield an equivalent cost of 2¢ per lb or greater.

CONCLUSIONS

Practical techniques have been developed for ferroalloy emission control, but substantial costs are involved.

It has become apparent that considerable additional effort and expenditures must be devoted to the control of ferroalloy furnace emissions. No standard solutions appear to be available because of the diversity of process and equipment, and each application must in the final analysis be treated on an individual basis. There do not appear to be any technological breakthroughs which would significantly reduce the expenditures required.

Major future developments will probably consist of: (1) process modifications, (2) reduction in the amount of gas actually handled and (3) alteration of fume characteristics to enable use of lower cost equipment.

Evolutionary developments will probably include: (1) greater reliability of collection devices and (2) some improvement in collector capability and performance.

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