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AIR POLLUTION EMISSIONS AND CONTROL TECHNOLOGY: FERROALLOY PRODUCTION AND ALLIED INDUSTRIES

by

K.H. Mah
Mineral and Metal Processes Division
Engineering Assessment Branch
Air Pollution Control Directorate

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NOTE TO READERS

The federal government is empowered to publish national guidelines on the emission of air contaminants from sources of any class. An important part of the development of such guidelines is the preparation of a technical review of the industry or commercial sector under consideration. The review includes a geographic profile of the industrial or commercial activity, a description of the principal processes used, the identification of emissions and emission sources, and an evaluation of the available abatement technology and control strategies.

This publication is the result of such a review and serves two main purposes. The first is to provide the background data necessary for establishing federal guidelines for new sources of emissions. In recommending national guidelines, the government adopts the view that new plants should achieve low emission levels through the installation of advanced control technologies at the time of initial plant construction to provide for minimum degradation of air quality and appropriate environmental protection for future generations of Canadians.

The second purpose is to serve as a source of information on applicable control technologies for use by provincial and municipal agencies in the development of their abatement programs for existing emission sources. Existing plants, although excluded from the guideline recommendations per se, should be subject to control on an individual basis as local conditions require. This allows provincial control agencies to weigh such variable factors as industrial density, the nature and quantities of specific plant emissions, meteorology and topography, engineering feasibility and local socio-economic conditions.

This report is the technological review of the ferroalloy production and allied industries.

ABSTRACT

This report provides the technical background for the ferroalloy production and allied industries. It includes emission data for 1975 as well as an assessment of available control strategies that could be applied to both new and existing operations in these industries.

The industries produce ferroalloys (including silicon metal and calcium carbide), fused alumina and silicon carbide. Ferroalloys are mainly used in alloying steel, while fused alumina and silicon carbide are extensively used in bonded abrasives and coated abrasives. The major non-abrasive use is in the production of refractories.

Emissions of particulates and sulphur dioxide from the industries during 1975 were calculated at 31 300 tonnes and 9 956 tonnes respectively. Estimates for 1979 were 11 251 tonnes and 8 434 tonnes respectively. The reductions are partly attributable to large expenditures in air pollution control invested by Quebec ferroalloy plants and Ontario fused alumina plants. One ferroalloy smelting furnace in Quebec and the silicon carbide plants still remain uncontrolled.

RÉSUMÉ

Le présent rapport contient les données techniques relatives à la production des ferro-alliages et aux industries connexes, une estimation des émissions en 1975 ainsi qu'une évaluation des stratégies de contrôle susceptibles d'être employées dans les installations nouvelles et existantes de ce secteur.

Ces industries produisent des ferro-alliages (y compris du silicium et du carbure de calcium), de l'alumine fondue et du carbure de silicium. Les ferro-alliages servent surtout à fabriquer les aciers spéciaux tandis que l'alumine fondue et le carbure de silicium sont largement utilisés comme abrasifs agglomérés et rapportés et dans la fabrication des réfractaires.

On a calculé que les émissions industrielles de matières particulaires et de dioxyde de soufre s'étaient élevées à 31 300 et 9 956 tonnes, respectivement, en 1975, et à 11 251 et 8 434 tonnes en 1979. Cette diminution est en partie attribuable aux dépenses considérables engagées par les usines de ferro-alliages du Québec et celles d'alumine fondue de l'Ontario pour réduire la pollution atmosphérique. Aucune mesure corrective n'a été prise par les usines de carbure de silicium, et il en reste de même pour une fonderie de ferro-alliages au Québec.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

METRIC CONVERSION FACTORS

To convert Imperial Units	Multiply by	To obtain SI Units
British thermal unit (Btu)	1054	Joule (J)
British thermal unit (Btu)	0.293	Watt (W)
Cubic foot (ft^3)	0.0283	Cubic metre (m^3)
Degrees Fahrenheit	5/9 (°F-32)	Degrees Celsius (°C)
Foot (')	0.3048	Metre (m)
Inch (")	0.0254	Metre (m)
Inch (")	2.54	Centimetre (cm)
Inches of water	248.8	Pascal (Pa)
Pound (lb)	0.4536	Kilogram (kg)
Ton, short	0.9072	Tonne

1 INTRODUCTION

1.1 Scope

This study describes technologies in air pollution control in the industries producing ferroalloys, (including silicon metal and calcium carbide), fused alumina and silicon carbide. The size and location of plants, the products, the relative importance of the industries to the Canadian economy, and process and emission control technologies are discussed. The cost of pollution control is estimated, based on data found in the literature supplemented by information supplied by the industries.

1.2 Purpose

The Air Pollution Control Directorate has prepared national emission guidelines for the ferroalloy production and allied industries, which consist of suggested emission limits for new plants. Forming part of these guidelines is the information in this report, which includes an evaluation of control strategies available to reduce emissions from existing plants, and technical and other industry information relevant to the development of the guidelines.

1.3 Information Sources

The primary source of information was questionnaires submitted in 1976 by the ferroalloy and allied industries producers. Other sources of information were the National Science Library, technical journals, equipment manufacturers' publications, and the United States Environmental Protection Agency.

Contacts were established with provincial regulatory agencies, the National Research Council of Canada and the federal departments of Energy, Mines and Resources, Industry, Trade and Commerce, and Statistics Canada.

2 INDUSTRY DESCRIPTION

2.1 Size

Tables 1 and 2 give data on the capacity and production of 17 Canadian plants in 1975. At the time of the survey, many plants were not operating close to the design capacity because of low demand for ferroalloys by the steel industry. The total production from these 17 plants during 1975 was 276 944 tonnes of ferroalloys, 120 899 tonnes of fused alumina compounds and 97 353 tonnes of silicon carbide. In 1976 a new Quebec plant with a process capacity of 50 803 tonnes per year of silicon metal and ferrosilicon started production from three electric submerged-arc furnaces (70 megawatts).

2.2 Employment

In 1975, the industries employed 2623 people. This increased by another 240 in 1976 when a new Quebec ferroalloy plant started production.

2.3 Geographic Distribution

All the Canadian ferroalloy and allied industries are in Ontario and Quebec (Figure 1). Almost all the plants are near economical sources of electric power and also near major markets, to reduce manufacturing and transportation costs.

2.4 Products

Table 3 lists the types of ferroalloys, abrasives and refractories produced in Canada in 1975. The value of production was more than $200 million.

Ferroalloys produced in Canada are mostly used in alloying steel. Ferroalloy additives improve steel properties such as strength, corrosion resistance and heat resistance. Ferroalloys are also used in the foundry industry. Silicon metal is chiefly used as an alloying agent for aluminum; another important use is in the production of silicone-type lubricants, hydraulic fluids, resins, plastics, enamels and rubbers. Other uses include miscellaneous ferrous and non-ferrous alloying and refining applications. Purified silicon metal is used as a semiconductor in electronic circuits and calcium carbide is chiefly used in the manufacturing of acetylene. The major abrasives and refractories are fused alumina and silicon carbide. They are extensively used in bonded abrasives, coated abrasives and as grains for working on many metallic and non-metallic materials. The major non-abrasive use is in the production of refractories.

TABLE 1 CANADIAN FERROALLOY PLANT CAPACITY AND PRODUCTION IN 1975

	Furnace Capacity (megawatts*)		Production
	Design	Operating	(tonnes/year**)
Quebec	231	182	239 794
Ontario	20	18	37 150
	251	200	276 944

TABLE 2 CANADIAN FUSED ALUMINA AND SILICON CARBIDE PLANT CAPACITY AND PRODUCTION IN 1975

	Furnace Capacity (megawatts*)		Production (tonnes/year**)	
	Design	Operating	Product	Ferrosilicon By-Product
Fused Alumina				
Ontario	81.8	69.2	106 374	10 679
Quebec	4.9	4.9	14 515	1 724
	86.7	74.1	120 889	12 403
Silicon Carbide				
Ontario			31 951	
Quebec			65 402	
			97 353	

* 1 megawatt (MW) = 10^6 watts

** 1 tonne (2204.6 lb) = 1.10 tons = 1000 kilograms

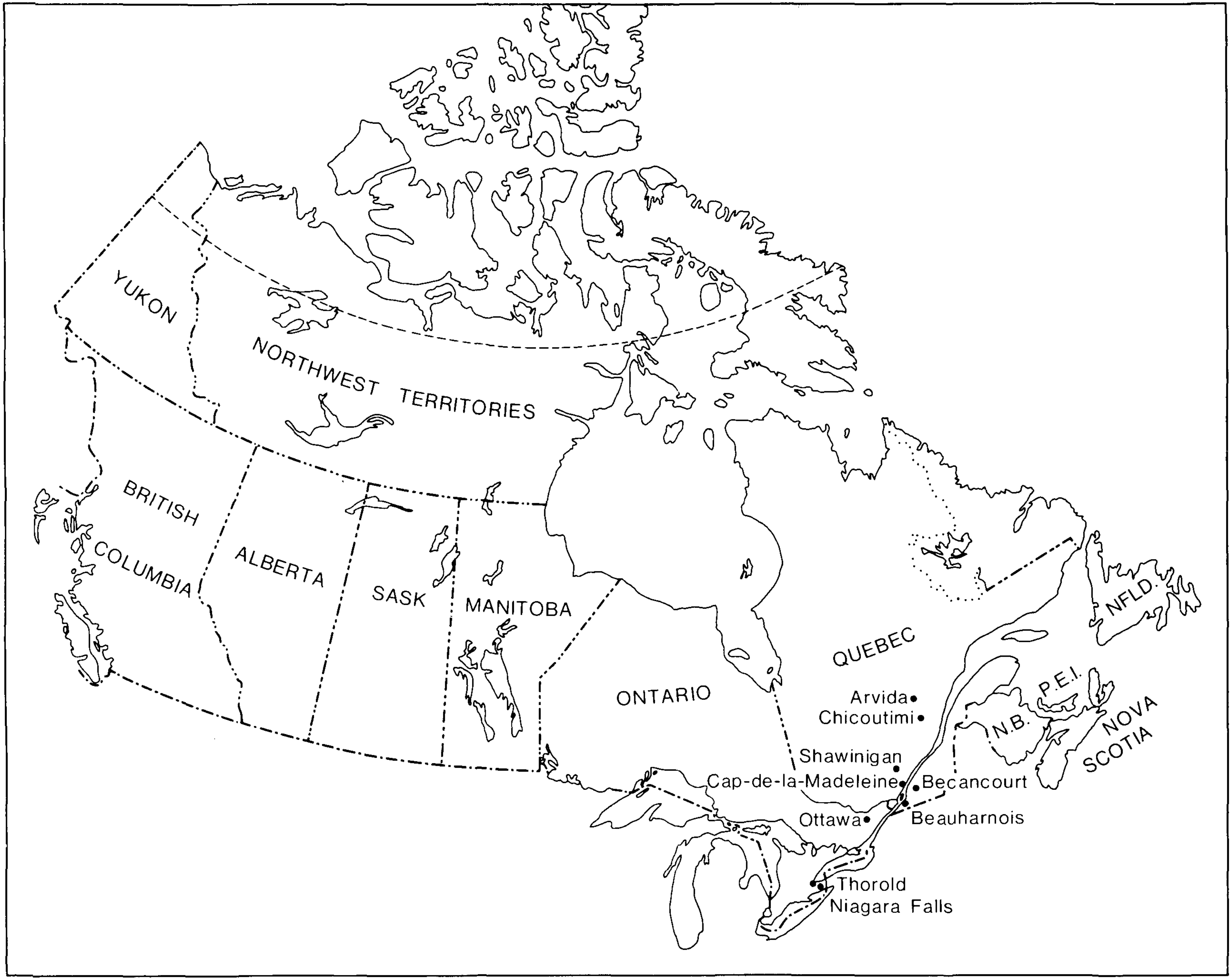

FIGURE 1 FERROALLOY, FUSED ALUMINA AND SILICON CARBIDE PLANTS IN CANADA, 1975

TABLE 3 TYPES OF FERROALLOYS, ABRASIVES AND REFRACTORIES PRODUCED IN CANADA IN 1975

		(Production)
Ferroalloys		
Ferromanganese	FeMn	51 710
Silicomanganese	SiMn	22 680
Ferrosilicon	FeSi	95 244*
Silicon Metal	Si	3 433
Calcium Carbide	CaC_2	117 936
Other		861
Total		291 864
Abrasives and Refractories		
Fused Alumina	Al_2O_3	116 983
Zirconia Alumina	Al_2O_3 ZrO_2	3 906
		120 889
Silicon Carbide	SiC	97 353
Total		218 242

* Includes 12 403 tonnes of by-product ferrosilicon (12-16% silicon) from fused alumina production.

3 INDUSTRIAL PROCESSES

3.1 General

3.1.1 **Ferroalloys** (1,2). Four major methods are used to produce ferroalloys: a) blast furnace, b) electric smelting furnace, c) alumino-silico thermic process and d) electrolytic deposition. Although both electric smelting and thermic processes are used in Canada, the primary manufacturing process is based on the electric submerged-arc furnace, which is the main focus of this report. The major products of electric furnace smelting are ferrosilicon, silicon metal, ferromanganese, silicomanganese and calcium carbide. These amounted to 288 303 tonnes* in 1975. They are produced from open and sealed furnace processes, each of which has advantages and disadvantages. The open furnace process offers high flexibility in its ability to change the furnace from the production of one type or family of ferroalloys to another. The sealed furnace process, with relatively low flexibility, can be operated with less pollution of the atmosphere. It essentially requires pretreatment of furnace feed such as drying of raw materials and sintering of ore and coke fines.

Production from the thermic reduction process in 1975 consisted of 861 tonnes of ferrotungsten, ferrocolumbium, ferromolybdenum, ferrovanadium and nickel-based alloys.

3.1.2 **Fused Alumina** (3,4). Higgins and casting furnaces are used for the production of fused aluminum oxides. Both furnaces use electric energy for smelting the charge materials. The Higgins is a pot-type batch furnace, while the casting is a conventional tilt-type open submerged-arc furnace. The casting furnace is favoured because it operates continuously and has a much higher smelting capacity. Thus it offers substantial savings in operating costs (less labour-intensive and better fuel economy) and control equipment costs. The total production from fused alumina plants was 120 889 tonnes** in 1975.

3.1.3 **Silicon Carbide** (5,6). Silicon carbide is produced in a long rectangular trough-shaped electrical resistance furnace which is typically 12 m long, 2.5 m high and 2.5 m wide. The furnace, known as the Acheson furnace, is named after Edward Goodrich

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* including 12 403 tonnes of by-product ferrosilicon produced from the fused alumina process.

** excluding the 12 403 tonnes of by-product ferrosilicon produced.

Acheson, who produced the first crystals of electric furnace silicon carbide on the end of a carbon electrode in 1891. Since then, the manufacturing technology for silicon carbide has essentially been unchanged in Canada. At present no control equipment has been installed for furnace exhaust gas cleaning in Canada. The production of abrasive grade ($\geq$ 95% SiC) and metallurgical grade (90-95% SiC) silicon carbide was 97 353 tonnes in 1975.

3.2 Process Flowsheet

Typical process flow diagrams for the three manufacturing processes are shown in Figures 2, 3 and 4.

3.3 Process Sequence

3.3.1 Raw Materials. Most smelting or reduction operations are close to economical electric power sources and major markets. Manganese, quartz, bauxite and other oxide ores, generally in the dressed form, and other raw materials, such as lime and coal/coke, are usually transported from outside and delivered to plant storage areas (inside and/or outside storage) for subsequent treatment.

3.3.2 Drying of Raw Materials. The ores and the reductant coke are usually dried in separate rotary dryer systems to reduce residual moisture content to about 3-4%. Moisture control is necessary to provide a consistent mix to the semi-sealed or sealed electric submerged-arc furnace. This reduces the hazards of a continuous furnace operation in the event of a cave-in and subsequent sudden charging of a large quantity of cold mix. In abrasive and refractory production, only the reductant coke is dried.

3.3.3 Crushing and Screening. To provide safe and efficient operation of a semi-sealed or sealed electric submerged-arc furnace, the oversize dry ore is crushed and screened to different sizes and conveyed to storage bins. The normal ore sizes are 7.6 x 2.5 cm and 2.5 x 0.6 cm, while the coke sizes are generally above 0.6 cm. The minus 0.6 cm fraction of ore and coke fines is sent to the sinter plant and agglomerated.

3.3.4 Sintering of Ore and Coke Fines. This operation is only used for the production of ferroalloys in a semi-sealed or sealed electric submerged-arc furnace. The ore and coke fines are continuously weigh-fed into a pug mill for blending with return fines and water, and the mix is then charged to the sintering machine. The downdraft sintering machine, with the charge on an endless travelling bed of linked grated sections, uses

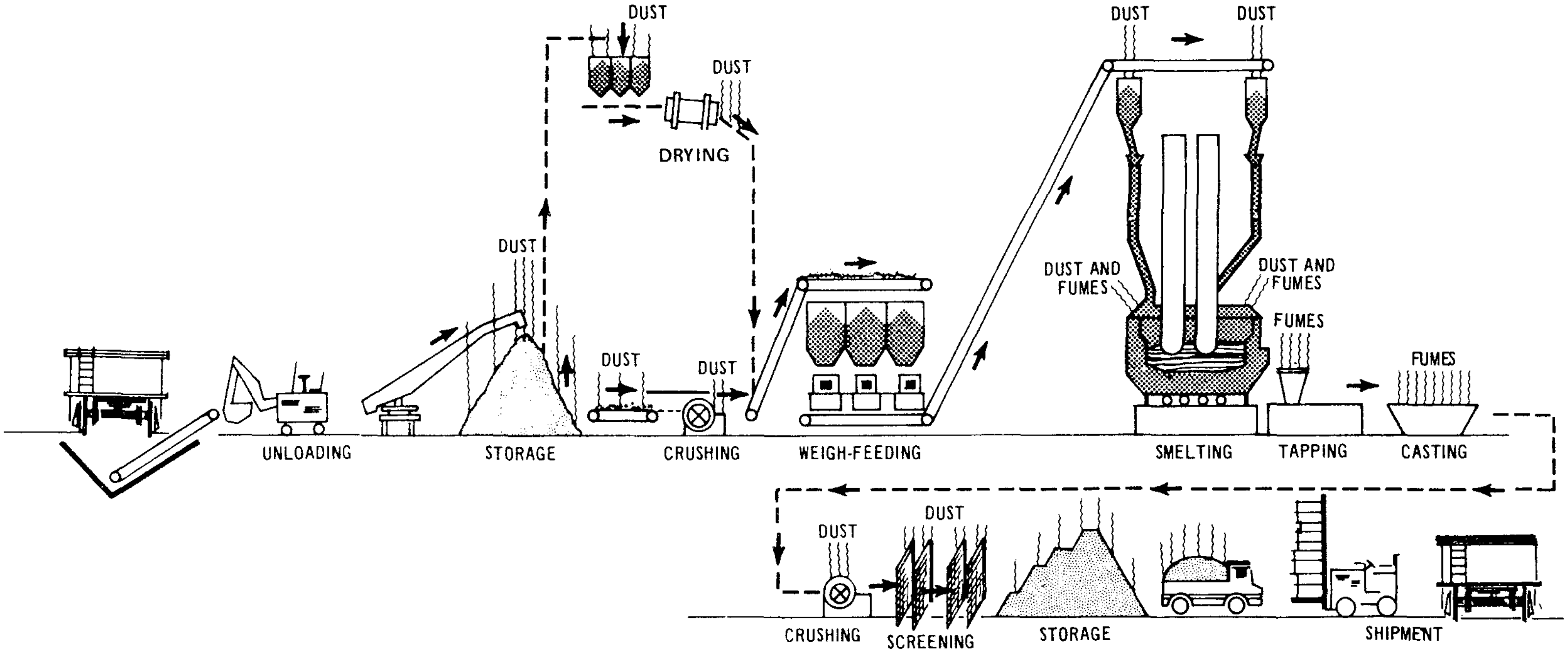

FIGURE 2 FERROALLOY PRODUCTION FLOW DIAGRAM SHOWING POTENTIAL EMISSION POINTS

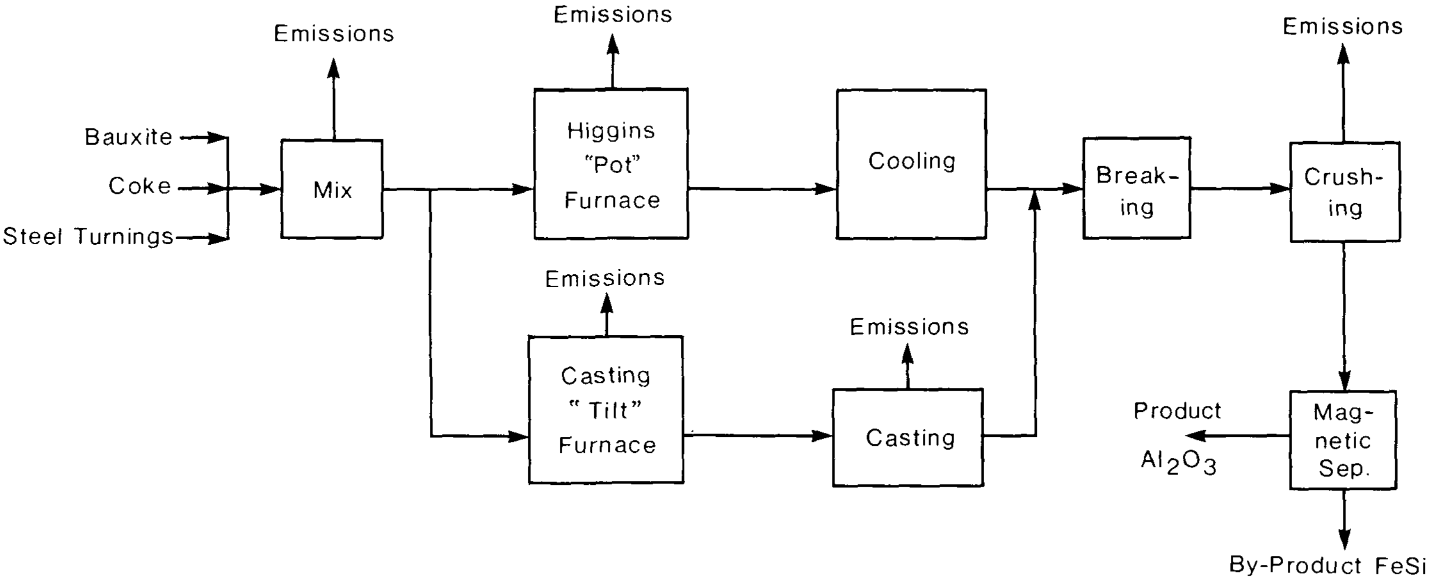

FIGURE 3 FUSED ALUMINA PRODUCTION PROCESS FLOWSHEET

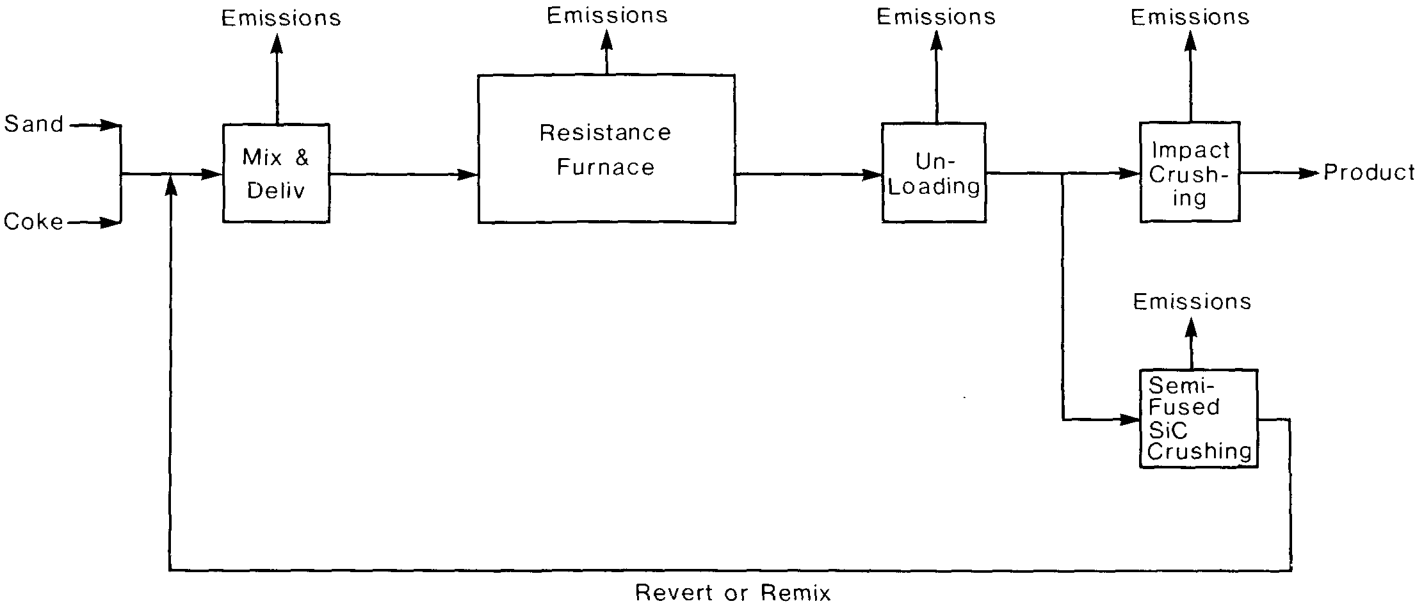

FIGURE 4 SILICON CARBIDE PRODUCTION PROCESS FLOWSHEET

oil-fired burners to agglomerate the fine particles of the charge mix. The coke fines in the charge not only provide energy but make a hard and porous product. After burn-through and cooling, the sinter is discharged and crushed. The product is screened into three fractions: a) the minus 0.6 cm fraction is returned to the pug mill, b) the minus 1.9 cm to plus 0.6 cm fractions are used as hearth layer material with surplus sent to the product bin, and c) the minus 7.6 cm to plus 1.9 cm fractions are stored in the product bin for subsequent use as furnace feed mix.

3.3.5 Mix Batching and Delivery of Mix to Furnace. Mix from the storage bins is batched using weigh hopper scales. The mix is discharged to a collecting conveyor and deposited into a surge weigh bin for total batch weight check. It is then discharged into a skip hoist bucket from where it is delivered to the furnace charge bins. The pre-mixed materials are charged to the electric arc furnace below the storage bins. In the production of silicon carbide, the mix is loaded to the horizontal trough-shaped furnace bed by a payloader or an open overhead conveyor and chute system.

3.3.6 Furnace Operations

3.3.6.1 Electric smelting (1). Open, semi-sealed or sealed submerged-arc furnaces are used for ferroalloy smelting operations. Figure 5 shows a typical submerged-arc furnace. It consists of a high temperature refractory-lined crucible with a taphole at the furnace bottom from which the molten metal and slag are intermittently tapped. Over the hearth are vertically suspended electrodes, usually three, arranged in a delta formation. The carbon electrodes, through a system of contact plates, electrode holders for providing vertical movement and bus bars connected to furnace transformers, convert electrical energy to heat energy within the furnace charge.

The electrodes protrude into the furnace charge to a depth of 0.9-1.5 m. The electrode depth is continually varied as required, by mechanical or hydraulic drive systems, to maintain a constant electrical load. The conventional submerged-arc furnace uses carbon to reduce metallic oxides in the charge and continuously generates large quantities of carbon monoxide, fumes of superheated metal along with other gases from volatile matter and moisture in the charge materials. The hot reaction gases rising through the furnace charge carry emissions from the extremely high-temperature (2200-2800°C) interior regions of the furnace and entrain fine particles of charge materials.

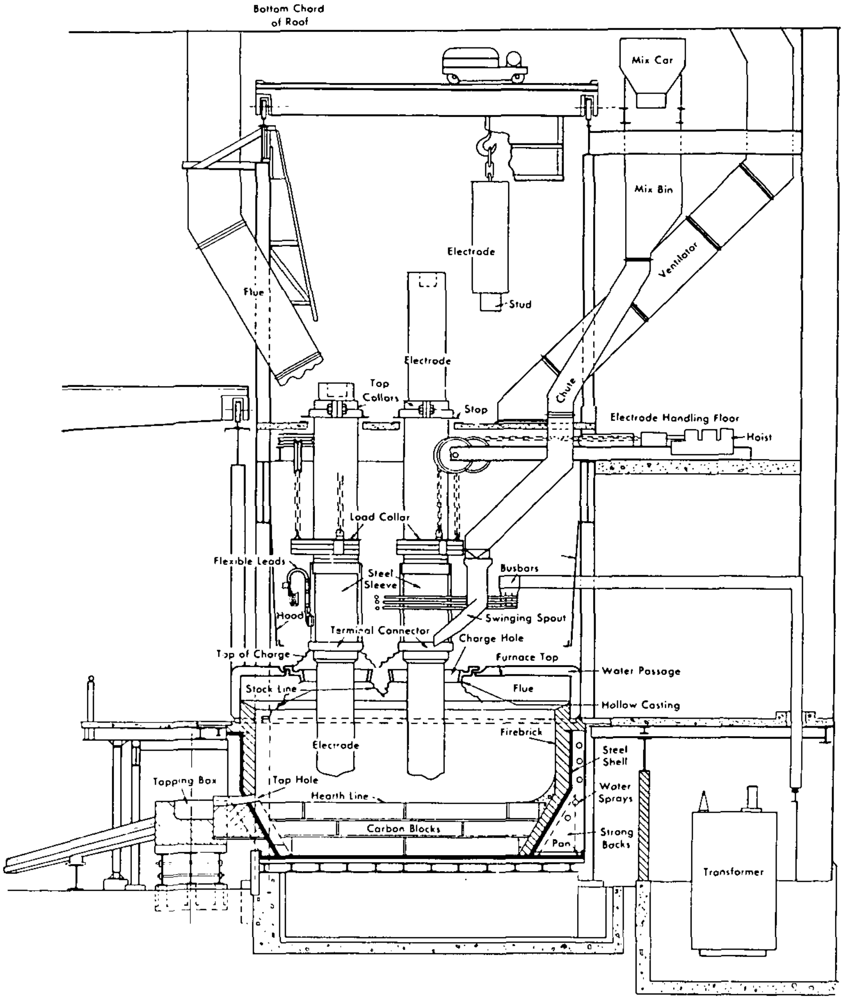

FIGURE 5 VERTICAL CROSS SECTION OF A TYPICAL SUBMERGED-ARC FERROALLOY FURNACE AND AUXILIARY FACILITIES (COURTESY UNION CARBIDE METALS CO.)

In open furnaces the carbon monoxide burns with induced air at the top of the furnace hearth, resulting in a large volume of high-temperature gas. In semi-sealed or sealed furnaces nearly all the carbon monoxide and the other gases are withdrawn from the furnace without combustion. The carbon monoxide is subsequently used for process heat, such as in drying raw materials, or flared in the stack exit gases.

A detailed description of the three types of submerged-arc furnaces follows.

Open furnaces. Figure 6 shows an open furnace. The furnace has a water-cooled canopy hood, normally 1.8-2.4 m above the furnace crucible rim. The vertical opening is required for stoking the charge. Stoking is necessary to prevent crusting and bridging which would prevent uniform descent of the charge into the furnace, and blows which could damage the furnace components. The large opening between the furnace crucible and hood allows large quantities of ambient air to be drawn into the hood, diluting the off-gas as much as 50 to 1. The induced ambient air can be reduced by decreasing the opening between the hood and furnace, either by adding a skirt to the hood or by hanging chain curtains around the perimeter of the hood.

Semi-sealed furnaces. A semi-sealed furnace is shown in Figure 7. The furnace has a water-cooled cover which completely seals the furnace except for the annular spaces around the three electrodes through which raw materials are charged. The gases and fumes generated in the furnace are drawn from beneath the cover through one or more ducts to a gas cleaning device. Because very little ambient air enters a semi-sealed furnace, the gases from the furnace are rich in carbon monoxide and can be used as fuel. However, the feed material only partially closes the annuli and emissions still pass through them. These emissions are generally controlled and captured by maintaining a slight negative pressure in the furnace freeboard or by installing hoods around the electrodes.

Because they cannot be stoked, semi-sealed furnaces have not been used in Canada to produce silicon metal or alloys containing more than 75% silicon.

Sealed furnaces. A sealed furnace, as shown in Figure 8, has a water-cooled cover which completely seals the furnace. Since there are no other openings, the furnace cannot be stoked as would be required for the production of silicon metal and high-ferrosilicon (greater than 75% silicon). By sealing the top of the furnace, including electrodes, charge chutes and excess openings, all the furnace gas can be collected with

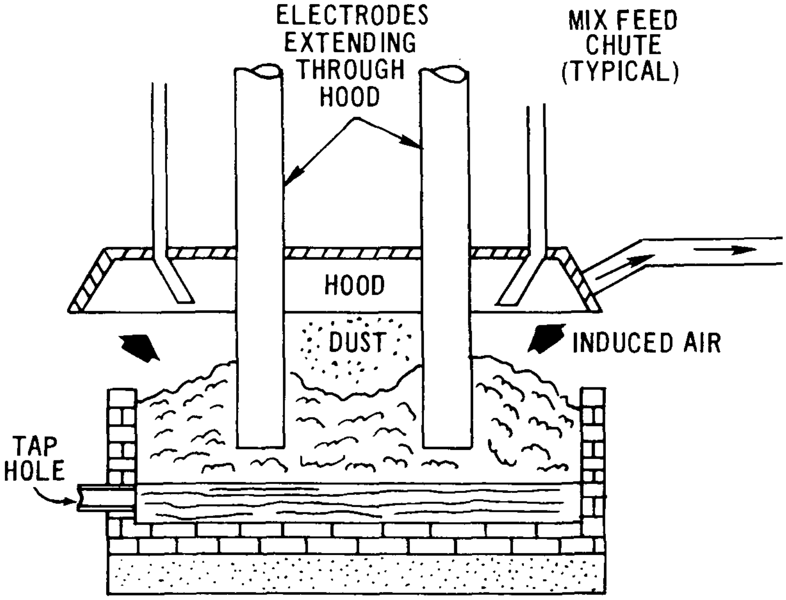

FIGURE 6 OPEN FURNACE

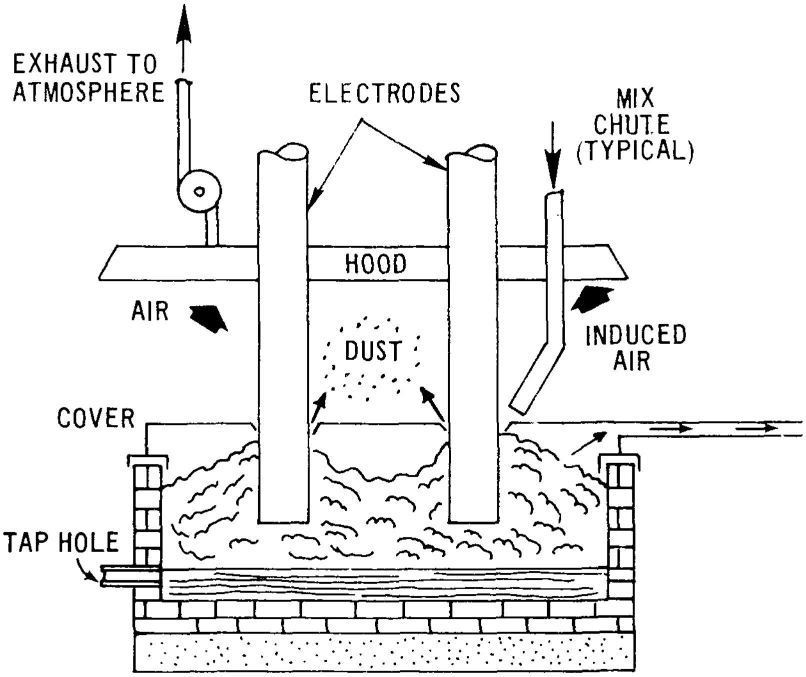

FIGURE 7 SEMI-SEALED FURNACE

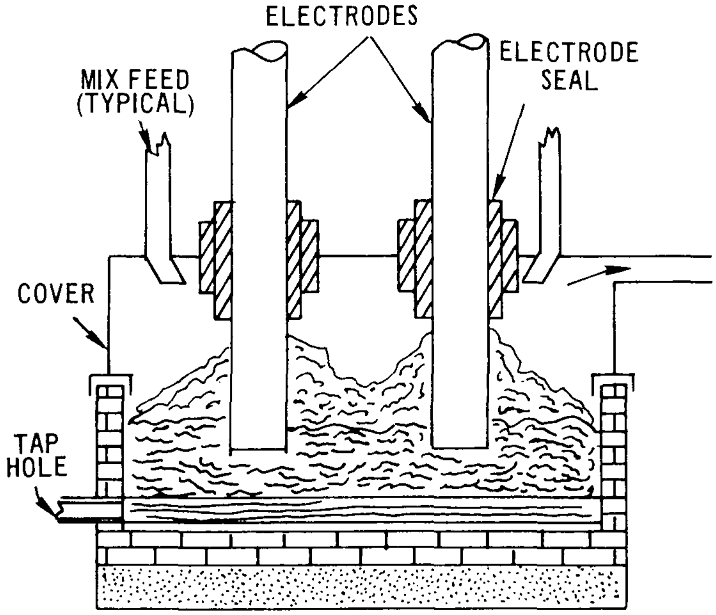

FIGURE 8 SEALED FURNACE

no fumes escaping and minimal air in-leakage to increase gas flow. The furnace exhaust gas, predominantly carbon monoxide, can be used as fuel.

Sealed furnaces used for ferroalloy production such as ferromanganese and silicomanganese require feed preparation processes such as drying, crushing of oversize ores, and sintering of ore and coke fines to promote uniform charge descent and uniform gas evolution, which are essential to obtain smooth furnace operation.

3.3.6.2 **Ferroalloy processes.** The major Canadian ferroalloy processes are a) silicon alloy, b) manganese alloy and c) calcium carbide. These are described below.

Silicon alloy process (7). The charge materials to the furnace consist of silica ore and reducing materials such as coke and charcoal. In the production of silicon metal, high-purity quartzite (99% SiO_2) is used, while quartz along with steel scrap and iron ore are used in the production of ferrosilicon.

Because silica is subject to rupture at certain transition points before melting at approximately 1723°C (3133°F) and because of the steep thermal gradients in a submerged-arc smelting furnace, silica fume may result from one or more side reactions during the transformation from low quartz (25-573°C) to high quartz (573-867°C), tridymite (867-1470°C) and cristobalite (1470°C-1723°C). Thus fusion and bonding of the raw material charge is characteristic of the silicon metal and high-ferrosilicon production processes. The process is also characterized by high-temperature gas blows generally in the vicinity of the electrodes. Jets of hot gas originating from the high-temperature zones of the furnace near the bottom of the electrodes can damage furnace components. Silica metal operations are also subject to hearth build-up of silicon carbide; more emissions occur under these conditions because the electrodes are operated at a higher position. Thus, the manufacturing processes require the use of open furnaces to permit the charge to be stoked to allow its uniform descent and uniform evolution of gas formed by the reduction of the ore. Semi-sealed or sealed furnaces have not been used because they cannot be stoked, which would present a safety hazard. Unlike other ferroalloy processes, slag is not produced in the silicon alloy processes. The general manufacturing processes can be summarized by the following reactions:

$$SiO_2 + 2C = Si + 2CO$$
$$Fe_2O_3 + 3C = 2Fe + 3CO$$
$$Fe + Si = FeSi$$

Manganese alloy process (8,9,10). Ferromanganese and silicomanganese are produced in Canada in open, semi-sealed and sealed electric submerged-arc furnaces. Because manganese ores contain a significant amount of water as well as higher oxides which release oxygen upon heating at temperatures below 1000°C, a manganese furnace can be subject to rough operation. A sudden release of gas can result in a substantial ejection of mix from the furnace. Furthermore, silicomanganese furnaces are also subject to slag boils, in which slag rises to cover the top surface of the charge, impeding mix delivery and uniform gas ascent. Thus the semi-sealed and sealed furnaces require feed preparation processes such as drying, crushing of oversize ores, and sintering of ore and coke fines to promote uniform charge descent and uniform gas evolution, which are essential to obtain smooth furnace operation and the desired quality of product on a continuous operation.

The slag from the ferromanganese furnace, containing up to 40% manganese, is used in the subsequent silicomanganese production, which is usually an integrated part of a ferromanganese smelting operation. Slag produced from the silicomanganese process is discarded as waste. The general manufacturing processes for manganese alloys can be summarized by the following reactions:

$$\begin{aligned}
& & MnO_2 &= MnO + \tfrac{1}{2}\,O_2 \\
MnO &+ & C &= Mn + CO \\
Fe_2O_3 &+ & 3C &= 2Fe + 3CO \\
SiO_2 &+ & 2C &= Si + 2CO \\
Fe &+ & Mn &= FeMn \\
Si &+ & Mn &= SiMn
\end{aligned}$$

Calcium carbide process (1, 4, 11). Calcium carbide (CaC_2) is manufactured by heating quicklime (CaO) and carbon at temperatures of about 2000-2200°C in an electric submerged-arc furnace, where the lime is reduced by the coke to calcium carbide and carbon monoxide according to the following reaction:

$$CaO + 3C = CaC_2 + CO$$

Metallurgical coke, petroleum coke or anthracite coal is used as the source of carbon. The molten carbide from the furnace is poured into chill cars or bucket conveyors and allowed to solidify. The finished calcium carbide is crushed in a jaw crusher and then a cone crusher to form a product of the desired size.

3.3.6.3 Thermic reduction process. Thermic smelting involves the reduction of metallic oxides with reducing metals such as aluminum, calcium or magnesium to their oxides. The reaction is sufficiently exothermic and the composition of the reaction mixture is designed to produce enough heat to melt the products of reaction, thus producing a separation of the metal from the slag due to the difference in densities of these materials. In cases where the heat of reaction is insufficient to produce good metal-slag separation, thermal boosters such as sodium chlorate or barium peroxide, which react with aluminum exothermically, may be used. Because of its low cost per chemical equivalent, low boiling point, high heat of formation and the relatively low melting temperature (2045°C) of its oxide, aluminum is the primary reducing metal used in the manufacturing process.

The reduction operation used in Canada is a batch process. The reactants consist of coarse aluminum powder mixed with metallic oxide and a little fluorspar or other fluxing agent added as an aid in the separation of the metal and the slag. The reaction is carried out in a steel crucible, 0.9-1.2 m in diameter by 1.2 m high, lined with slag from previous reactions, or in a silica sand bed pit with a refractory-lined steel sidewall as the reaction container. It is started by placing a small portion of the charge in the container and igniting it with a fuse consisting of fine aluminum powder and sodium chlorate or barium peroxide. Once the reaction starts the remainder of the charge is fed on top. The complete reaction is finished in 10 to 20 minutes or less, but many hours are needed for the crucible and its contents to be cooled to the point where the slag can be broken away from the metal without fear of oxidation. Although the charge size does not usually exceed 5 tonnes, relatively large quantities of smoke are evolved.

Ferroalloys produced from the thermic processes in Canada are ferrocolumbium, ferromolybdenum, ferrotungsten, ferrovanadium and nickel-based alloys.

3.3.6.4 Fused aluminum oxide process (3,4). Fused aluminum oxide, together with ferrosilicon by-product, is produced by the smelting of a charge mixture of bauxite*, steel turnings and coke in a Higgins or casting furnace. In the presence of carbon, silica in the bauxite ore is reduced, and the resultant silicon combines with the iron to form ferrosilicon.

In the Higgins furnace, the electrodes are lowered to a point just above the level of the charge. The top of the furnace is open so that the batch charge mix of about 10 tonnes, consisting of approximately 90% bauxite, 6% steel turnings and 4% coke, can be added as fusion proceeds at a furnace core temperature of about 2000°C. After a fusion time of about 18 hours, the furnace pot is removed to an adjacent work area for cooling. The mould is cast about 5 hours later. A complete cycle for fusion, cool-off and restart of the furnace is about 24 hours.

In the casting furnace, the raw material mix is charged to the furnace intermittently, while the molten product is poured into receiving pots at about 3-hour intervals. The casting furnace is similar to the conventional submerged-arc furnace used for ferroalloy production except that it has no taphole at the bottom. The top of the furnace is open so that the molten product can be poured out by tilting the open furnace.

3.3.6.5 Silicon carbide process (3,4,6). Silicon carbide is produced by heating a charge mixture of sand ($\sim$60%) and petroleum coke ($\sim$40%) in an electrical resistance (Acheson) furnace. Voltage is applied to a graphite core running through the centre of a horizontal trough-shaped furnace with removable side sections of refractory bricks and with permanent refractory ends holding carbon electrode terminals. The heat generated causes

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* The ore mainly consists of hydrated aluminum oxide ($Al_2O_3.2H_2O$) and impurities such as free silica (SiO_2), iron oxide (Fe_2O_3) and titanium oxide (TiO_2).

the formation of silicon carbide crystals at temperatures in the 2400-2500°C range. Firing usually takes place for about 36 hours; the temperature of the central core reaches 2400-2500°C at the end of the first 3 hours and then the furnace core is held at this temperature for the next 33 hours. After the run, the current is turned off and the furnace is allowed to cool for up to 24 hours before the side walls are removed to expose a cylindrical shell of silicon carbide crystals which are formed around the core. After further cooling, which may last for 4 to 5 days, the core product is hand broken into lumps and then reduced to 2.5 cm or smaller pieces by impact crushing. However, the cooling period might be shortened to get the furnace ready for another run. The partially converted silicon carbide layers on the external shell of the core product, known as revert or re-mix, are recycled to the process.

Various additions are made to aid the process - sawdust is often added to induce porosity and thereby release gaseous carbon monoxide in the basic chemical reaction:

$$SiO_2 + 3C = SiC + 2CO \uparrow$$

A typical production process is shown in Figure 4.

3.3.7 **Product Discharge from Furnace.** Most electric submerged-arc furnaces are tapped intermittently over periods of 1.5 to 5 hours. The molten alloy and slag* are tapped through a taphole at the furnace bottom into refractory-lined ladles. The slag is skimmed off through the slag runner. The ferroalloy is then cast into moulds. After sufficient cooling and solidification the cast is removed from the mould, graded and placed in hot skip boxes where the alloy is held for further processing.

In the smelting of fused aluminum oxide in Higgins or pot-type furnaces, the furnace pot is removed to an adjacent work area for cooling, after a fusion time of about 18 hours. The magnetic ferrosilicon by-product formed during the smelting process is allowed to settle in the bottom of the product mould. The mould, which generally weighs about 5-6 tonnes, is cast about 5 hours later. Where smelting is carried out in the casting furnace, the molten product is poured out into receiving pots at about 3-hour intervals by tilting the open furnace. The casts or ingots from both Higgins and casting furnaces are broken into chunks by 3000-pound (2 700 kg) drop balls in the adjacent work area before final size reduction and magnetic separation of the ferrosilicon from the fused alumina.

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*Slag is not produced from the silicon alloy processes.

In the production of silicon carbide the reduced furnace bed product is unloaded by dumping. The core product is hand broken into lumps before being transferred to the crushing department for further size reduction.

3.3.8 Product Sizing and Packaging. The ferroalloys and fused alumina casts or ingots, after being broken into chunks, are further reduced by jaw crushing. The ferroalloys are screened to various sizes, while the fused alumina casts are reduced to 2.5 cm or smaller pieces. The liberated ferrosilicon by-product is recovered from the aluminum oxide primary product by magnetic separation.

In the silicon carbide operation the core product, after being hand broken into lumps, is subsequently reduced to one inch or smaller pieces by impact crushing. The screened products are packaged directly from the conveyor discharge or discharged to various product bins for storage. The outside core layers of semi-reduced silicon carbide, also known as revert, are returned to the furnace process.

4 TYPES OF EMISSIONS

The major pollution problem from the ferroalloy, fused alumina and silicon carbide production facilities is the emission of large quantities of particulates during the furnace smelting or reduction operations. Emissions of particulates vary considerably for the different operations producing various types and grades of ferroalloys, abrasives and refractories. The conventional electric submerged-arc furnace and the resistance (Acheson) furnace also produce large quantities of carbon monoxide. In the open furnace and resistance furnace nearly all the carbon monoxide burns with induced air at the top of the charge, while in the sealed or semi-sealed furnace most or all of the carbon monoxide is withdrawn from the furnace without combustion with air. The carbon monoxide is subsequently flared in the stack or cleaned and used as fuel in the drying of raw materials. Significant quantities of fumes and dust particles are also emitted from other sections of the process. Emission sources, in order of importance, are a) furnace tapping, casting and unloading, b) preparation of raw materials and c) product sizing and packaging. Possible sources of particulate emissions listed in production sequence are given in Table 4.

TABLE 4 PARTICULATE EMISSIONS ACCORDING TO TYPE OF OPERATION IN THE CANADIAN FERROALLOY PRODUCTION AND ALLIED INDUSTRIES

Operation	Process and Type of Emissions		
	Ferroalloys	Fused Alumina	Silicon Carbide
1) Preparation of Raw Materials			
a) conveying and feeding of raw materials to dryer	ore coke	petroleum coke	petroleum coke
b) drying	ore coke	petroleum coke	petroleum coke
c) crushing and screening of oversize ore material	ore	not applicable	petroleum coke
d) sintering of blended ground ore and coke fines	ore coke	not applicable	not applicable
2) Furnace Operations			
a) feeding of premixed materials to furnace	ore coke	ore petroleum coke	sand petroleum coke
b) furnace exhaust gas*	coke metallic oxides	petroleum coke metallic oxides	petroleum coke silicon carbide silica, some alkali and alkali earth metal oxides
c) furnace product discharge	metallic oxides	metallic oxides	silicon carbide
3) Product Sizing and Packaging	ferroalloy dust	fused alumina dust	silicon carbide dust

* Gaseous emissions contain sulphur compounds, unburned carbon monoxide and hydrocarbons

5 NATIONAL EMISSION INVENTORY DATA - PARTICULATES

5.1 Emissions from Canadian Industrial Processes

A nationwide inventory of emissions of air contaminants for 1976 reported that the ferroalloy production and allied industries were responsible for 33 060 tonnes of particulate matter (12). This is a reduction of 3341 tonnes over 1974 when the last nationwide inventory was taken. A breakdown of emissions by industry is shown in Table 5. It shows that the ferroalloy production and allied industries contributed about 2.8% of the total particulate emissions from Canadian industrial processes.

5.2 Data Obtained from Ferroalloy Production and Allied Industries Questionnaires, 1976

Information reported in Air Pollution Control Directorate questionnaires in 1976 were used for compiling data on particulate and sulphur dioxide emissions from the Canadian ferroalloy production and allied industries for the base year 1975. This information is given in Table 6. A breakdown of emissions and emission factors according to type of operation is shown in Tables 7 and 8.

The furnace smelting and reduction operations accounted for approximately 97% of the total particulate matter (31 300 tonnes*) released by the Canadian ferroalloy production and allied industries in 1975. The largest source of these smelting emissions, as shown in Table 7, is in Quebec, where more than 86% of the ferroalloys are produced. The high emission levels prevailed because some of the electric furnaces were uncontrolled in 1975. Sulphur dioxide (9956 tonnes) is chiefly emitted from the coke used in the smelting and reduction processes.

Emission factors for various operations are given in Table 8. The highest degree of control for electric arc furnaces for the smelting of ferroalloys and fused alumina was in Ontario. The survey found that all resistance (Acheson) furnaces, where electric reduction of silicon carbide is carried out, are uncontrolled, mainly because control of emissions from the outmoded furnace is unmanageable.

Since 1976 large expenditures for air pollution control have been invested by the Quebec ferroalloy plants and the Ontario fused alumina plants. Those plants are required by their provincial environmental control agency to install control equipment to

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*The increase in emissions in 1976 over 1975 (33 060 vs 31 300 tonnes) was mainly due to the higher production of ferroalloys, fused alumina and silicon carbide in 1976.

reduce emissions. As a result, all smelting furnaces in Ontario and Quebec are now controlled except for one ferroalloy smelting furnace in Quebec. However, the silicon carbide plants still remain uncontrolled. The estimated emissions for 1979 are given in Table 9.

Fabric filters have been installed by both Quebec and Ontario plants for emission control. These result in the highest degree of reduction of particulate emissions from the electric smelting operations. The reduction of sulphur dioxide emissions results from the elimination of elemental sulphur use in the process used by the only fused alumina plant in Ontario.

TABLE 5 PARTICULATE EMISSIONS FROM INDUSTRIAL PROCESSES, 1976 (12)

	Particulate Emissions	
Industry	(tonnes)	(%)
Ferroalloy production and allied industries	33 060	2.8
Iron ore mining and beneficiation	329 714	27.6
Asbestos production	86 703	7.3
Cement manufacturing	68 466	5.7
Grain milling and handling	55 034	4.6
Stone, sand and gravel processing	36 476	3.0
Primary non-ferrous metals production	58 058	4.9
Mineral products processing	56 145	4.7
Mining and rock quarrying	123 514	10.4
Kraft pulping	98 577	8.3
Iron and steel production	48 536	4.1
Asphalt production	37 304	3.1
Petroleum refining	12 729	1.1
Metallurgical coke manufacturing	7 313	0.6
Other	140 724	11.8
TOTAL	1 192 353	100.0

TABLE 6 CALCULATED PARTICULATE AND SULPHUR DIOXIDE EMISSIONS FOR 1975 (a) FROM THE CANADIAN FERROALLOY PRODUCTION AND ALLIED INDUSTRIES

	Number of plants	Production		Emissions (tonnes)	
		(tonnes)	(%)	Particulates	SO_2
Ferroalloys					
Ontario	2	37 150[b]	13.4	55	738
Quebec	4	239 795	86.6	24 382	1 717
	6	276 945	100.0	24 437	2 455
Fused Alumina					
Ontario	4	117 052	87.8	2 934	1 674
Quebec	1	16 239	12.2	1 492	41
	5	133 291[c]	100.0	4 426	1 715
Silicon Carbide					
Ontario	3	31 951	32.8	774	1 484
Quebec	3	65 402	67.2	1 663	4 302
	6	97 353	100.0	2 437	5 786
Total	17	507 589		31 300	9 956

a. Based on normal operations from data reported in Air Pollution Control Directorate questionnaires, 1976.

b. Includes 861 tonnes produced by the alumino-thermic reduction processes.

c. Includes by-product ferrosilicon (Ontario - 10 679 tonnes, Quebec - 1724 tonnes).

TABLE 7 CALCULATED PARTICULATE EMISSIONS FOR 1975, ACCORDING TO TYPE OF OPERATION, FROM THE CANADIAN FERROALLOY PRODUCTION AND ALLIED INDUSTRIES

	Emissions (tonnes)							
	Drying	Crushing	Calcining and Sintering	Batching and Delivery	Smelting and Reduction	Product Sizing	Total (tonnes)	Total (%)
Ferroalloys								
Ontario	1			3	51	0	55	0.2
Quebec	30		330	203	23 776	43	24 382	99.8
% of Total	0.1		1.4	0.8	97.5	0.2		100.0
Fused Alumina								
Ontario	21	13		20	2 875	5	2 934	66.3
Quebec				1	1 487	4	1 492	33.7
% of Total	0.5	0.3		0.5	98.5	0.2		100.0
Silicon Carbide								
Ontario	21	13			738	2	774	31.8
Quebec	117	32			1 510	4	1 663	68.2
% of Total	5.6	1.9			92.2	0.3		100.0

TABLE 8 CALCULATED AVERAGE PARTICULATE AND SULPHUR DIOXIDE EMISSION FACTORS FOR 1975, ACCORDING TO TYPE OF OPERATION, FROM THE CANADIAN FERROALLOY PRODUCTION AND ALLIED INDUSTRIES

	Average Emission Factor (kg/1000 kg)							
	Drying	Crushing	Calcining and Sintering	Batching and Delivery	Smelting and Reduction	Product Sizing	Total Particulates	Total SO_2
Ferroalloys								
Ontario	0.02		-	0.08	1.4	0.01	1.5	19.9
Quebec	0.13		1.38	0.84	99.2	0.18	101.7	7.2
Fused Alumina								
Ontario	0.18	0.1		0.17	24.6	0.04	25.1	14.3
Quebec	-	-		0.06	91.6	0.25	91.9	2.5
Silicon Carbide								
Ontario	0.66	0.42			23.1	0.07	24.3	46.4
Quebec	1.78	0.49			23.1	0.07	25.4	65.8

TABLE 9 ESTIMATED PARTICULATE AND SULPHUR DIOXIDE EMISSIONS FOR 1979 FROM THE CANADIAN FERROALLOY PRODUCTION AND ALLIED INDUSTRIES

	Emissions (tonnes)					
	Particulates			Sulphur Dioxide		
	Ontario	Quebec	Total	Ontario	Quebec	Total
Ferroalloys	55	8 096	8 151	738	1 717	2 455
Fused Alumina	402	1 492	1 894	152	41	193
Silicon Carbide	774	1 663	2 437	1 484	4 302	5 786
TOTAL	1 231	11 251	12 482	2 374	6 060	8 434

6 CONTROL METHODS

6.1 General

This survey has revealed a large variance in particulate emissions from various operations. For example, resistance (Acheson) furnace emissions are still uncontrolled, while others have a very high degree of control. The survey shows that conventional technology such as mechanical collectors, in conjunction with higher-efficiency scrubbers and fabric filters, can be utilized to reduce emissions to a very low level. Section 6.2 further describes the various techniques and technologies that can be applied to existing and new plants. Emissions from other non-smelting production operations can be efficiently controlled by dust collection systems using regular equipment such as mechanical collectors, venturi scrubbers and/or fabric filters.

6.2 Existing Installations

6.2.1 Raw Materials Storage. Most raw materials are generally stored in the open. Ore fines, sand and coke particles that have not compacted and settled in the open stockpiles could become airborne under windy conditions. It is common practice to use water spray to suppress dust emissions.

6.2.2 Drying of Raw Materials. The dryers, usually rotary-type, are usually heated by fuel oil. Large volumes of hot air from the dryer exhaust entraining fine dust and coke particles are passed through fabric filters to reduce emissions to acceptable levels.

6.2.3 Crushing and Screening of Oversize Ore. Oversize ore is crushed, screened and conveyed for mix batching and delivery of the mix to furnace storage bins. Emissions of generally coarse particulates from the crushing and screening operations are controlled by cyclones and/or fabric filters.

6.2.4 Sintering of Ore and Coke Fines. Coke fines and ore dust returns from drying, crushing and screening operations are continuously fed into the pug mill for blending with return fines and water. The mix is charged to a sintering machine, essentially a downdraft roasting conveyor with the charge on an endless travelling bed of linked grate sections. Wet scrubbers have been successfully used to reduce dust emissions. Other collectors, such as fabric filters, could be equally effective for dust control.

6.2.5 Furnace Operations

6.2.5.1 Semi-sealed and sealed furnaces (13,14,15, 16). In the semi-sealed and sealed furnaces used for the production of manganese alloys (silicomanganese, ferromanganese, etc.), calcium carbide and ferrosilicon containing up to 50% silicon, the most commonly used control equipment is the high-energy venturi scrubber. A typical high-energy venturi scrubbing system is shown in Figure 9. The volume of flue gas from a semi-sealed or sealed furnace is relatively small compared with an open furnace because very little ambient air enters the furnace. The cleaned gas contains a high carbon monoxide content (greater than 40% by volume), which could be used as fuel (11.17×10^6 joules per SCM of CO) in the pretreatment process or flared. The use of fabric filters could pose operational problems due to the explosion hazard of the high carbon monoxide content of the gas and the potential for blinding the fabric filters by organics in the emissions. For these reasons, fabric filters are not used in North America on semi-sealed or sealed furnaces.

6.2.5.2 Open furnaces (13,14,17,18,19). Because of the large volumes of off-gases from open furnaces, fabric filters have been the preferred collectors. The baghouse systems are preceded by multiclone precleaners or spark arrestors and heat transfer surfaces. The precleaners remove overheated large-size particulate matter that may have been ejected from the raw material charge, while the heat transfer surfaces cool the hot gases to safe operating levels (less than 260°C) before they enter the baghouse. Treated fibreglass (260°C maximum operating temperature) filter media is most commonly used. The fabric collectors are usually designed to operate at low air-to-cloth ratios (0.43 to 0.61 actual cubic metre per square metre of cloth area) because the furnace fume has a high percentage of sub-micron particulates and the high electrostatic charge can build up on the bags, which may result in bag blinding. A typical baghouse system is shown in Figure 10.

Electrostatic precipitators are generally not used in North America (not in Canada) partly because of the high electrical resistivity of the ferroalloy fumes which limit the precipitator performance unless the furnace gas temperature and moisture content are properly conditioned, e.g., humidified with water.

6.2.5.3 Resistance (Acheson) furnaces. Most emissions occur during the firing period when voltage applied (firing) to the furnace charge causes the formation of silicon carbide particles at 2400-2500°C, and in the first 20 minutes after the side gates of the furnace

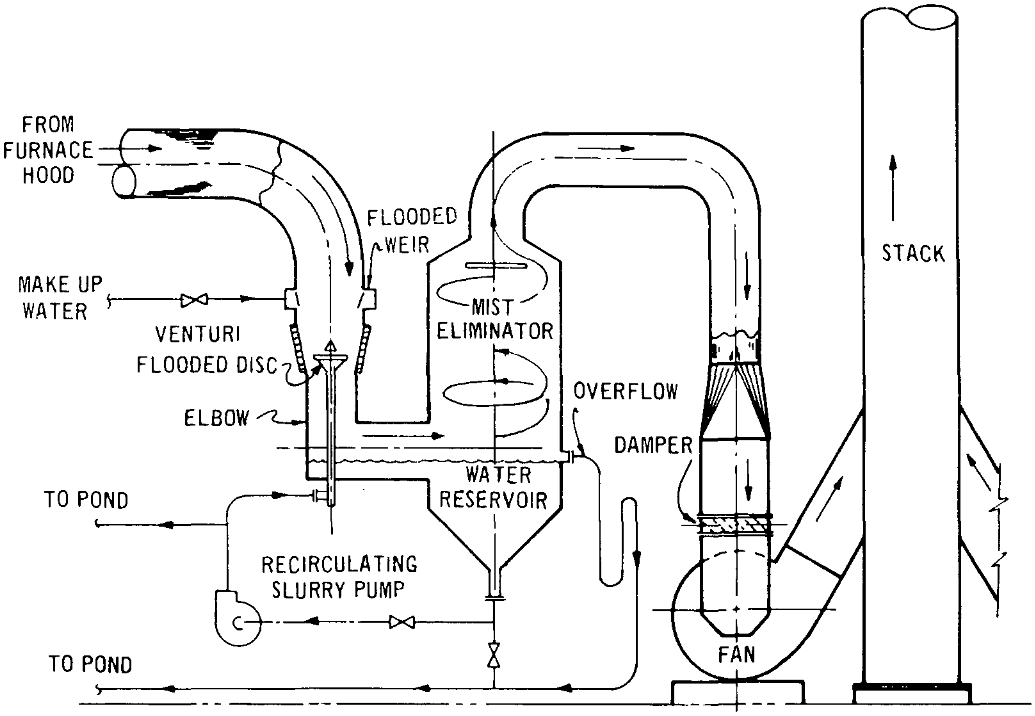

FIGURE 9 HIGH ENERGY FUME SCRUBBING SYSTEM FOR SUBMERGED-ARC FURNACE

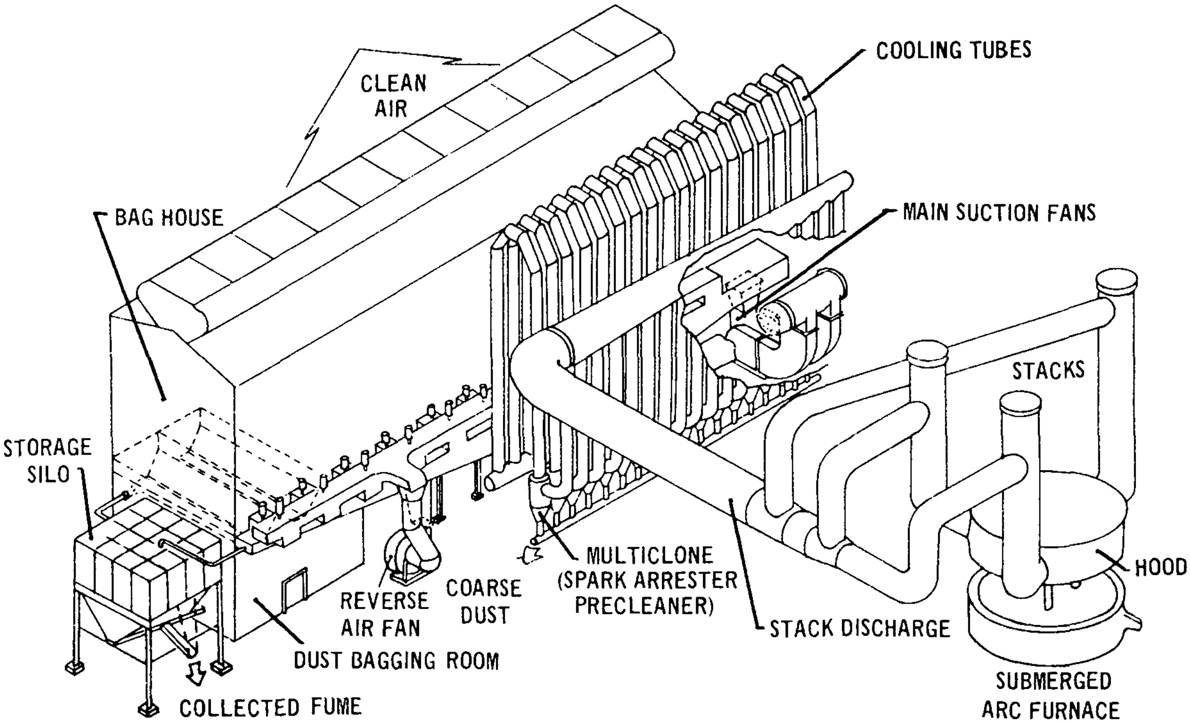

FIGURE 10 BAGHOUSE SYSTEM WITH COOLING TRAIN FOR SUBMERGED-ARC FURNACE

are removed (dumping) for cooling the reduced product. Emissions from all resistance furnaces in Canada are currently uncontrolled. The furnace gases containing particulate matter, unreacted carbon monoxide, methane and gaseous sulphur compounds are vented to the outside atmosphere through the building roof monitor.

6.2.6 Tapping Operations. Since most electric arc furnaces are tapped intermittently over periods of 1.5 to 5 hours, taphole emissions occur 10-20% of the furnace operating time.

In open furnaces a hood installed directly over the taphole and ladle is used to capture and direct the furnace fumes to the baghouse or venturi scrubber collector used by the furnace.

In sealed or semi-sealed furnaces a fume hood directly over the taphole and ladle is used to capture and direct the fumes to a separate gas cleaning system. Where a baghouse is used for emission control, the hot gas is cooled with dilution air before it enters the collector.

6.2.7 Casting Operations. The casting operations are another source of fumes. In a modern plant a hood is used to capture and direct fumes to the air pollution control system. Fabric filters have been the preferred collector because the volume of air induced through the collector is large.

6.2.8 Product Sizing and Packaging. Dust generated from jaw crushing and screening of alloy casts and impact reduction of silicon carbide crystals is efficiently controlled by cyclones and/or fabric filters.

6.3 New Technology

6.3.1 Ferroalloys and Fused Alumina. The furnace smelting operation is the chief source of particulate and gaseous emissions in the production of ferroalloys, abrasives and refractories. The furnace operation can be modified to decrease the quantity of emissions requiring collection or to decrease the off-gas volumes, which reduce the size of collection equipment required. The volumes of off-gas can be substantially reduced (by a factor greater than 20) by decreasing the opening between the hood and the furnace. On the other hand, a completely sealed furnace will result in the greatest reduction of off-gas volumes. However, the sealed furnace is not used for the production of high-silicon alloys ($\geq$75% silicon content) in Canada or the U.S. as they present a problem in manufacture because of bridging, high-temperature blows and serious control problems.

Nevertheless, a sealed furnace (12 MW) has been used in Russia and in Japan since 1971 producing 75% FeSi (15, 20). The Japanese sealed furnace is provided with fixed and mobile poking devices, and therefore there is no problem of dust build-up. In addition, the Japanese furnace substitutes iron-ore pellets for ferrous scrap (as used in Canada and the U.S.). Whereas a sealed furnace is used in Canada for the production of high ferromanganese, pretreatment of the feed mix, including drying and sizing the mix and sintering the fines, is carried out (8). The high-temperature off-gas (about 240 SCM per minute or 8500 SCF per minute) from the 30-MW furnace is cleaned by a high-energy venturi scrubber system. The clean gas, rich in carbon monoxide (40-70%), is recovered to provide heat for the ore and coke dryers or can be diverted to the flare stack.

Elkem Spigerverket, a leading Norwegian producer of silicon alloys, has developed a double-rotation ferrosilicon furnace that eliminates stoking and poking (Figure 11). The key design innovation is a split furnace body using the principle of double rotation. The furnace body is divided into two parts. The upper part, a relatively narrow polygonal band called the Krogsrud ring, oscillates in relation to the main furnace body below. The dual revolutions impart force to the charge in two ways - radially inward from the circumference and axially downward from the centre.

At the dividing plane, where the ring and the body are moving at different speeds, the charge is worked by powerful shearing forces that produce a porous, clean, non-sticking mix. Gas is distributed across the surface of the charge more evenly than in a conventional furnace, producing lower and more stable temperatures. The double rotation also causes a more uniform charge sink. The problems of crust formation, pocketing, and blowing due to uneven gas temperatures and silicon losses are reduced by the design.

Benefits claimed for the double-rotation furnace, in addition to the elimination of stoking, include reduced burning of silicon monoxide at the surface, improved silicon recovery, and - when completely closed - improved plant atmosphere around the closed furnace and reduced gas cleaning costs.

Three furnaces using the new design are currently in operation in Norway: two open furnaces (10 MW and 30 MW) and an 8.5-MW closed furnace producing 75% ferrosilicon. The closed furnace has been reported to have 90-92% silicon recovery, with no changes in quality (24).

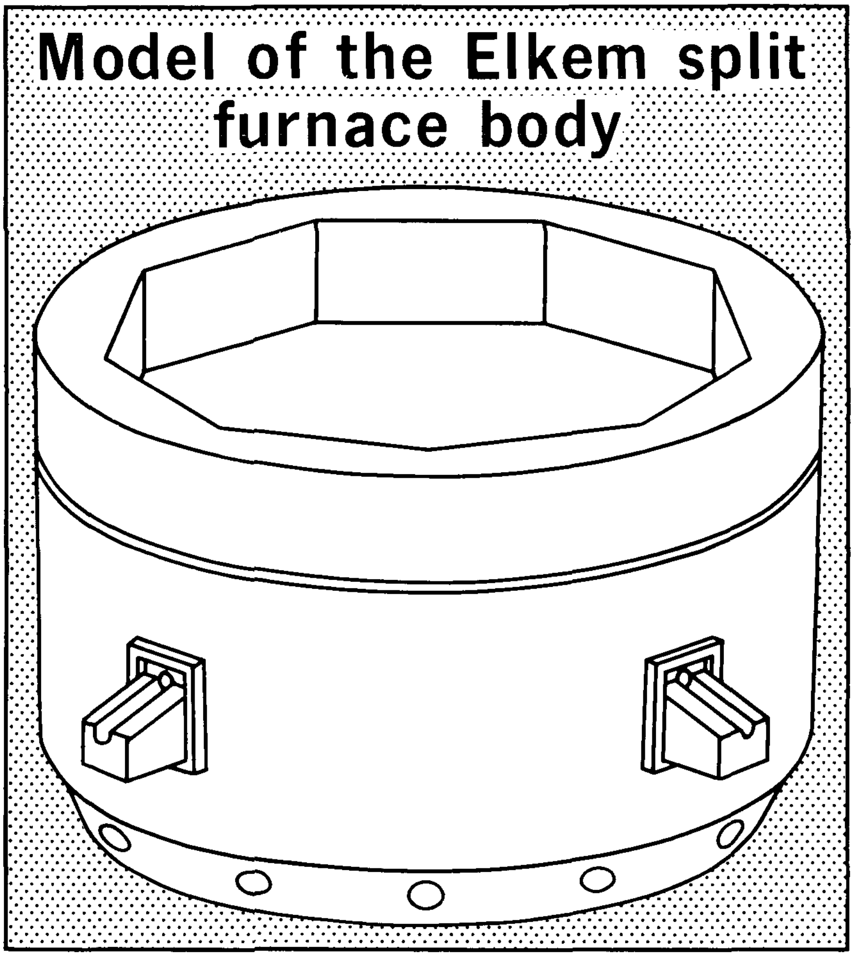

FIGURE 11 MODEL OF THE ELKEM SPLIT FURNACE BODY
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NEW YORK 10020,
OCTOBER 1978,
P. 45.

Innovative emission control equipment for further reducing control costs and improving collection efficiency has been developed (1, 18, 21). One such system uses waste heat from the open furnace to provide energy for gas scrubbing without the use of exhaust fans (Figure 12). The typical open furnace is equipped with an Aronetics scrubbing system. As dust-laden gas (590-650°C) flows from the furnace, a standard heat exchanger transfers heat from the gas to high-pressure water that then enters a two-phase jet nozzle. A two-phase mixture (steam/water) occurs as the high-pressure heated water (2500 kPa absolute at 204°C or 370 PSIA at $400^{\circ}F$) passes through the hot nozzle at the inlet of the mixing duct. The mixture thus leaves the nozzle at high velocity (110-370 m/s) and as it passes through the long venturi section, dust-laden gases are intermixed with the mixture. Concurrently, transfer of momentum of the mixture to the furnace gas stream results in a pressure rise across the mixing section, which produces the force to move the fumes from the furnace into the scrubbing mixture. The collection efficiency has been reported to vary from 92.6% to 97.6% on a silicomanganese furnace (1). Another exhaust system vents the tapping station and tapping fumes to the top part of the furnace hood, where it helps to supply combustion air for burning the carbon monoxide furnace off-gas to carbon dioxide. Improvements made to the scrubbing system have subsequently increased efficiency to more than 99%.

Another novel emission control system being developed in Japan involves the use of a shaft kiln on a sealed furnace (1, 9). The shaft kiln, which is followed by a wet scrubber system for removing the extremely sub-micron-size particles from the gas stream, simultaneously preheats the furnace feed mixture and collects and recharges dust effluent, providing significant savings in both energy and materials (Figure 13). The dust is collected by impaction on the feed mixture as the hot gas stream is exhausted from the furnace. About 80-90% of the dust containing 32.5% manganese oxide (MnO) from a high-ferromanganese operation is reported to be retained in the feed mixture and returned to the furnace.

6.3.2 Silicon Carbide. The new technology and pollution control for silicon carbide operations is designed to separate the production sequences so that emissions can be properly controlled individually as follows:

1. Mixing and loading
2. Firing (electric reduction of silicon dioxide by carbon to silicon carbide)
3. Dumping
4. Unloading

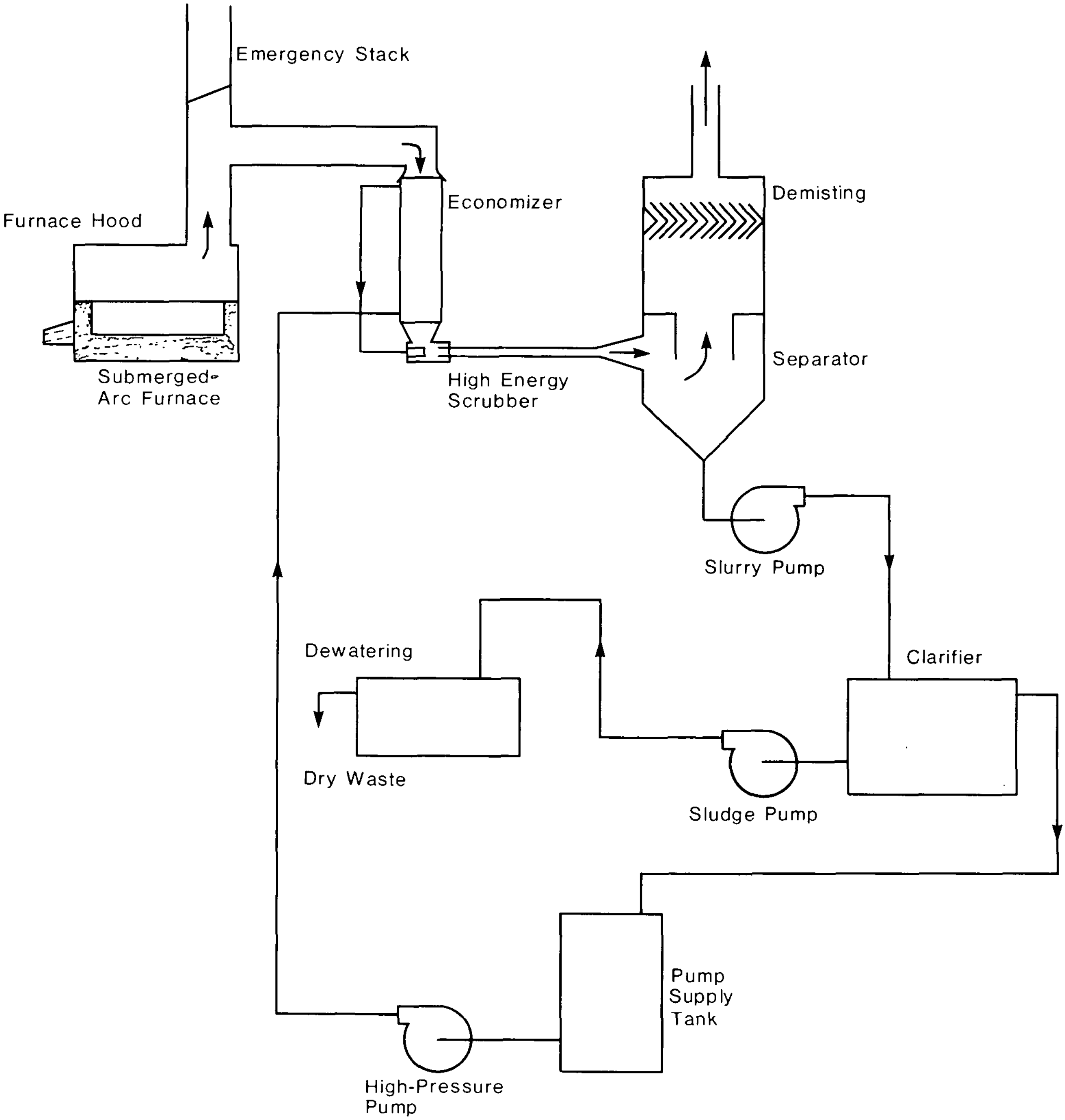

FIGURE 12 ARONETICS TWO-PHASE JET SCRUBBER

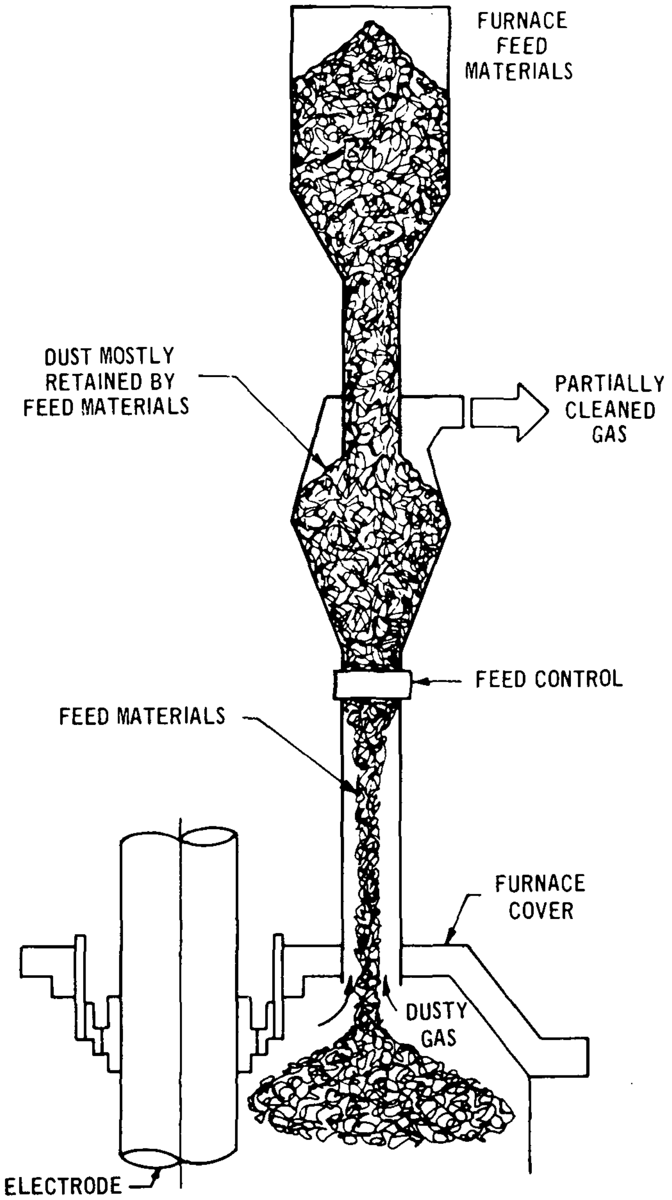

FIGURE 13 SHAFT KILN ON HC FERROMANGANESE FURNACE

The separation technique reduces considerably the volumes of off-gas from the production operation to be controlled by conventional collection equipment such as baghouses and high-energy venturi scrubbers.

One company in the U.S. uses a furnace that resembles a railroad flat car with a concrete bottom and electrode connection on each end, so that the mobile furnace can be moved from one section to the next following the production sequences. The firing is carried out in the open and hence the emissions from the reduction are uncontrolled. However, the emissions generated during the removal of the gates (dumping) and unloading phases, which are carried out inside a building, are collected and exhausted through a venturi scrubber.

Another company, ESK Inc., has recently started producing silicon carbide from the new furnaces at its Kennepin, Illinois, plant (25). The new furnaces are built and operated in an open furnace yard. After the feed mix is loaded to the furnace, which is about 34 m long, 21 m wide and 6 m high, a plastic sheet is placed over the complete pile and sealed around the perimeter. During the process the liberated gas is collected under the plastic cover and is conveyed by pipe to a flaring system which burns off this low-grade gas (heat content of approximately 11.17 J/m^3 or 300 Btu/ft^3) (26). In the future this gas will be collected and transported by pipe to the local power plant for burning.

The fugitive dust generated during dumping and unloading, which are carried out at the same location, is controlled by water sprays.

6.4 Evaluation of Control Technology

6.4.1 General. Particulate emissions vary considerably, especially for the different types of furnaces producing various types and grades of ferroalloys and fused alumina. The degree of particulate emission control for open, semi-sealed and sealed furnaces has been reported to vary from 92% to 99% depending on the type of collector used. The primary collectors for furnace off-gas control are wet scrubbers (usually high-energy venturi scrubbers), baghouses and electrostatic precipitators. In practice, mechanical precleaners (such as multiclones, spark arrestors and settling chambers) in addition to heat transfer surfaces (i.e., U-tube coolers), are used ahead of the baghouse systems serving open furnaces. The precleaners remove overheated particles, while the heat transfer surfaces cool the hot gases to safe operating levels before they enter the baghouses. On the other hand, wet cyclones, low-energy venturi scrubbers or evaporative cooling towers are used to ensure proper conditioning of the off-gases for maximum electrostatic precipitator performance.

6.4.2 Best Practicable Technology. The emission control technology being used by some plants has been described in this chapter. The control of particulate emissions from drying, crushing and conveying operations is achieved by high-efficiency cyclones or fabric filters. The control of emissions from sintering and electric smelting operations can be achieved using high-efficiency venturi scrubbers or fabric filters.

Sulphur dioxide emissions from the electric smelting and reduction operations can be minimized by using coke with a low-sulphur content.

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APPENDIX I PARTICULATE EMISSION FACTORS FOR UNCONTROLLED OPEN FURNACES

	Emission Factor		
Product	kg / tonne product	kg / tonne charge	kg / MW-h
Silicon alloys			
Si	600	123	39
75% FeSi	458	102	47
50% FeSi	223	90	40
Silvery iron (15-22% FeSi)	58	32	20
Manganese alloys			
FeMnSi	158	37	26
SiMn	110	36	23
FeMn	168	42	28
Fused alumina	92		
Silicon carbide	25		

APPENDIX II RANGES OF REPORTED CONTROLLED PARTICULATE EMISSION FACTORS

Product	Furnace Type	Emission Factor $\frac{\text{kg}}{\text{tonne product}}$
Silicon alloys		
Si	Open	24 - 5.3
50% FeSi	Open	9.0 - 0.2
Manganese alloys		
FeMn	Closed	0.14 - 0.04
SiMn	Closed	0.14
Other		
CaC_2	Open	1.1
Fused alumina	Open	7.4 - 0.6

APPENDIX III FERROALLOY PARTICULATE EMISSION STANDARDS THROUGHOUT THE WORLD

Country		Emission Standards		Application
Quebec	Si	10 kg/tonne		1979
(Canada)	FeSi (65-95%Si)	7.5 kg/tonne		
	CrSi	7.5 kg/tonne		
EPA	Si, FeSi	0.45 kg/MW-h	(new plant)	1976
(U.S.)	SiMn, FeMn	0.23 kg/MW-h	(new plant)	
Sweden	FeSi	10 kg/tonne	(new plant; monthly average)	1977
		15 kg/tonne	(existing plant; monthly average)	
	SiMn	0.3 kg/tonne	(monthly average)	
	Si	300 mg/Nm^3	(monthly average)	
Norway	FeSi	100 mg/Nm^3		1979
Switzerland	FeSi	70 mg/Nm^3		1975

mg/Nm^3 = milligrams per normal cubic metre

APPENDIX IV COMPOSITION OF FERROALLOYS[a], FUSED ALUMINA[b] AND SILICON CARBIDE[b]

	Percent										
	Mn	Fe	C	Si	Al	Ca	Mo	V	Ti	W	Cb
Ferromanganese	78										
Spiegeleisen	16 - 19										
	19 - 21										
	21 - 23										
Ferromanganese silicon	63 - 66			28 - 22							
Medium-carbon (MC) ferromanganese	80 - 85		1.25 - 1.50	1.50 max.							
Low-carbon (LC) ferromanganese			0.10 max.								
			0.30								
			0.75								
Silicon metal		0.35									
		0.50									
		1.00									
		1.50									
Ferromolybdenum							50 - 60				
50% Ferrosilicon				50	0.40 max.						
					0.10						
65% Ferrosilicon				65							
High purity				65							
75% Ferrosilicon				75							
0.5% Ca				75							
Low Al				75							
85% Ferrosilicon				85		0.5					
0.5% Ca				85							
Low Al				85							
0.5 - 1.5% Ca				85		0.5 - 1.5					
Silvery pig iron				14							
				16							
				22							

APPENDIX IV COMPOSITION OF FERROALLOYS[a], FUSED ALUMINA[b] AND SILICON CARBIDE[b] (Cont'd)

	Percent											
	Mn	Fe	C	Si	Al	Ca	Mo	V	Ti	W	Cb	Zn
Ferrotitanium			0.10 max.						70			
Ferrocolumbium		35									55 60	
Ferrotungsten												
High purity										77 - 83		
Low moly										76 - 84		
High moly										76 - 84		
Ferrovanadium								52 - 57 70 - 75				
Silicomanganese												
3% C grade	65 - 68		3	12 - 14.5								
2% C grade	65 - 68		2	15 - 17.5								
1.5% C grade	65 - 68		1.5	18 - 20								
Low C	65 - 68											
High Mn	73											
Calcium carbide			26 - 32			44 - 53						
Fused alumina				0.3 - 0.7	50 - 52							
Zirconia alumina				0.4	37 - 39				1.5 - 2.6		18 - 20	
Silicon carbide			27 - 29	63 - 68					1			

a American Metal Market, February 3, 1972
b From data reported in Air Pollution Control Directorate questionnaires, 1976

APPENDIX V GLOSSARY OF TERMS

ACM	-	Actual cubic metre; refers to the volume of gas at the prevailing temperature and pressure.
Acheson furnace	-	An electric resistance furnace used to heat a charge mixture of sand and coke by applying a voltage to a graphite core running through the centre of the trough-shaped furnace.
Alkaline metal earth oxides	-	Family of oxides including calcium, magnesium, sodium, etc.
Baghouse	-	A large chamber for holding fabric filters used to filter gas streams from a furnace or an emission source to recover metal oxides and other solids suspended in the gas.
Charging	-	The process by which raw materials (charge) are added to the furnace.
Cyclone	-	An inertia separator without moving parts; separates particulate matter from a carrier gas by transforming the velocity of an inlet stream into a double vortex confined within the cyclone.
Dust collector	-	A device to remove solid particles from a gas stream.
Electrostatic precipitator	-	A dust collector using a high-voltage electrostatic field formed by negative and positive electrodes; the positive, uncharged electrode attracts and collects the gas-borne particles.
Endothermic reaction	-	A reaction in which heat is absorbed.
Exothermic reaction	-	A reaction in which heat is evolved.
Fabric filter	-	A dust collector using filters made of synthetic, natural or glass fibres within a baghouse for removing solid particulate matter from the air or gas stream.
Ferroalloy	-	An intermediate material used as an additive or charge material in the production of steel and other metals. Historically, these materials were ferrous alloys, hence the name. In modern usage, the term has been broadened to cover materials such as calcium, silicon, calcium carbide, etc., which are produced in a manner similar to that used for the true ferroalloys.

Flux - A material (or mixture of materials) that causes other compounds with which it comes in contact to fuse at a temperature lower than their normal fusion temperature.

Fume - Fine solid particles dispersed in air or gases and formed by condensation, sublimation or chemical reaction.

Higgins furnace - A cylindrical, pot-type batch furnace lined with refractories for smelting a charge mixture of bauxite, steel turnings and coke by the energy from an electric arc.

Ladle - A refractory-lined vessel into which molten metal is poured from a furnace.

Mechanical collector - A dust collector such as a cyclone, a centrifigual separator, etc.

Micron - A unit of measurement which is 1/25000 of an inch or a millionth of a metre; often designated by the Greek letter μ.

Open furnace - An electric furnace with the surface of the charge exposed to the atmosphere, whereby the reaction gases are burned by the inrushing air.

SCM/SCF - Standard Cubic Metre (Foot). The volume of gas measured at standard conditions, 101.325 kilopascals of pressure and 25°C.

Sealed furnace - An electric furnace with a water-cooled cover over the top to limit the admission of air to burn the gases from the reduction process. The furnace may have sleeves at the electrodes (fixed seals) with the charge introduced through ports in the furnace cover, or the charge may be introduced through annular spaces surrounding the electrodes (mix seals).

Sintering - The formation of large particles, conglomerates or masses from small particles by heating alone, or by heating and pressing so that certain constituents of the particles coalesce, fuse or otherwise band together.

Slag - The more or less completely fused and vitrified matter separated during the reduction of a metal from its ore.

Spark arrestor - A device over the top of the furnace and in front of the gas cleaning device to prevent the emission of sparks.

Stoking -	The means by which the upper portion of the charged material in the furnace is stirred up. This loosens the charge and allows free upward flow of the furnace gas.
Submerged-arc furnace -	In ferroalloy reduction furnaces, the electrodes usually extend to a considerable depth into the charges; hence, such furnaces are called submerged-arc furnaces. This name is used for the furnaces whose loads are almost entirely of the resistance type.
Tapping -	A process whereby slag or product is removed from the electric submerged-arc furnace.
Tapping period -	That period of time during which product or slag flows from the electric submerged-arc furnace.
Venturi scrubber -	A gas cleaning device in which the liquid injected at the throat of a venturi is used to scrub particulate matter from the gas flowing through the venturi.
Wet scrubber -	A dust collector which uses a liquid to achieve or assist in the removal of solid or liquid dispersoids from a carrier gas.