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# Air Pollution Emissions and Control Technology: Ferrous Foundry Industry

Economic and Technical Review
Report EPS 3-AP-78-1

...tion Control Directorate

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# AIR POLLUTION EMISSIONS AND CONTROL TECHNOLOGY: FERROUS FOUNDRY INDUSTRY

by

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## NOTE TO READERS

The federal government is empowered to publish national guidelines concerning 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. It might, therefore, be considered a description of the current state-of-the-art.

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 the federal guideline for new sources. In recommending national emission guidelines, the federal 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 in order 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 specific abatement programs for existing sources. Existing plants, although excluded from the guideline recommendation 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 Ferrous Foundry Industry.

## ABSTRACT

This report provides background information for establishing national emission guidelines, as set forth in Section 8 of the Clean Air Act, for the Canadian ferrous foundry industry. The main source of information was replies to two questionnaires distributed in 1974 to the headquarters of the various foundries in the country. The information reported pertains to the year 1973.

The industry in Canada is reviewed with respect to plant sizes and locations, products and emissions. Control technology is discussed and its potential for emission reduction is estimated.

The ferrous foundry industry supplies a multitude of casting components to the automotive, farm equipment, construction and resource industries, which play an important role in the Canadian economy. Total emissions of particulate matter from the production of castings in Canada during 1973 were calculated at 14 126 tons. Other air pollutants such as carbon monoxide, sulphur oxides, hydrocarbons and odour associated with production of castings were found to create only local problems and should not be considered on a national basis.

Most of the ferrous foundry plants are located in industrial and residential communities. There have been complaints about the high levels of emissions from some of the plants located in residential areas. As a result the operators of these plants are striving to reduce particulate emissions to acceptable levels. Their efforts are demonstrating that the application of available technology can result in emission control sufficient to satisfy regulatory limits being considered by government agencies.

A glossary of terms is included to help readers understand the sometimes complex terminology used in the report.

## RÉSUMÉ

Ce rapport fournit des renseignements fondamentaux en ce qui a trait à l'établissement des directives nationales de dégagement, prévues à l'article 8 de la Loi sur la lutte contre la pollution atmosphérique, à l'intention de la sidérurgie canadienne. Ces données proviennent principalement des deux questionnaires distribués en 1974 aux sièges sociaux des différentes fonderies canadiennes. Ces renseignements se rapportent donc à l'année 1973.

On étudie l'industrie canadienne en tenant compte de la dimension des usines, de leur emplacement, de la nature des produits manufacturés et de la pollution atmosphérique engendrée. On discute également des moyens techniques de réduire les émissions et de l'efficacité éventuelle de ces procédés.

L'industrie sidérurgique fournit une multitude de pièces de fonte pour la fabrication des automobiles et de l'outillage agricole. Elle sert également l'industrie primaire et celle du bâtiment; tous ces secteurs représentent des leviers importants de l'économie canadienne. Pour l'année 1973, les émissions totales de particules, provenant de la production de pièces de fonte, furent évaluées à 14 126 tonnes. Ce genre d'émissions aurait été réduit de 55 p. 100 si l'on avait appliqué les mesures de lutte proposées. On a jugé que les autres polluants atmosphériques associés à la production de pieces de fonte, comme le monoxyde de carbone, les oxydes de soufre, les hydrocarbures et les odeurs nauséabondes, ne causaient que des problemes locaux et que, par conséquent, il n'apparaissait pas nécessaire d'en tenir compte à l'échelle nationale.

La plupart des usines sidérurgiques sont situées dans les secteurs industriels et résidentiels. Des plaintes ont été formulées à l'égard de certaines usines de quartiers résidentiels en raison de leurs émissions excessives d'agents de pollution. Par conséquent, la direction de ces usines s'efforce de réduire ces émissions de particules à un niveau acceptable. Il en ressort que l'application des moyens techniques peut se traduire par une réduction telle qu'elle satisfasse aux exigences fixées par les organismes gouvernementaux.

La terminologie de ce rapport étant parfois complexe, un glossaire y est inclus dans le but d'en faciliter la compréhension.

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# 1 INTRODUCTION

## 1.1 Scope

In this report are described the various technologies in air pollution control as applied to the ferrous foundry industry. The size and location of plants, products, relative importance of the industry to the Canadian economy, and process and emission control technology are discussed. Results from a national emissions inventory (1973) are included. The cost of pollution control is estimated, using data from the literature and information supplied by the ferrous foundry industry.

## 1.2 Purpose

The primary purpose of this report is to provide the necessary information for the preparation of national emission guidelines for new ferrous foundry 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.

The secondary purpose is to provide information to update the national emissions inventory published by the Air Pollution Control Directorate and to assist in the development of federal briefs, state-of-the-art reviews and other documents related to air pollution emanating from ferrous foundry plants.

## 1.3 Information Sources

The main source of information for this report was replies to two questionnaires sent by the Air Pollution Control Directorate in August 1974 to the headquarters of the ferrous foundry companies. There were 176 iron and steel foundries operating in Canada in 1973 according to a survey by the Department of Industry, Trade and Commerce (3).

The questionnaries - one relating to foundries generally and the other to those with electric arc furnaces - were drafted by the Abatement and Compliance Branch. They were reviewed by Statistics Canada, provincial regulatory agencies and Environmental Protection Service regional offices. Final revisions were made in consultation with the Canadian Foundry Association.

Copies of the questionnaires are available, in both official languages, from the author on request.

A computer search of the literature was conducted by the National Science Library and the Environmental Protection Agency (EPA) of the United States. Copies of original papers were acquired through the Environment Canada library and articles from the most recent trade literature were reviewed. A general source of information was the Kearney report (1) on the ferrous foundry industry, supplemented by a more detailed study by Hatch Associates (2), contracted for the Mining, Mineral and Metallurgical Division of the Abatement and Compliance Branch.

Personal contacts were made with members of the National Research Council of Canada and the federal government departments of Energy, Mines and Resources, Industry, Trade and Commerce, and Statistics Canada.

# 2 INDUSTRY DESCRIPTION

## 2.1 Size

One hundred and ten iron foundries and 31 steel foundries completed and returned the questionnaires. Those that did not were presumably the very small foundries producing less than 2500 tons of castings a year. Possibly some had ceased operations by the time the questionnaires were sent, as there has been a trend toward fewer cast iron foundries. A combination of increasing labour costs, rising raw material prices and unwillingness or inability to raise capital for improvement, expansion or installation of pollution control equipment, has resulted in the demise of some of the smaller or less efficient foundries.

Total 1973 production of the 110 iron and 31 steel foundries reporting was 1 375 523 tons and 462 845 tons, respectively. Tables 1 and 2 show a breakdown of these figures by region and foundry size.

## 2.2 Employment

There were 20 708 employees in the ferrous foundry industry in 1973, a 12% increase since 1968 (3). Table 3 shows a breakdown of employment according to foundry type and province.

## 2.3 Geographic Distribution

The geographic distribution of ferrous foundries in Canada is shown in Figure 1. Ontario and Quebec together have about two-thirds of the total. Most of the plants are near major markets to keep transportation costs and, accordingly, the total purchase price to the consumer as low as possible.

## 2.4 Products

Cast iron includes gray, ductile, white, alloy and malleable irons. They are commonly alloys of iron, carbon and silicon. Carbon, low alloy, high alloy and manganese steel are products of steel foundries.

Gray iron castings are the most important product of iron foundries, whereas carbon steel represents more than 80% of steel foundry production. Table 4 lists the types of iron and steel castings produced in Canada in 1973.

TABLE 1 CANADIAN IRON AND STEEL FOUNDRY CAPACITY AND PRODUCTION OF CASTINGS, 1973*

| Iron Foundries Region | Number of Foundries | Production Capacity (3) (tons) | Production of Castings (tons) |
|---|---|---|---|
| Ontario | 54 | 1 238 100 | 1 045 625 |
| Quebec | 15 | 267 700 | 180 800 |
| Northwest[a] | 17 | 86 600 | 83 238 |
| Pacific[b] | 8 | 50 700 | 37 750 |
| Atlantic[c] | 16 | 30 700 | 28 110 |
| Canada Total | 110 | 1 673 800 | 1 375 523 |
| **Steel Foundries Region** | **Number of Foundries** | **Production Capacity (tons)** | **Production of Castings (tons)** |
| Ontario | 6 | 86 400 | 81 150 |
| Quebec | 10 | 91 500[d] | 270 329 |
| Northwest | 5 | 90 100 | 77 953 |
| Pacific | 9 | 22 600 | 31 413 |
| Atlantic | 1 | | 2 000 |
| Canada Total | 31 | 290 600 | 462 845 |
| Total Iron and Steel Foundries | 141 | 1 964 400 | 1 838 368 |

a Northwest Region includes the provinces of Alberta, Saskatchewan and Manitoba and the Northwest Territories.

b Includes the Yukon.

c Includes Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland.

d Value included production capacity of one Atlantic region steel foundry, but excluded the production capacity of Hawker Siddeley Canada Limited, Montreal.

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

*Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 2 REPORTED TOTAL CASTING PRODUCTION BY FOUNDRY SIZE AND REGION, 1973*

| Region | Foundry Size (tons of castings/year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 - 2 500 | 2 501 - 5 000 | 5 001 - 10 000 | 10 001 - 20 000 | 20 001 - 50 000 | 50 001 - 100 000 | >100 000 | Total | % of Total |
| ONTARIO | | | | | | | | | |
| No. of Foundries | 23 | 11 | 9 | 6 | 6 | 2 | 3 | 60 | 42.5 |
| Production (tons) | 27 348 | 41 250 | 67 800 | 85 000 | 233 625 | 112 752 | 559 000 | 1 126 775 | 61.3 |
| QUEBEC | | | | | | | | | |
| No. of Foundries | 8 | 4 | 5 | 3 | 3 | 1 | 1 | 25 | 17.7 |
| Production (tons) | 6 679 | 14 500 | 31 325 | 48 000 | 88 125 | 82 500 | 180 000 | 451 129 | 24.5 |
| NORTHWEST | | | | | | | | | |
| No. of Foundries | 11 | 5 | 3 | 1 | 1 | 1 | - | 22 | 15.6 |
| Production (tons) | 10 888 | 19 700 | 21 312 | 13 250 | 31 000 | 65 041 | - | 161 191 | 8.8 |
| PACIFIC | | | | | | | | | |
| No. of Foundries | 11 | 3 | 1 | 2 | - | - | - | 17 | 12.1 |
| Production (tons) | 12 163 | 12 500 | 7 500 | 37 000 | - | - | - | 69 163 | 3.8 |
| ATLANTIC | | | | | | | | | |
| No. of Foundries | 14 | 1 | 1 | 1 | - | - | - | 17 | 12.1 |
| Production (tons) | 7 110 | 3 000 | 5 500 | 14 500 | - | - | - | 30 110 | 1.6 |
| CANADA | | | | | | | | | |
| No. of Foundries | 67 | 24 | 19 | 13 | 10 | 4 | 4 | 141 | 100.0 |
| Production (tons) | 64 188 | 90 950 | 133 437 | 197 750 | 352 750 | 260 293 | 739 000 | 1 838 368 | 100.0 |
| % of Foundries | 47.5 | 17.1 | 13.5 | 9.2 | 7.1 | 2.8 | 2.8 | 100.0 | |
| % of Production | 3.5 | 4.9 | 7.2 | 10.8 | 19.2 | 14.2 | 40.2 | 100.0 | |

Metric Conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

*Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 3 EMPLOYMENT IN CANADIAN FERROUS FOUNDRIES (3)*

| Province | Number of Employees | |
|---|---|---|
| | 1968 | 1973 |
| IRON | | |
| British Columbia | 353 | 416 |
| Alberta-Saskatchewan | 422 | 596 |
| Manitoba | 204 | 507 |
| Ontario | 11 257 | 10 702 |
| Quebec | 1 806 | 2 515 |
| New Brunswick | 240 | 264 |
| Nova Scotia | 62 | 64 |
| Total | 14 344 | 15 064 |
| STEEL | | |
| Quebec-Atlantic | 1 826 | 2 242 |
| Ontario | 1 558 | 2 182 |
| Prairies | 337 | 445 |
| British Columbia | 475 | 775 |
| Total | 4 196 | 5 644 |
| Total Iron and Steel Foundries | 18 540 | 20 708 |

*Report of the Canadian Ferrous Foundry Industry: 1974 National Survey, Department of Industry, Trade and Commerce.

## 2.5 Relative Importance

The ferrous foundry industry supplies a multitude of casting components to the automotive, farm equipment, construction and resource industries (Table 5). In 1973, combined sales were approximately $535 million ($411 million for iron foundries and $124 million for steel foundries). Domestic sales accounted for $452 million and exports $83 million (3).

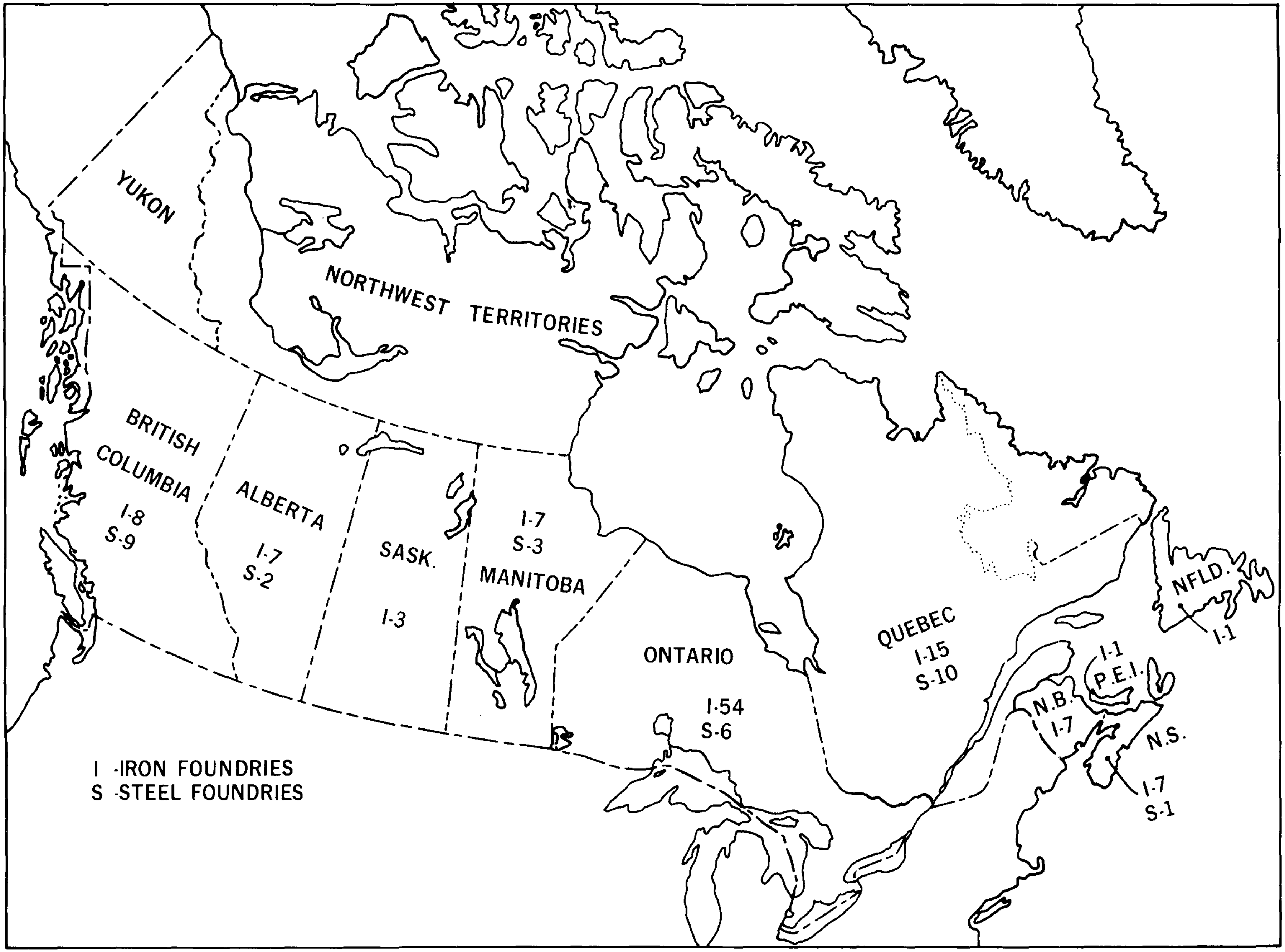



FIGURE 1 DISTRIBUTION OF IRON AND STEEL FOUNDRIES IN CANADA

TABLE 4 REPORTED IRON AND STEEL CASTING PRODUCTION BY CATEGORY, 1973

| Iron Foundries | Production of Castings (tons) | % of Total |
|---|---|---|
| Gray | 788 527 | 57.3 |
| Ductile | 473 412 | 34.4 |
| Malleable | 49 377 | 3.6 |
| White | 21 580 | 1.6 |
| Alloy | 42 627 | 3.1 |
| Total | 1 375 523 | 100.0 |
| **Steel Foundries** | **Production of Castings (tons)** | **% of Total** |
| Carbon | 400 723 | 86.6 |
| Low Alloy | 20 387 | 4.4 |
| High Alloy | 1 987 | 0.4 |
| Manganese | 39 748 | 8.6 |
| Total | 462 845 | 100.0 |
| Total Iron and Steel Castings | 1 838 368 | |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

*Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 5 PREFERRED MARKETS FOR IRON AND STEEL CASTINGS, 1973 (3)*

| Market | Iron Casting Production (%) | Steel Casting Production (%) |
|---|---|---|
| Automotive | 39 | 19 |
| Agriculture | 6 | - |
| Construction and Municipal | 26 | 6 |
| Mining | 6 | 19 |
| Railway Operation and Equipment | 2 | 36 |
| Other | 21 | 20 |

*Report of the Canadian Ferrous Foundry Industry: 1974 National Survey, Department of Industry, Trade and Commerce.

# 3 INDUSTRIAL PROCESSES

## 3.1 General

Ferrous foundries include iron and steel foundries. Iron foundries are those that melt iron in furnaces, pour the molten iron into moulds and treat it in either the molten or cast state to make gray, malleable or ductile cast iron. Steel foundries normally melt and refine scrap steel to produce castings. The iron and steel molten metal, which is used for castings, is produced in cupola, induction, electric arc or reverberatory air furnaces.

Foundry processes are classified into melting and non-melting operations. Figure 2 is a simplified flow diagram illustrating most of the foundry processes.

## 3.2 Melting Operations (1, 2)

Metallic and flux materials are charged into the melting furnace. The molten metal from the furnace is then tapped directly into any one of the following: a ladle for direct mould pouring, a transfer ladle for conveying to the moulding area, or a heated or unheated holding device.

**3.2.1 Cupola Furnaces.** The cupola furnace is a vertical furnace with a circular cross section. Two widely used types are the conventional refractory lined cupola and the unlined, water-cooled cupola (Figure 3).

At the beginning of the melting cycle, a coke bed is placed on a 6- to 10-inch deep sand-bed bottom, to support and contain the molten metal, and ignited. More coke is added to a height of five feet above the tuyeres (located at the bottom) after which regular layered charges of metal, limestone and coke are placed on the coke bed up to the normal operating height. As the metallic charge moves downward, it is preheated by the hot gases resulting from combustion. These gases include carbon monoxide, carbon dioxide, nitrogen, hydrogen and sulphur dioxide. As the metal enters the melting zone, the atmosphere is highly reducing in nature, with no free oxygen. The molten iron, trickling over the incandescent coke and becoming hotter, reaches the combustion zone where the atmosphere becomes oxidizing because of the presence of oxygen from the blast air. As melting proceeds, metal collects at the bottom of the cupola or well. The molten metal may be tapped off at intervals (most commonly) or left to flow continuously through the taphole. Slag may be drained from a slag hole at the back, or in some installations it flows from the front and is separated in a slag well or in a ladle. When a

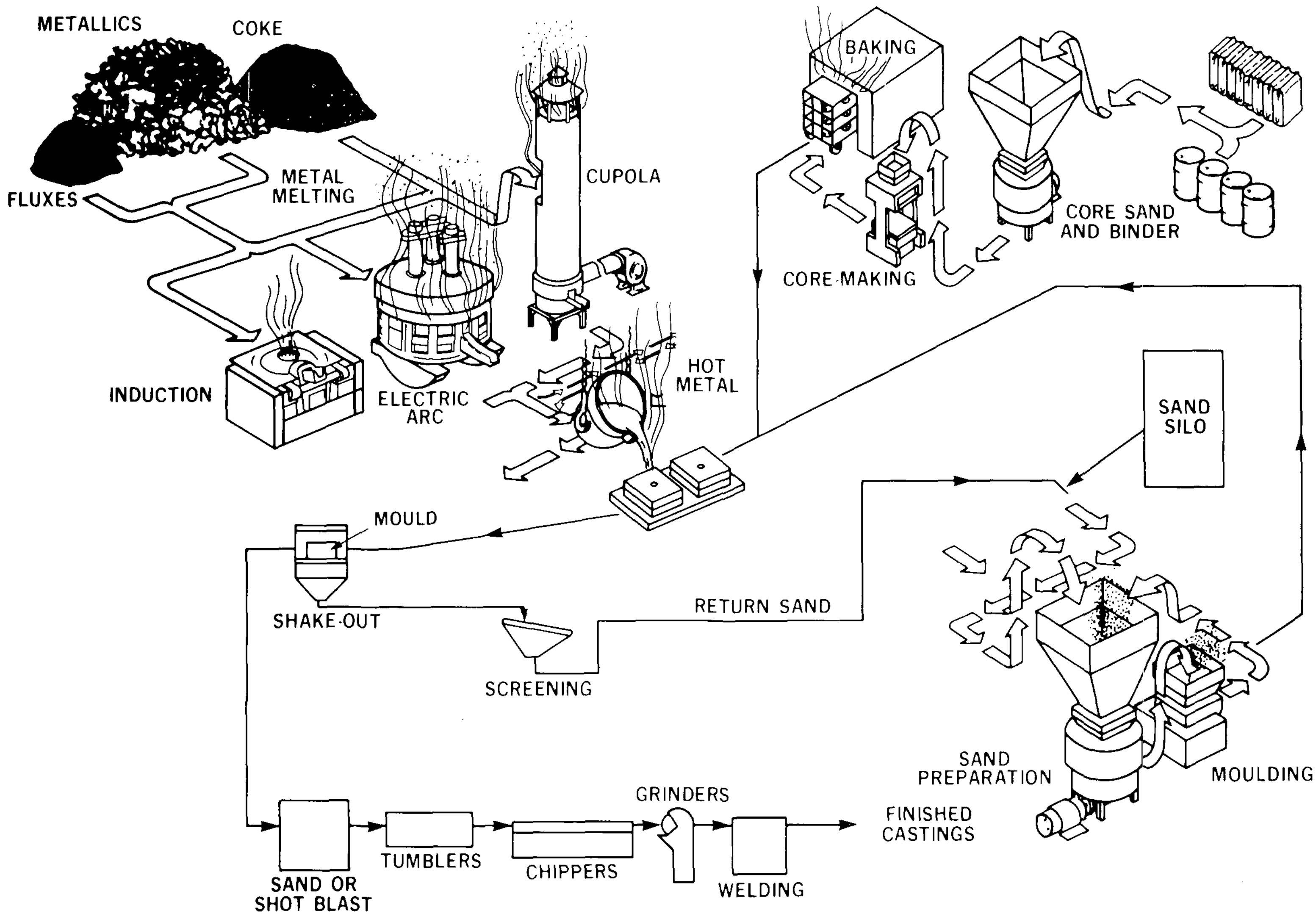



FIGURE 2 FERROUS FOUNDRY PROCESS FLOW DIAGRAM

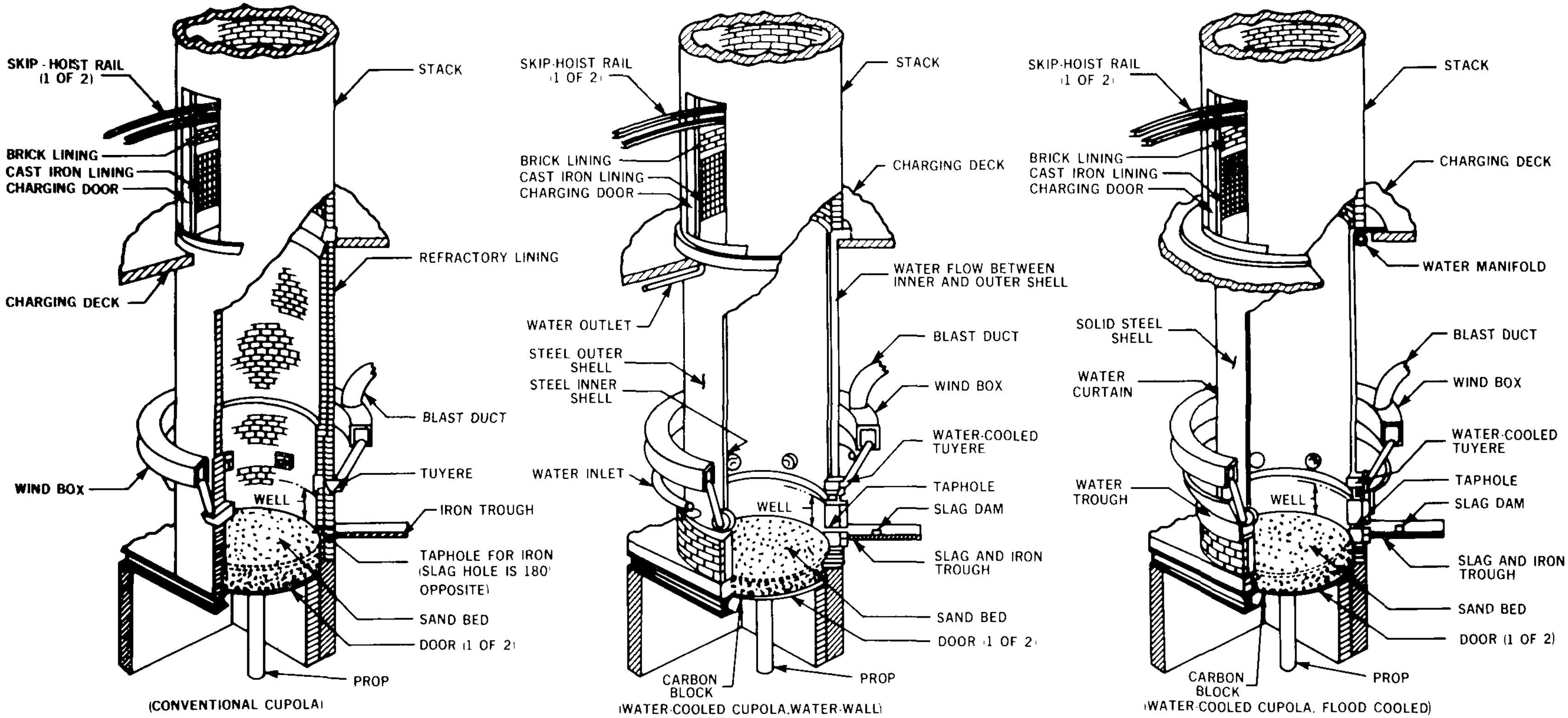



FIGURE 3 ILLUSTRATION OF CUPOLA FURNACES
SOURCE: METALS HANDBOOK, 8th EDITION, VOL.5, FORGING AND CASTING, AMERICIAN SOCIETY FOR METALS, 1970, p. 337.

production cycle (commonly an eight-hour shift) is complete, the bottom door is dropped and all unburned coke, slag and molten metal falls. After the unit has cooled, it is patched and readied for the next cycle (usually the next day). In high-volume operations using water-lined cupolas, a cycle may last one to six weeks before the charge is dropped.

3.2.2 **Induction Furnaces.** The induction furnace is a cup- or drum-shaped vessel that converts electrical energy into heat, using the transformer principle, to melt the charge (Figure 4). The charge usually consists of steel scrap, cast iron scrap, foundry returns, and ferrosilicon and carbon to adjust composition, and is made from the top. Both coreless and channel induction furnaces are used to produce either iron or steel castings.

3.2.3 **Electric Arc Furnaces.** The electric arc furnace can be used for both iron and steel casting production. In Canada, however, it is used primarily in steel foundries. It consists of a refractory lined, cylindrical vessel made of heavy welded steel plates. It has three electrodes, made of graphite or carbon, which are mounted on a superstructure above the furnace and can be lowered and raised through holes in the furnace roof. A transformer vault adjacent to the furnace is required to house items such as current and potential transformers and circuit breakers. Multi-voltage, tap charger transformers are used to make voltage changes as necessary during the melting cycle (Figure 5).

Melt-down begins by striking an arc through the electrodes using the highest voltage tap in the transformer. After the scrap has melted, the metal bath surface becomes completely flat, with no unmelted pieces floating in it. When the desired temperature is reached, the molten material is skimmed to remove the slag (power off) followed by a further refining of the melt (power restored at a lower tap).

3.2.4 **Reverberatory Furnaces.** The reverberatory furnace is a long, rectangular unit with an arched or suspended roof, generally fired from one end, and with waste gases exhausting into a stack from the other end. The large, stationary reverberatory or air furnace is used mainly to receive molten iron from the cupola, and to refine and superheat it for pouring. The small type is generally used for melting. Only one foundry in Canada is using a reverberatory for melting.

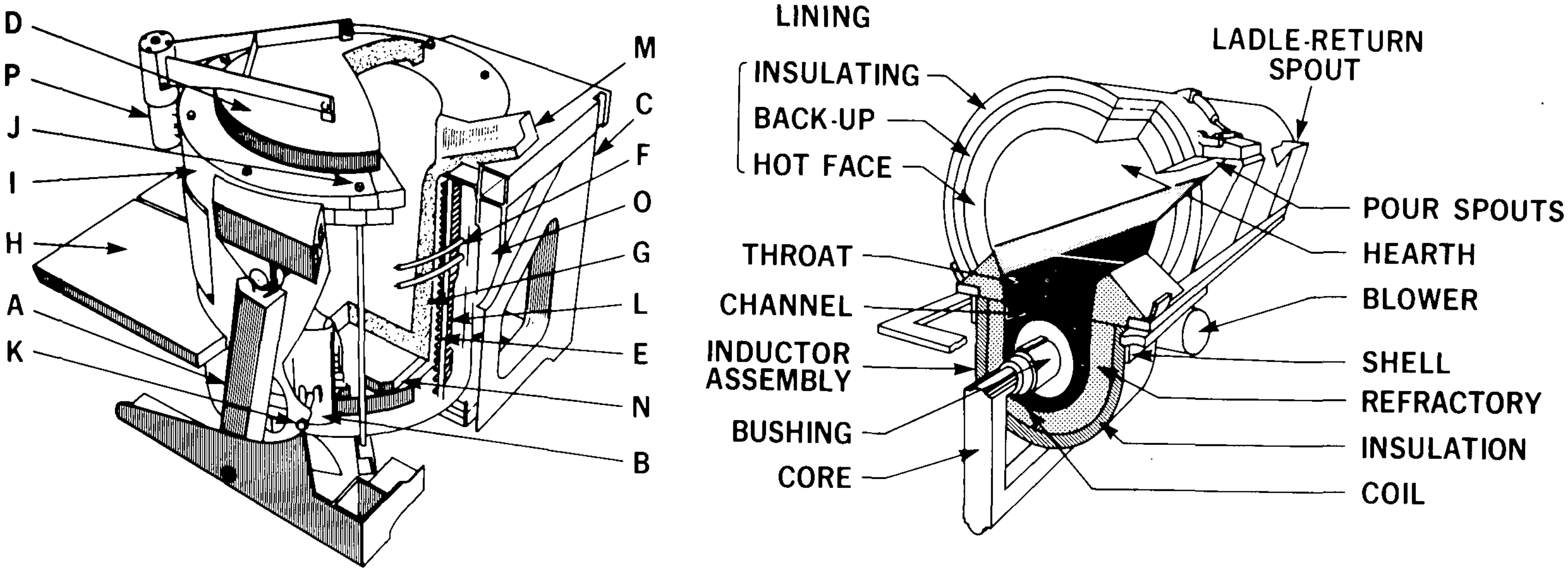
### 3.3 Non-Melting Operations (1, 2)

Non-melting operations comprise the following:

- raw material storage, preparation and charging
- sand conditioning and reclamation

CORELESS INDUCTION FURNACE

CHANNEL INDUCTION FURNACE




A HYDRAULIC TILT CYLINDERS
B SHUNTS
C STANCHION
D COVER
E COIL
F LEADS
G WORKING REFRACTORY
H OPERATOR'S PLATFORM
I STEEL SHELL
J TIE RODS
K CLAMPING BOLTS
L COIL SUPPORT
M SPOUT
N REFRACTORY BRICK
O ACCESS PORT
P LID HOIST MECHANISM

**FIGURE 4 ILLUSTRATION OF INDUCTION FURNACES**

SOURCE: ELECTRIC MELTING FOR MASS PRODUCTION
IN U.S. IRON FOUNDRIES,
MODERN CASTING, JULY, 1968 , p. 47.

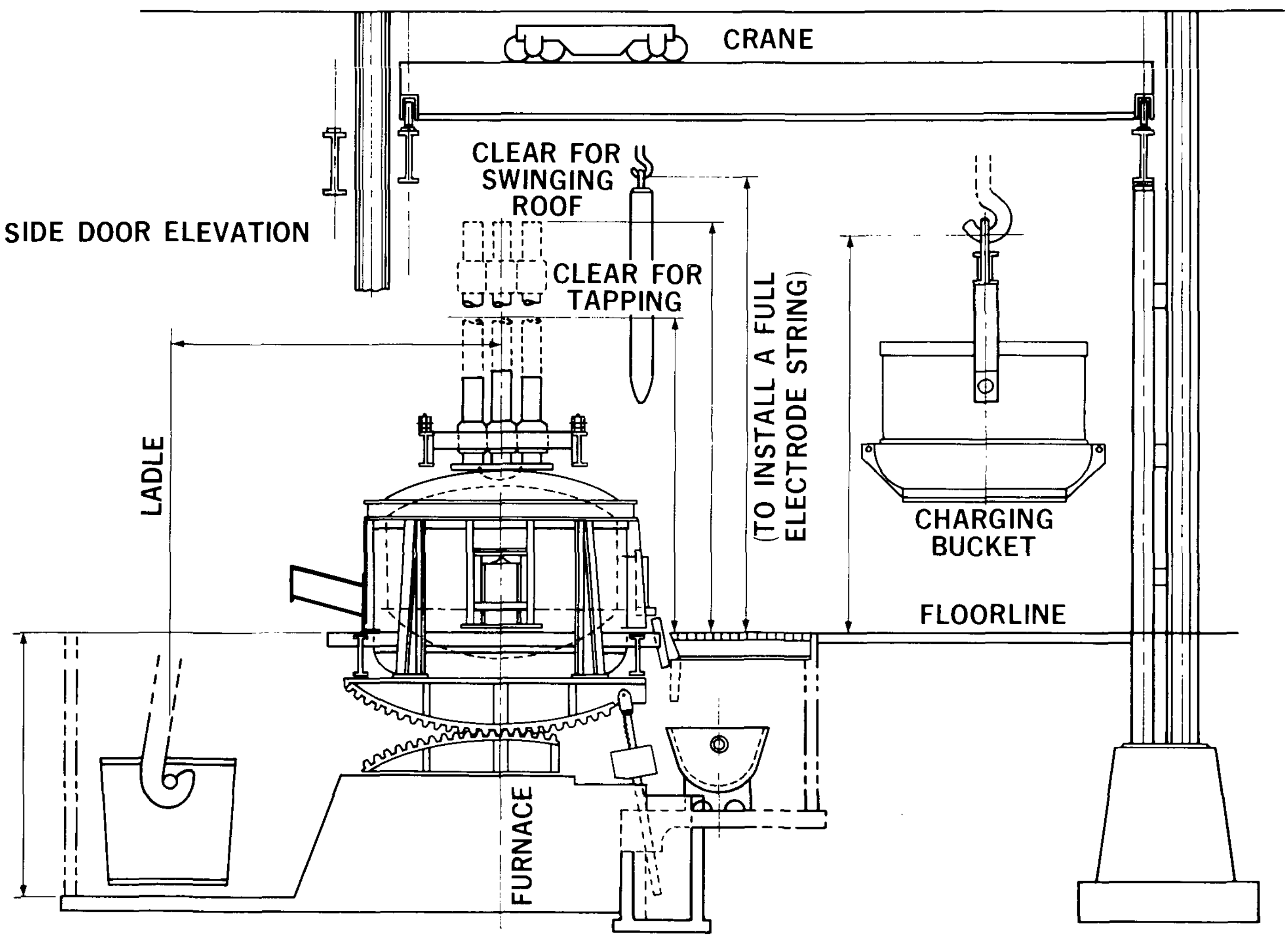



FIGURE 5 ILLUSTRATION OF ELECTRIC ARC FURNACE

SOURCE: AMERICAN BRIDGE - DIVISION OF UNITED STATES STEEL

- pattern-making
- core-making
- moulding, pouring and shake-out
- cleaning, heat treating and finishing.

3.3.1 **Raw Material Storage, Preparation and Charging.** The raw materials used for iron production are metallics, fluxes, fuels (coke, for cupolas) and refractories. These materials are stored in the foundry scrapyard. Although open scrapyards are common, the use of covered storage is desirable.

Scrap materials are mainly used as received. If scrap preparation is required, it may involve cutting to size, cleaning by degreasing and burning of surface coatings, drying or preheating. With the exception of the cutting operation, scrap preparation is not widely performed.

Methods of make-up and handling of melting furnace charges vary from the completely manual to the highly mechanized. Charges are normally loaded directly into the furnace charging bucket. The prescribed combination of metallics, flux and coke (for cupolas) is weighed either before or during loading.

3.3.2 **Sand Conditioning and Reclamation.** Sand is used in substantial volume as a moulding medium. It is the major raw material used, four to ten tons being required to make one ton of steel castings.

Raw materials requiring handling and storage after receiving include the silica sand and various additives such as clay, carbonaceous materials, synthetic resins and cereal binders. Pre-mixed bonded sand is used by foundries doing shell moulding.

The naturally bonded moulding sand formerly used for green sand moulding has been almost completely replaced by clean silica sand to which are added water and various binders required to produce the desired moulding characteristics. High-volume foundries normally reuse the moulding sand several times each shift. If the sand is not properly cooled after each use its characteristics will change, resulting in casting defects. Conventional cooling is accomplished by directing cool air through the return sand system during transport, screening and fluffing.

Three basic types of sand reclamation units are available: dry, wet and thermal. Dry reclamation may consist of magnetic separation followed by crushing, screening and air separation. A pneumatic scrubber may be used to remove some of the coatings on the sand grains. In wet reclamation all fines and foreign materials are removed from the sand and individual sand grains are cleansed of their tenacious coating.

The thermal reclaimer removes organic and carbonaceous residues which would be left by the wet process, by heating the sand to 650°C - 815°C (1200°F-1500°F) in furnaces. A combination of wet and thermal reclamation will restore foundry sands to their original quality.

3.3.3 **Pattern-making.** Wood patterns are used to make the moulds for small production runs. Patterns can also be made of aluminum, magnesium, iron or plastic.

3.3.4 **Core-making.** Cores are normally made of silica sand and organic or inorganic binders. Selection of the core formulation and process best suited to a particular application requires consideration of many factors including green strength, dry strength, porosity, core complexity, quantity of core required, raw material, equipment and production costs. The following are the major core-making processes in current use for castings.

3.3.4.1 **Oil sand cores.** Vegetable and mineral oil are commonly used as binders, although cereal binders and clay are often used in conjunction with them. Cereal binders are added to improve green and dry bond strength and to improve collapsability of the core. Clay is often added in small amounts to increase the green strength.

3.3.4.2 **Shell cores.** Shell cores are usually made with phenol-formaldehyde resin and sand. Hollow shell cores are made by the investment process, and small, solid cores can be made in a hot-box machine. No oven is required because the cores cure quickly in the core-making machine.

3.3.4.3 **Silicate bonded cores.** Silicate bonded cores are made in a moulding or core-blowing machine and set by applying carbon dioxide in a manner that permits the gas to completely permeate the core.

3.3.4.4 **Furan air-set cores.** Furan air-set cores employ resins made from furfuryl alcohol, ureas and formaldehydes. The resins are mixed with core sand and a phosphoric acid activator in conventional mixing equipment.

3.3.4.5 **Hot-box resin cores.** Hot-box resins include furfuryl alcohol, urea-formaldehyde and phenol urea-formaldehyde. The liquid resin is mixed with the core sand and activated in conventional mixing equipment. An exothermic reaction between the resin and the activator progresses quickly when the mixture enters the heated core box in a core blower.

Core-finishing operations consist of cleaning, sizing and assembling. The cleaning operations include trimming, brushing, coating, mudding and venting. Sizing includes gauging of the core and filing or grinding to the required dimensions.

3.3.5 **Moulding.** Many moulding materials and types of equipment are used in the production of ferrous castings. The following techniques are in current use:

3.3.5.1 **Green sand moulds.** These moulds are commonly made of silica sand, clay, water and organic binders mulled together to form a mould mixture suitable for use with manual or automated moulding machines and sand slingers. The moulds are occasionally skin or air dried to produce a better finish. Of all types of moulds used today, the greatest tonnage is produced from green sand moulds. No baking operation is required.

3.3.5.2 **Dry sand moulds.** The sand used in these moulds contains additives such as pitch, sodium silicate, gilsonite, cereal, molasses, dextrin, gluten and resins, which produce a high dry strength and rigid mould walls. Smaller mould parts are prepared in the same type of equipment as that used for green sand moulds where the dry sand mix is introduced into the flask or core box and becomes part of the mould itself. These smaller mould parts are then baked or dried at temperatures of 149°C-316°C (300°F-600°F).

3.3.5.3 **Shell and hot-box moulds.** The sand used consists of a mixture of dry sand grains and a synthetic resin binder. The resin must be the thermosetting type since the strength developed by the mould depends primarily on the strength of the binder after the mould has been heated. The sand mix is introduced into a metal box or laid against the pattern plate at a temperature of 177°C-371°C (350°F-700°F), and the resin becomes partially thermoset and builds up a coherent thin shell next to the pattern.

3.3.5.4 **Full mould process.** Polyurethane or polystyrene foam is used to fabricate a pattern. The pattern is either machined from a single block, or individual pattern pieces are cut and then glued or fastened together. Metal is poured into the mould, vapourizing the pattern and replacing it with metal.

3.3.5.5 **No-bake processes.** The three most commonly used processes are the Rheinstahl, the alkyd-isocyanate and the phenol-isocyanate.

The Rheinstahl process uses cement as a binder that promotes a high density mould mix resulting in a cement-bonded, fluid moulding sand.

The alkyd-isocyanate process involves the use of a synthetic oil binder which, when mixed with sand and activated chemically, produces cores that cure at room temperature.

The phenol-isocyanate process, introduced in 1971, is based on a urethane resin system. One type consists of a binder and catalyst used in equal portions.

3.3.6 **Ladle Inoculation.** Hot iron metal from cupola, induction or other furnaces may be inoculated with magnesium, among other ingredients. It is a process applied either in the production of ductile iron, where it is known as magnesium treatment, or to improve the mechanical properties of the castings, such as gray iron. An inoculant can be introduced to the molten metal in the cupola spout, forehearth, transfer ladle, pouring ladle or mould.

3.3.7 **Pouring.** In high-volume foundries, finished moulds are set out on conveyors and poured within minutes of completion; in low-volume foundries, the moulds are set out on the floor until hot metal is available.

3.3.8 **Shake-out.** In many foundries the casting is separated from the moulding sand manually. However, in modern, more mechanized foundries, a heavy-duty vibrating screen is used. The sand flows through the screen openings to the return system for transfer to the sand conditioning system. The castings can be removed from the shake-out grid manually with a hoist, or by action of the vibrating screen, for cooling and sorting.

3.3.9 **Cleaning, Heat Treating and Finishing.** Cleaning of castings generally refers to the operations in the removal of sand, scale, sprues, gates and risers or any other metal not part of the casting. Normally sprues, gates and risers are removed first. This is done by impact, shearing, abrasive cut-off, sawing or torch-cutting depending on the size and type of metal. Surface cleaning operations ordinarily are the next step and include abrasive techniques such as shot-blasting, sand-blasting and tumbling. The sand and scale may also be removed by wire-brushing, bluffing or pickling. Only malleable iron castings are heat treated before surface cleaning, while most other castings requiring heat treatment undergo it after surface cleaning.

Heat treatment is used to improve physical characteristics and machinability of castings. Batch-type or continuous furnaces may be used depending on the type of heat treatment and production requirements.

Finishing operations follow cleaning and heat treatment to remove all surface imperfections that are not part of the casting's final dimensions. Chipping hammers and grinders are used for these operations. Castings that can be handled manually are trimmed or ground on bench, floor-stand or portable grinders. Swing-frame or portable grinders are used for trimming castings too heavy to be carried or held by hand.

Most castings are ready for shipment after finishing operations are completed. However, to prevent rust a surface coating is sometimes applied. The painting may be done in spray booths or dip tanks followed by drying in an oven.

## 4 TYPES OF EMISSIONS

The major air contaminants emitted by ferrous foundries are particulates, with the cupola melting operation the largest single source. Possible sources and types of emissions, listed in production sequence, are as follows (4):

| DEPARTMENT | OPERATION | | TYPE OF EMISSION |
|---|---|---|---|
| Raw Material Storage and Charge Make-up | a) | Store metal scrap, coke, limestone, dolomite, fluorspar, silica sand | coke dust<br>limestone and sand dust |
| | b) | Centrifuge or heat metal borings and turnings to remove cutting oil | oil vapours<br>smoke<br>unburned hydrocarbons |
| | c) | Weigh charge materials | coke and limestone dust |
| Melting | a) | Cupola | fly ash<br>coke breeze<br>smoke<br>metallic oxides<br>sulphur dioxide<br>oil vapours<br>carbon monoxide |
| | b) | Electric Arc | smoke<br>metallic oxides<br>oil vapours |
| | c) | Induction | oil vapours<br>metallic oxides |
| | d) | Furnace charge pre-heating or drying | smoke<br>oil vapours<br>metallic oxides |
| | e) | Inoculation | metal oxides |
| Sand Conditioning | a) | New sand storage | fines |
| | b) | Sand handling system | fines<br>steam |
| | c) | Screening | fines |
| | d) | Mixing | fines<br>cereal binder<br>bentonites<br>sea coal<br>cellulose |

| | | | |
|---|---|---|---|
| | e) | Drying and reclamation | dust<br>vapours<br>products of combustion |
| Core-making | a) | Sand storage | sand fines<br>flour<br>binders |
| | b) | Core-making | sand fines<br>dust |
| | c) | Baking | vapours<br>smoke |
| Moulding, Pouring and Shake-out | a) | Moulding | sand dust<br>vapour |
| | b) | Pouring | core oil vapours<br>facing fumes<br>metallic oxides<br>fluoride fumes<br>magnesium oxide fumes<br>organic vapours |
| | c) | Shake-out | sand fines<br>fumes<br>water vapour<br>dust |
| Cleaning and Finishing | a) | Abrasive Cleaning | dust |
| | b) | Grinding | metal dust<br>sand fines<br>abrasives<br>wheel bond material<br>vitrified resins |
| | c) | Annealing and heat treatment | combustion vapours |
| | d) | Painting - spray and dip | volatile fumes<br>paint and water<br>spray carryover |

# 5 NATIONAL EMISSIONS INVENTORY DATA - PARTICULATES

## 5.1 Data Previously Published

Emissions of particulates from various industrial processes during 1970 were calculated to be 1 400 200 tons, as reported in a nationwide inventory of air pollutant emissions (5). A breakdown of particulate emissions by these industries (Table 6) shows that the ferrous foundry industry emitted 25 600 tons of particulates or approximately 1.8% of the total. However, in the past few years the industry has been investing in air pollution control equipment to reduce emissions of particulates as provincial regulatory requirements are introduced. The data in this report show the industry's success in combatting pollution, as emissions of particulates were substantially reduced to 14 126 tons in 1973.

## 5.2 Data Obtained from the Air Pollution Control Directorate Questionnaires, 1974

Data reported in the Air Pollution Control Directorate questionnaires were used for compiling particulate emissions from the Canadian ferrous foundry industry (Tables 7 and 8). A breakdown of emissions and emission factors according to foundry type, size and operation is shown in Tables 9 to 16.

Of the 14 126 tons of particulates released by the industry in 1973, the melting operations accounted for approximately 48%, while the non-melting operations accounted for the remainder (Table 9). The cupola furnace is the largest single source of particulate emissions in the melting operation, accounting for approximately 35% of the total. Sand conditioning and pouring are the two largest emission sources in the non-melting operations, releasing approximately 34% of the total particulates.

As indicated in Tables 10 to 14, the small foundries producing up to 10 000 tons of hot metal a year generally have the greatest emission factors. Most of these foundries, particularly those producing iron castings, have fewer and less efficient emission control installations than the large foundries. Many small foundries generally use low efficiency control systems such as wet caps, dry and wet rotoclones or multiclones. Larger foundries frequently use high-efficiency control devices such as baghouses and high-energy venturi scrubbers for controlling emissions from both melting and non-melting operations.

Emission factors for various operations and regions are given in Table 15. The highest degree of control for both cupola and electric arc furnaces is obtained in Ontario.

TABLE 6 PARTICULATE EMISSIONS FROM INDUSTRIAL PROCESSES, 1970 (5)*

| Industry | Emissions tons/year | Emissions % |
|---|---|---|
| FERROUS FOUNDRIES | 25 600 | 1.8 |
| Primary iron and steel mills | 152 900 | 10.9 |
| Other primary metals | 110 900 | 7.9 |
| Metallurgical coke manufacturing | 10 600 | 0.8 |
| Petroleum refining | 1 300 | 0.1 |
| Cement manufacturing | 247 700 | 17.7 |
| Lime | 53 900 | 3.8 |
| Kraft pulping | 86 400 | 6.2 |
| Asbestos mining and milling | 80 000 | 5.7 |
| Stone, sand and gravel pollution | 401 100 | 28.6 |
| Grain handling | 83 500 | 6.0 |
| Grain milling | 4 200 | 0.3 |
| Ferroalloy, fertilizer application or manufacture and asphalt | 65 500 | 4.7 |
| Other | 76 600 | 5.5 |
| TOTAL | 1 400 200 | 100.0 |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

*These figures were obtained from a search of published information from various sources.

TABLE 7 CALCULATED PARTICULATE EMISSIONS FROM THE CANADIAN FERROUS FOUNDRY INDUSTRY, 1973*

| Region | No. of Foundries | Foundry Production (tons/year) | | Hot Metal to Casting Ratio | Total Emissions | |
|---|---|---|---|---|---|---|
| | | Castings | Hot Metal | | tons/year | % of Total |
| Ontario | 60 | 1 126 775 | 1 761 352 | 1.56 | 5 805 | 41.1 |
| Quebec | 25 | 451 129 | 654 671 | 1.45 | 4 390 | 31.1 |
| Northwest | 22 | 161 191 | 236 080 | 1.46 | 2 552 | 18.0 |
| Pacific | 17 | 69 163 | 99 889 | 1.44 | 605 | 4.3 |
| Atlantic | 17 | 30 110 | 44 466 | 1.48 | 774 | 5.5 |
| Canada | 141 | 1 838 368 | 2 796 458 | 1.52 | 14 126 | 100.0 |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 8 CALCULATED CASTING PRODUCTION AND PARTICULATE EMISSIONS FROM THE CANADIAN FERROUS FOUNDRY INDUSTRY, 1973*

| | Total Iron and Steel Foundries | | | Iron Foundries | | | Steel Foundries | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | No. | Production of Castings (tons) | Emissions (tons) | No. | Production of Castings (tons) | Emissions (tons) | No. | Production of Castings (tons) | Emissions (tons) |
| Ontario | 60 | 1 126 775 | 5 805 | 54 | 1 045 625 | 5 482 | 6 | 81 150 | 323 |
| Quebec | 25 | 451 129 | 4 390 | 15 | 180 800 | 3 423 | 10 | 270 329 | 967 |
| Northwest | 22 | 161 191 | 2 552 | 17 | 83 238 | 1 335 | 5 | 77 953 | 1 217 |
| Pacific | 17 | 69 163 | 605 | 8 | 37 750 | 401 | 9 | 31 413 | 204 |
| Atlantic | 17 | 30 110 | 774 | 16 | 28 110 | 729 | 1 | 2 000 | 45 |
| Canada | 141 | 1 838 368 | 14 126 | 110 | 1 375 523 | 11 370 | 31 | 462 845 | 2 756 |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 9 CALCULATED PARTICULATE EMISSIONS BY OPERATION FROM THE CANADIAN FERROUS FOUNDRY INDUSTRY, 1973*

| | Particulate Emissions (tons) | | | | | | |
|---|---|---|---|---|---|---|---|
| Operation | Canada Total | Ontario Region | Quebec Region | Northwest Region | Pacific Region | Atlantic Region | % of Total |
| Cupola Furnace | 4 985 | 1 405 | 2 108 | 719 | 130 | 623 | 35.3 |
| Electric Arc Furnace | 1 442 | 55 | 262 | 1 054 | 42 | 29 | 10.2 |
| Induction Furnace | 265 | 228 | 8 | 24 | 5 | 0 | 1.9 |
| Reverberatory Furnace | 5.6 | 5.6 | 0 | 0 | 0 | 0 | 0.1 |
| Raw Materials Handling | 56 | 34 | 13 | 6 | 2 | 1 | 0.4 |
| Sand Conditioning | 2 006 | 909 | 621 | 266 | 177 | 33 | 14.2 |
| Moulding | 8.8 | 5.1 | 2.0 | 0.8 | 0.7 | 0.2 | 0.1 |
| Core-making | 639 | 414 | 145 | 61 | 12 | 7 | 4.5 |
| Pouring | 2 842 | 1 791 | 662.4 | 241 | 102 | 45.6 | 20.1 |
| Treatment for Ductile Iron | 351 | 225 | 68 | 42 | 16 | 0 | 2.5 |
| Shake-out | 1 119 | 471 | 421 | 116 | 86 | 25 | 7.9 |
| Shot- and Sand-Blasting | 276 | 176 | 53 | 12 | 27 | 8 | 1.9 |
| Grinding | 131 | 86 | 27 | 11 | 5 | 2 | 0.9 |
| Total Emissions | 14 126.4 | 5 804.7** | 4 390.4 | 2 552.8 | 604.7 | 773.8 | 100.0 |
| Melting Emissions | 6 697.6 | 1 693.6 | 2 378 | 1 797 | 177 | 652 | 47.5 |
| Non-melting Emissions | 7 428.8 | 4 111.1 | 2 012.4 | 755.8 | 427.7 | 121.2 | 52.5 |

Metric Conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

** Includes 10 tons from one reverberatory furnace foundry.

TABLE 10 CALCULATED PARTICULATE EMISSIONS BY FOUNDRY SIZE AND REGION FROM THE CANADIAN FERROUS FOUNDRY INDUSTRY, *1973**

| Region | Foundry Size (Tons of Hot Metal Production /Year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 - 2 500 | 2 501 - 5 000 | 5 001 - 10 000 | 10 001 - 20 000 | 20 001 - 50 000 | 50 001 - 100 000 | >100 000 | Total | % of Total |
| ONTARIO | | | | | | | | | |
| No. of Foundries | 15 | 12 | 9 | 7 | 9 | 5 | 3 | 60 | 42.5 |
| Production (tons) | 18 811 | 45 300 | 66 500 | 95 325 | 280 500 | 354 916 | 900 000 | 1 761 352 | 63.0 |
| Emissions (tons) | 227 | 464 | 611 | 465 | 786 | 1 006 | 2 246 | 5 805 | 41.1 |
| QUEBEC | | | | | | | | | |
| No. of Foundries | 8 | 1 | 6 | 2 | 5 | 2 | 1 | 25 | 17.7 |
| Production (tons) | 10 290 | 4 000 | 43 681 | 22 200 | 144 500 | 160 000 | 270 000 | 654 671 | 23.4 |
| Emissions (tons) | 182 | 81 | 527 | 78 | 1 804 | 1 213 | 505 | 4 390 | 31.1 |
| NORTHWEST | | | | | | | | | |
| No. of Foundries | 9 | 4 | 3 | 4 | 1 | 1 | | 22 | 15.6 |
| Production (tons) | 9 374 | 13 313 | 21 613 | 54 718 | 39 500 | 97 562 | | 236 080 | 8.4 |
| Emissions (tons) | 114 | 120 | 226 | 736 | 316 | 1 040 | | 2 552 | 18.1 |
| PACIFIC | | | | | | | | | |
| No. of Foundries | 9 | 2 | 4 | | 2 | | | 17 | 12.1 |
| Production (tons) | 11 489 | 5 775 | 27 625 | | 55 000 | | | 99 889 | 3.6 |
| Emissions (tons) | 138 | 25 | 207 | | 235 | | | 605 | 4.3 |
| ATLANTIC | | | | | | | | | |
| No. of Foundries | 13 | 2 | 1 | | 1 | | | 17 | 12.1 |
| Production (tons) | 8 341 | 7 125 | 8 250 | | 20 750 | | | 44 466 | 1.6 |
| Emissions (tons) | 167 | 126 | 148 | | 333 | | | 774 | 5.4 |
| CANADA TOTAL | | | | | | | | | |
| No. of Foundries | 54 | 21 | 23 | 13 | 18 | 8 | 4 | 141 | 100.0 |
| Production (tons) | 58 305 | 75 513 | 167 669 | 172 243 | 540 250 | 612 478 | 1 170 000 | 2 796 458 | 100.0 |
| Emissions (tons) | 828 | 816 | 1 719 | 1 279 | 3 474 | 3 259 | 2 751 | 14 126 | 100.0 |
| % of Foundries | 38.3 | 14.9 | 16.3 | 9.2 | 12.8 | 5.7 | 2.8 | 100.0 | |
| % of Production | 2.1 | 2.7 | 6.0 | 6.2 | 19.3 | 21.9 | 41.8 | 100.0 | |
| % of Emissions | 5.9 | 5.8 | 12.1 | 9.0 | 24.6 | 23.1 | 19.5 | 100.0 | |
| Emission Factor (lb/ton hot metal) | 28.4 | 21.6 | 20.5 | 14.9 | 12.9 | 10.6 | 4.7 | 10.1 | |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 11 CALCULATED PARTICULATE EMISSIONS AND IRON HOT METAL PRODUCTION FROM CUPOLA FURNACE FOUNDRIES, 1973*

| Region | Cupola Furnace Foundry Size (Tons of Hot Metal Production/Year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 - 2 500 | 2 501 - 5 000 | 5 001 - 10 000 | 10 001 - 20 000 | 20 001 - 50 000 | 50 001 - 100 000 | >100 000 | Total | % of Total |
| ONTARIO | | | | | | | | | |
| No. of Foundries | 13 | 8 | 6 | 4 | 4 | 3 | 3 | 41 | 45.0 |
| Production (tons) | 16 346 | 29 750 | 44 000 | 58 750 | 141 250 | 215 750 | 830 000 | 1 335 846 | 76.4 |
| Emissions (tons) | 218 | 415 | 535 | 340 | 342 | 523 | 2 078 | 4 451 | 44.3 |
| QUEBEC | | | | | | | | | |
| No. of Foundries | 5 | 1 | 4 | | 3 | 1 | | 14 | 15.4 |
| Production (tons) | 9 375 | 4 000 | 26 931 | | 96 250 | 100 000 | | 236 556 | 13.5 |
| Emissions (tons) | 179 | 81 | 365 | | 1 697 | 1 040 | | 3 362 | 33.5 |
| NORTHWEST | | | | | | | | | |
| No. of Foundries | 6 | 4 | 1 | 2 | 1 | | | 14 | 15.4 |
| Production (tons) | 6 024 | 12 563 | 6 563 | 23 750 | 39 500 | | | 88 400 | 5.1 |
| Emissions (tons) | 92 | 117 | 133 | 480 | 315 | | | 1 137 | 11.3 |
| PACIFIC | | | | | | | | | |
| No. of Foundries | 3 | | 2 | | 1 | | | 6 | 6.6 |
| Production (tons) | 4 238 | | 16 375 | | 25 000 | | | 45 613 | 2.6 |
| Emissions (tons) | 69 | | 155 | | 137 | | | 361 | 3.6 |
| ATLANTIC | | | | | | | | | |
| No. of Foundries | 13 | 1 | 1 | | 1 | | | 16 | 17.6 |
| Production (tons) | 8 341 | 4 125 | 8 250 | | 20 750 | | | 41 466 | 2.4 |
| Emissions (tons) | 167 | 81 | 148 | | 333 | | | 729 | 7.3 |
| CANADA TOTAL | | | | | | | | | |
| No. of Foundries | 40 | 14 | 14 | 6 | 10 | 4 | 3 | 91 | 100.0 |
| Production (tons) | 44 324 | 50 438 | 102 119 | 82 500 | 322 750 | 315 750 | 830 000 | 1 747 881 | 100.0 |
| Emissions (tons) | 725 | 694 | 1 336 | 820 | 2 824 | 1 563 | 2 078 | 10 040 | 100.0 |
| % of Foundries | 43.9 | 15.4 | 15.4 | 6.6 | 11.0 | 4.4 | 3.3 | 100.0 | |
| % of Production | 2.5 | 2.9 | 5.8 | 4.7 | 18.5 | 18.1 | 47.5 | 100.0 | |
| % of Emissions | 7.2 | 6.9 | 13.3 | 8.2 | 28.1 | 15.6 | 20.7 | 100.0 | |
| Emission Factor (lb/ton hot metal) | 32.7 | 27.5 | 26.2 | 19.9 | 17.5 | 9.9 | 5.0 | 11.5 | |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 91 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 12 CALCULATED PARTICULATE EMISSIONS AND STEEL HOT METAL PRODUCTION FROM ELECTRIC ARC FURNACE FOUNDRIES, 1973*

| Region | Foundry Size (Tons of Hot Metal Production/Year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 - 2 500 | 2 501 - 5 000 | 5 001 - 10 000 | 10 001 - 20 000 | 20 001 - 50 000 | 50 001 - 100 000 | >100 000 | Total | % of Total |
| ONTARIO | | | | | | | | | |
| No. of Foundries | | 2 | 1 | 1 | | 1 | | 5 | 19.2 |
| Production (tons) | | 9 150 | 5 625 | 14 700 | | 86 541 | | 116 016 | 16.8 |
| Emissions (tons) | | 28 | 17 | 39 | | 218 | | 302 | 11.1 |
| QUEBEC | | | | | | | | | |
| No. of Foundries | 1 | | 1 | 2 | 2 | 1 | 1 | 8 | 30.8 |
| Production (tons) | 45 | | 9 000 | 22 200 | 45 750 | 60 000 | 270 000 | 406 995 | 59.1 |
| Emissions (tons) | 1 | | 116 | 78 | 91 | 174 | 505 | 965 | 35.4 |
| NORTHWEST | | | | | | | | | |
| No. of Foundries | 1 | | 1 | 1 | | 1 | | 4 | 15.4 |
| Production (tons) | 600 | | 6 300 | 11 718 | | 97 562** | | 116 180 | 16.9 |
| Emissions (tons) | 7 | | 38 | 128 | | 1 040 | | 1 213 | 44.5 |
| PACIFIC | | | | | | | | | |
| No. of Foundries | 4 | 2 | 1 | | 1 | | | 8 | 30.8 |
| Production (tons) | 5 438 | 5 775 | 5 625 | | 30 000 | | | 46 838 | 6.8 |
| Emissions (tons) | 59 | 25 | 21 | | 97 | | | 202 | 7.4 |
| ATLANTIC | | | | | | | | | |
| No. of Foundries | | 1 | | | | | | 1 | 3.8 |
| Production (tons) | | 3 000 | | | | | | 3 000 | 0.4 |
| Emissions (tons) | | 45 | | | | | | 45 | 1.6 |
| CANADA TOTAL | | | | | | | | | |
| No. of Foundries | 6 | 5 | 4 | 4 | 3 | 3 | 1 | 26 | 100.0 |
| Production (tons) | 6 083 | 17 925 | 26 550 | 48 618 | 75 750 | 244 103 | 270 000 | 689 029 | 100.0 |
| Emissions (tons) | 67 | 98 | 192 | 245 | 188 | 1 432 | 505 | 2 727 | 100.0 |
| % of Foundries | 23.1 | 19.2 | 15.4 | 15.4 | 11.5 | 11.5 | 3.9 | 100.0 | |
| % of Production | 0.9 | 2.6 | 3.8 | 7.1 | 11.0 | 35.4 | 39.2 | 100.0 | |
| % of Emissions | 2.5 | 3.6 | 7.0 | 9.0 | 6.9 | 52.5 | 18.5 | 100.0 | |
| Emission Factor (lb/ton hot metal) | 22.0 | 10.9 | 14.5 | 10.1 | 5.0 | 11.7 | 3.7 | 7.9 | |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 26 foundries in Air Pollution Control Directorate questionnaires, 1974.

** Fabric filters have been installed on the electric arc furnaces for emission control in 1976.

TABLE 13 CALCULATED PARTICULATE EMISSIONS AND IRON/STEEL HOT METAL PRODUCTION FROM INDUCTION FURNACE FOUNDRIES, 1973*

| | Induction Furnace Foundry Size (Tons of Hot Metal Production/Year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | 0 - 2 500 | 2 501 - 5 000 | 5 001 - 10 000 | 10 001 - 20 000 | 20 001 - 50 000 | 50 001 - 100 000 | >100 000 | Total | % of Total |
| ONTARIO | | | | | | | | | |
| No. of Foundries | 5 | 3 | 2 | 1 | 5 | 2 | | 18 | 58.0 |
| Production (tons) | 2 965 | 11 400 | 16 500 | 11 250 | 139 250 | 122 500 | | 303 865 | 85.9 |
| Emissions (tons) | 11 | 31 | 58 | 58 | 445 | 433 | | 1 036 | 77.1 |
| QUEBEC | | | | | | | | | |
| No. of Foundries | 3 | | 1 | | | | | 4 | 12.9 |
| Production (tons) | 3 370 | | 7 750 | | | | | 11 120 | 3.1 |
| Emissions (tons) | 17 | | 46 | | | | | 63 | 4.7 |
| NORTHWEST | | | | | | | | | |
| No. of Foundries | 3 | | 2 | 1 | | | | 6 | 19.4 |
| Production (tons) | 3 500 | | 16 750 | 11 250 | | | | 31 500 | 8.9 |
| Emissions (tons) | 19 | | 109 | 74 | | | | 202 | 15.1 |
| PACIFIC | | | | | | | | | |
| No. of Foundries | 2 | | 1 | | | | | 3 | 9.7 |
| Production (tons) | 1 813 | | 5 625 | | | | | 7 438 | 2.1 |
| Emissions (tons) | 11 | | 31 | | | | | 42 | 3.1 |
| ATLANTIC | | | | | | | | | |
| No. of Foundries | | | | | | | | 0 | |
| Production (tons) | | | | | | | | 0 | |
| Emissions (tons) | | | | | | | | 0 | |
| CANADA TOTAL | | | | | | | | | |
| No. of Foundries | 13 | 3 | 6 | 2 | 5 | 2 | | 31 | 100.0 |
| Production (tons) | 11 648 | 11 400 | 46 625 | 22 500 | 139 250 | 122 500 | | 353 923 | 100.0 |
| Emissions (tons) | 58 | 31 | 244 | 132 | 445 | 433 | | 1 343 | 100.0 |
| % of Foundries | 41.9 | 9.7 | 19.3 | 6.5 | 16.1 | 6.5 | | 100.0 | |
| % of Production | 3.3 | 3.2 | 13.2 | 6.4 | 39.3 | 34.6 | | 100.0 | |
| % of Emissions | 4.3 | 2.3 | 18.2 | 9.8 | 33.1 | 32.3 | | 100.0 | |
| Emission Factor (lb/ton hot metal) | 10.0 | 5.4 | 10.5 | 11.7 | 6.4 | 7.1 | | 7.6 | |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 31 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 14 CALCULATED AVERAGE EMISSIONS FOR 1973* FOR CANADIAN FERROUS FOUNDRIES, ACCORDING TO TYPE OF FOUNDRY

| | Emissions (lb/ton Hot Metal) | | |
|---|---|---|---|
| Region | Iron Foundries | Steel Foundries | Iron and Steel Foundries |
| Ontario | 6.69 | 5.20 | 6.59 |
| Quebec | 27.74 | 4.74 | 13.41 |
| Northwest | 22.41 | 20.82 | 21.62 |
| Pacific | 15.21 | 8.65 | 12.10 |
| Atlantic | 35.16 | 30.00 | 34.73 |
| Canada | 10.85 | 7.89 | 10.10 |

Metric conversion: 1 lb/ton = 0.50 kg/1000 kg = 0.50 kg/tonne.
1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

* Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 15 CALCULATED AVERAGE EMISSIONS FOR 1973* FOR CANADIAN FERROUS FOUNDRIES, ACCORDING TO TYPE OF OPERATION

| | Average Emission Factor (lb/ton Hot Metal) | | | | | |
|---|---|---|---|---|---|---|
| Process | Canada | Ontario | Quebec | Northwest | Pacific | Atlantic |
| MELTING OPERATIONS | 4.79 | 1.92 | 7.27 | 15.22 | 3.54 | 29.28 |
| Cupola Furnace | 5.70 | 2.10 | 17.83 | 16.27 | 5.70 | 30.00 [μ] |
| Electric Arc Furnace | 4.19 | 0.95 | 1.29 | 18.14 | 1.79 | 19.0 [μ] |
| Induction Furnace | 1.50 [μ] | 1.50 [μ] | 1.50 [μ] | 1.50 [μ] | 1.50 [μ] | - |
| Reverberatory Furnace | 2.00 [μ] | 2.00 [μ] | - | - | - | - |
| NON-MELTING OPERATIONS | 5.31 | 4.67 | 6.14 | 6.40 | 8.56 | 5.45 |
| Raw Materials Handling | 0.039 | 0.039 | 0.040 | 0.051 | 0.040 | 0.045 |
| Sand Conditioning | 1.43 | 1.03 | 1.90 | 2.25 | 3.54 | 1.48 |
| Moulding | 0.006 | 0.006 | 0.006 | 0.007 | 0.014 | 0.009 |
| Core-making | 0.46 | 0.47 | 0.44 | 0.52 | 0.24 | 0.31 |
| Pouring | 2.04 [1] | 2.04 [1] | 2.04 [1] | 2.04 [1] | 2.04 [1] | 2.04 [1] |
| Treatment for Ductile Iron | 0.25 [1] | 0.26 [1] | 0.21 [1] | 0.36 [1] | 0.32 [1] | - |
| Shake-out | 0.80 | 0.53 | 1.29 | 0.98 | 1.72 | 1.12 |
| Shot- and Sand-Blasting | 0.20 | 0.20 | 0.16 | 0.10 | 0.54 | 0.36 |
| Grinding | 0.09 | 0.098 | 0.08 | 0.09 | 0.10 | 0.09 |
| Total Emissions | 10.10 | 6.59 | 13.41 | 21.62 | 12.10 | 34.73 |

Metric conversion: 1 lb/ton = 0.50 kg/1000 kg = 0.50 kg/tonne
1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

μ Uncontrolled emissions.

1 Little or no emission control.

Note: Emission factors are calculated by dividing total emissions by total hot metal produced. Many foundries do not have all the non-melting operations (e.g., electric arc furnace foundries do not have treatment for ductile iron).

* Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

TABLE 16 AVERAGE PARTICULATE EMISSIONS FROM THE CANADIAN FERROUS FOUNDRY INDUSTRY*, 1973

| | Particulate Emissions (tons/year) | | | | | |
|---|---|---|---|---|---|---|
| Operation | Ontario Region | Quebec Region | Northwest Region | Pacific Region | Atlantic Region | Canada |
| MELTING OPERATIONS | 850.39 | 1 900.88 | 1 561.17 | 8.59 | 311.25 | 4 632.28 |
| Cupola Furnace | 594.15 | 1 638.89 | 502.60 | 3.15 | 311.25 | 3 050.04 |
| Electric Arc Furnace | 51.61 | 261.99 | 1 050.13 | 5.44 | - | 1 369.17 |
| Induction Furnace | 204.63 | - | 8.44 | - | - | 213.07 |
| NON-MELTING OPERATIONS | 3 642.43 | 1 800.62 | 514.56 | 247.18 | 21.90 | 6 226.69 |
| Raw Materials Handling | 30.32 | 10.47 | 4.34 | 1.08 | 0.73 | 46.94 |
| Sand Conditioning | 741.79 | 550.37 | 176.02 | 105.06 | - | 1 573.24 |
| Moulding | 4.22 | 1.38 | 0.76 | 0.14 | - | 6.50 |
| Core-making | 370.79 | 127.28 | 45.32 | 1.78 | - | 545.17 |
| Pouring | 1 658.13 | 610.22 | 194.30 | 61.84 | 21.17 | 2 545.66 |
| Treatment for Ductile Iron | 218.54 | 62.50 | 31.69 | 15.63 | | 328.36 |
| Shake-out | 389.54 | 371.64 | 50.98 | 40.81 | | 852.97 |
| Shot- and Sand-Blasting | 153.92 | 42.78 | 4.74 | 20.42 | | 221.86 |
| Grinding | 75.18 | 23.98 | 6.41 | 0.42 | | 105.99 |
| Total Emissions | 4 492.82 | 3 701.50 | 2 075.73 | 255.77 | 333.15 | 10 858.97 |

Metric conversion: 1 ton (2 000 lb) = 0.9072 tonnes = 907.2 kilograms.

Emissions from (1) all cupola and induction furnace foundries producing more than 10 000 tons of iron hot metal/year and (2) all electric arc furnace foundries producing more than 5 000 tons of steel hot metal/year.

* Based on normal operations, from data reported by 141 foundries in Air Pollution Control Directorate questionnaires, 1974.

The table also shows that all induction furnaces, cupola and electric arc furnaces in the Atlantic Region, and the one reverberatory furnace in Ontario, are uncontrolled. The survey also found little or no emission control is used during the pouring and alloy treatment of ductile iron in all regions of Canada. Other operations such as shot- and sand-blasting, and grinding are generally well controlled in most regions.

A significant reduction in particulate emissions from both melting and non-melting operations is probable based on the expected expenditures for air pollution control equipment by the Canadian ferrous foundry industry, or because of changes in operating practice or technology (Section 6.4). One such substantial emission reduction is the recent installation of fabric filters on electric arc furnaces in one plant in the Northwest Region.

Table 16 gives the estimated emissions from all Canadian ferrous foundries producing more than 10 000 tons of iron hot metal a year and 5 000 tons of steel hot metal.

# 6 CONTROL METHODS

## 6.1 General

This survey has revealed that levels of particulate emissions still vary greatly among foundry operations. For example, in some areas of Canada cupola and electric arc furnace emissions are still uncontrolled while in others there is a very high degree of containment. The survey shows that conventional technology such as high efficiency venturi scrubbers and fabric filters can be used either alone or in conjunction with mechanical collectors 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 foundry areas 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 for Melting Processes

**6.2.1 Cupola.** There are three basic steps in a cupola emission control system (7, 8): particulate capture, gas conditioning and particulate collection. Figure 6 shows the combinations and alternatives that are used for each.

Hot gases leaving the cupola are generated by three principal sources:

- blast air which leaves as a mixture of $N_2$, CO and $CO_2$
- infiltration air through the charge door
- products of combustion of afterburners

The volume of blast air is a main factor affecting the size and cost of the system. Gas volume is increased on its way up by infiltration air and combustion requirements. Where the gas take-off is located below the charge door, the volume of gas to be handled by the control system is smaller. For most existing installations the gas take-off is above the charge door. Locating the gas take-off below the charge door will often require stack modifications to preserve the same charge pre-heat conditions.

The size of the cupola gas take-off system may be reduced by increasing the melting period; changing the position of the gas take-off to below the door; and changing the in-charge door area (modifying the method of feeding, decreasing the size of the charge, altering the charge make-up, etc.).

Conditioning is required to remove the combustibles from the dust-laden gases and to cool the gas for subsequent collection. These two procedures are accomplished through the use of afterburners and cooling devices.

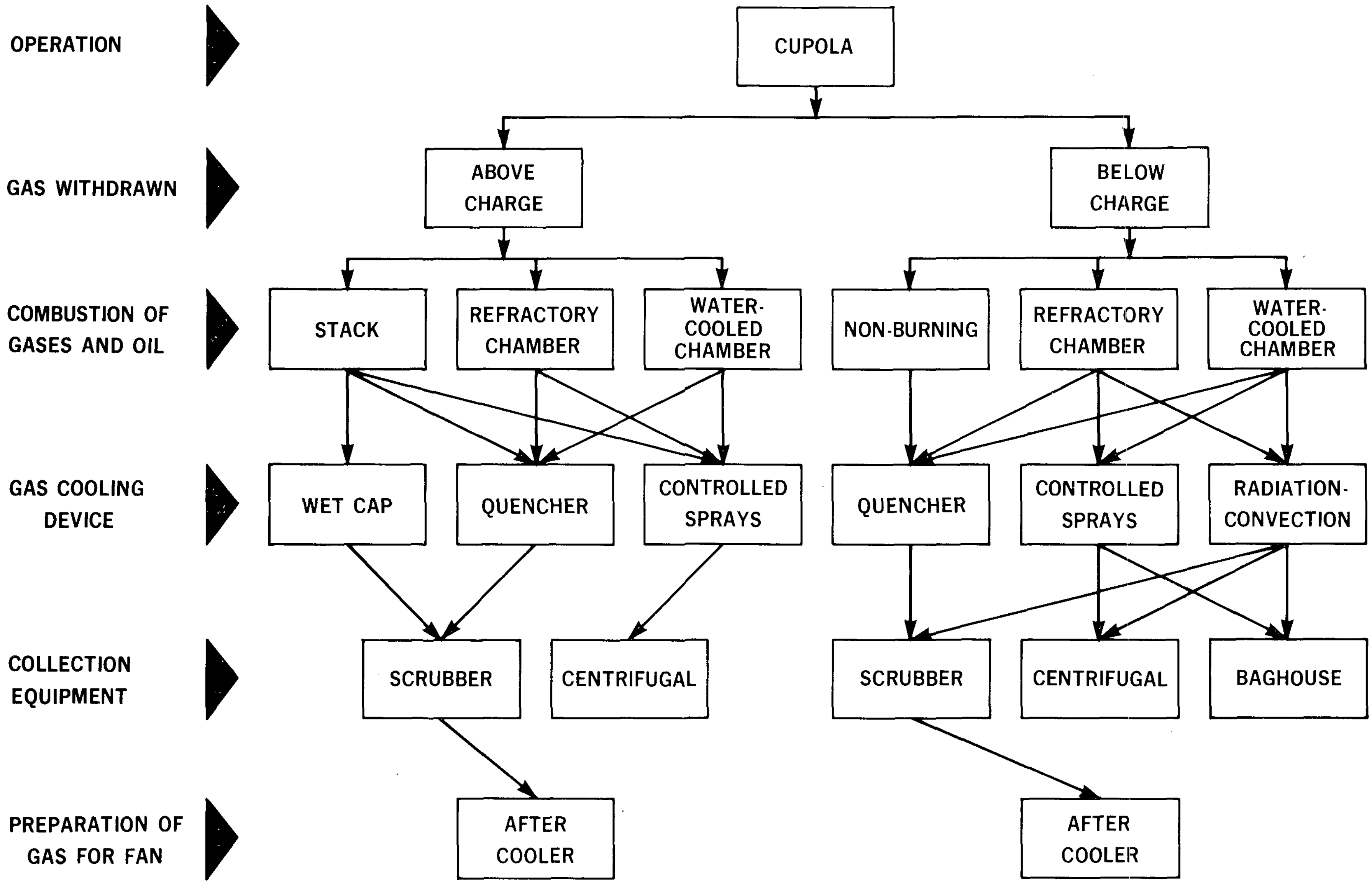



FIGURE 6 ALTERNATES FOR CUPOLA PARTICULATE CONTROL SYSTEMS (6)

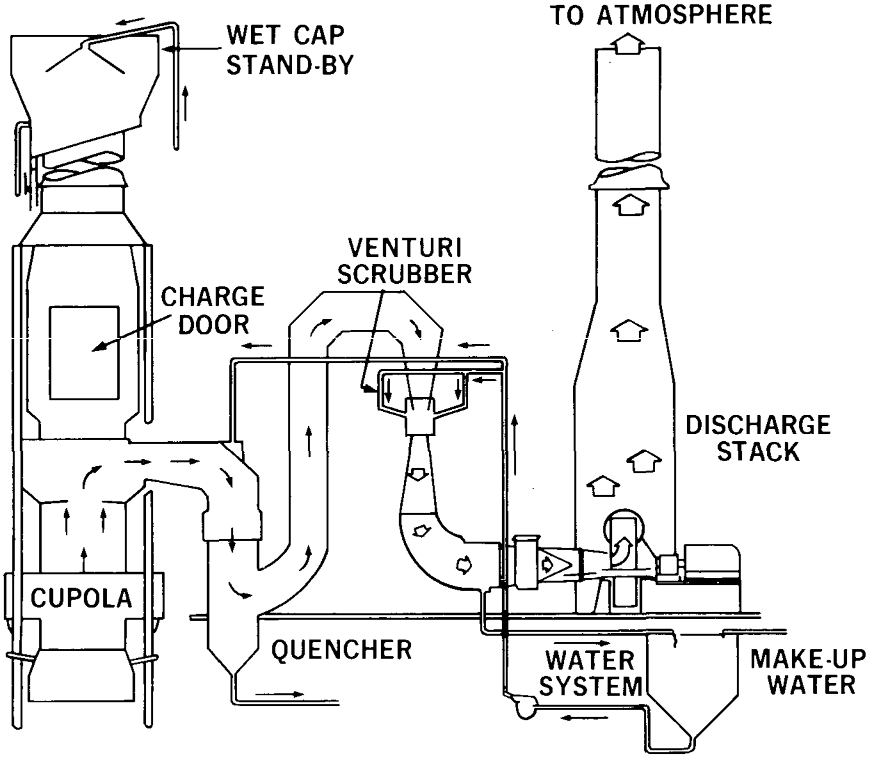
Afterburners are required particularly where oily scrap or hydrocarbons are charged. In self-modulating installations, conditions may be such that an ignitor is not required because of fuel considerations. Afterburners are considered almost a necessity for the below-the-door take-off arrangement. The unburned charge in this case, built up above the melting level, acts as a restriction on the air entering the door. The volume of gases is thus reduced to the sum of the blast air, the products of combustion and the volume from the charge door. Where incineration with the below-charge-door system is required, significant volumes of combustion air are necessary to ensure proper operation of the afterburners. Where the take-off position is above the charge door, a volume of air approximately equal to the blast air volume will be added to the cupola blast air and to the products of combustion.

In above-the-door charge cupolas the off-take gases have temperatures of 537°C-982°C (1000°F-1800°F) and must be cooled. Any one of three cooling methods can be used: diluting with air; quenching with water (evaporative cooling) and removing heat through radiation.

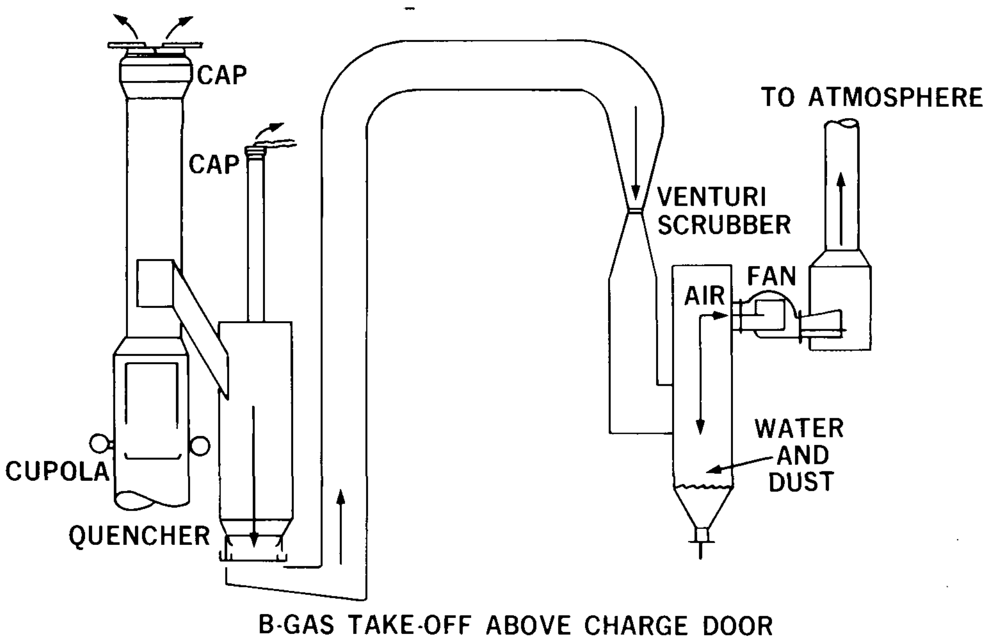
Radiation cooling requires a large surface area to remove the heat. The cooling effect is brought about by natural air draft, with no moisture being added. Both evaporative and radiation cooling, in addition to reducing gas temperature, have the effect of reducing the gas volume. Radiation cooling results in the greater reduction in volume.

There are many different types of gas cleaning equipment used on cupola installations in Canada. These include fabric filters, dry mechanical collectors such as cyclones, rotoclones, multiclone cool caps, and wet scrubbers such as rotoclones, wet caps and venturi scrubbers. The wet scrubbers are more common. Medium-energy (≥20-inch water gauge pressure drop) and high-energy (≥40-inch water gauge pressure drop) venturi scrubbers are generally used in the more efficient and high-volume foundries. Venturi scrubbers with adjustable opening area are often used because they can be readily designed for the required efficiency and automatically adjusted to variations in gas volume. Designs such as the flooded disc and units that apply the energy to the water rather than the gas stream are also used. Typical flowsheets for a scrubber installation are shown in Figures 7A and 7B.

Where fabric filters are used, the most successful system for emission control consists of an afterburner followed by some method of cooling. The cooled gas is then passed through the filters with fibreglass tubes. Two important design criteria are an




A-GAS TAKE-OFF BELOW CHARGE DOOR




B-GAS TAKE-OFF ABOVE CHARGE DOOR

**FIGURE 7 CUPOLA SCRUBBER SYSTEMS FOR GAS TAKE-OFF ABOVE AND BELOW CHARGE DOOR**

elaborate failsafe system to protect filter bags from high temperatures, and dewpoint considerations. Temperatures must be maintained at a point above the condensation level but below the maximum allowed by the fabric.

Other high-efficiency collectors such as electrostatic precipitators are not used in Canada primarily because of their high capital costs, and operating and maintenance problems. The operation of electrostatic precipitators is dependent upon maintaining an appropriate particle resistivity which is, in part, dependent upon close control of the moisture and temperature of the gas.

**6.2.2 Electric Arc Furnaces** (1, 7). The emission from melting in the electric arc furnace comes from two principal sources - the burning or vapourization of combustible materials that may be in the charged raw materials, and the burning of the electrodes and some of the charge metallics during meltdown. Highest gas evolution and particulate generation is usually during charging of scrap and/or during oxygen lancing. Particulates are typically high in iron oxide, with varying amounts of other oxides such as silica, calcium and zinc.

As in the case for cupolas, the design of the particulate control system can be divided into three steps: particulate capture, gas conditioning and particulate collection (Figure 8).

There are four basic methods for particulate capture: direct evacuation, side draft hood, roof mounted hood and canopy (Figure 9). Furnaces with side draft or direct evacuation hoods are not covered when the roof is lifted for charging or tilted for pouring and emissions are not controlled at this time. Most of the new electric arc furnace installations have canopy hoods to control charging and tapping emissions. Some of the furnaces also have charging through the side door and thus particulate control is provided, since the direct evacuation ducts, roof mounted hoods or side draft hoods are in place.

In most cases, the oxygen lancing operation represents the highest rate of gas evolution and particulate generation from the furnace and thus particulate capture is the critical design factor for the emission control system. For the other design factors (gas conditioning and particulate collection), most of the comments applying to the cupola are pertinent here. One exception is that fabric filters, the most frequently used collector in Canadian electric arc furnace foundries, are best suited to electric arc furnaces because of the extremely fine size of particulate emitted. Generally, the fabric is protected from excessively hot gases by the use of a simple damper to by-pass the baghouse until the danger is over, or a damper in the duct to bleed in atmospheric air for cooling.

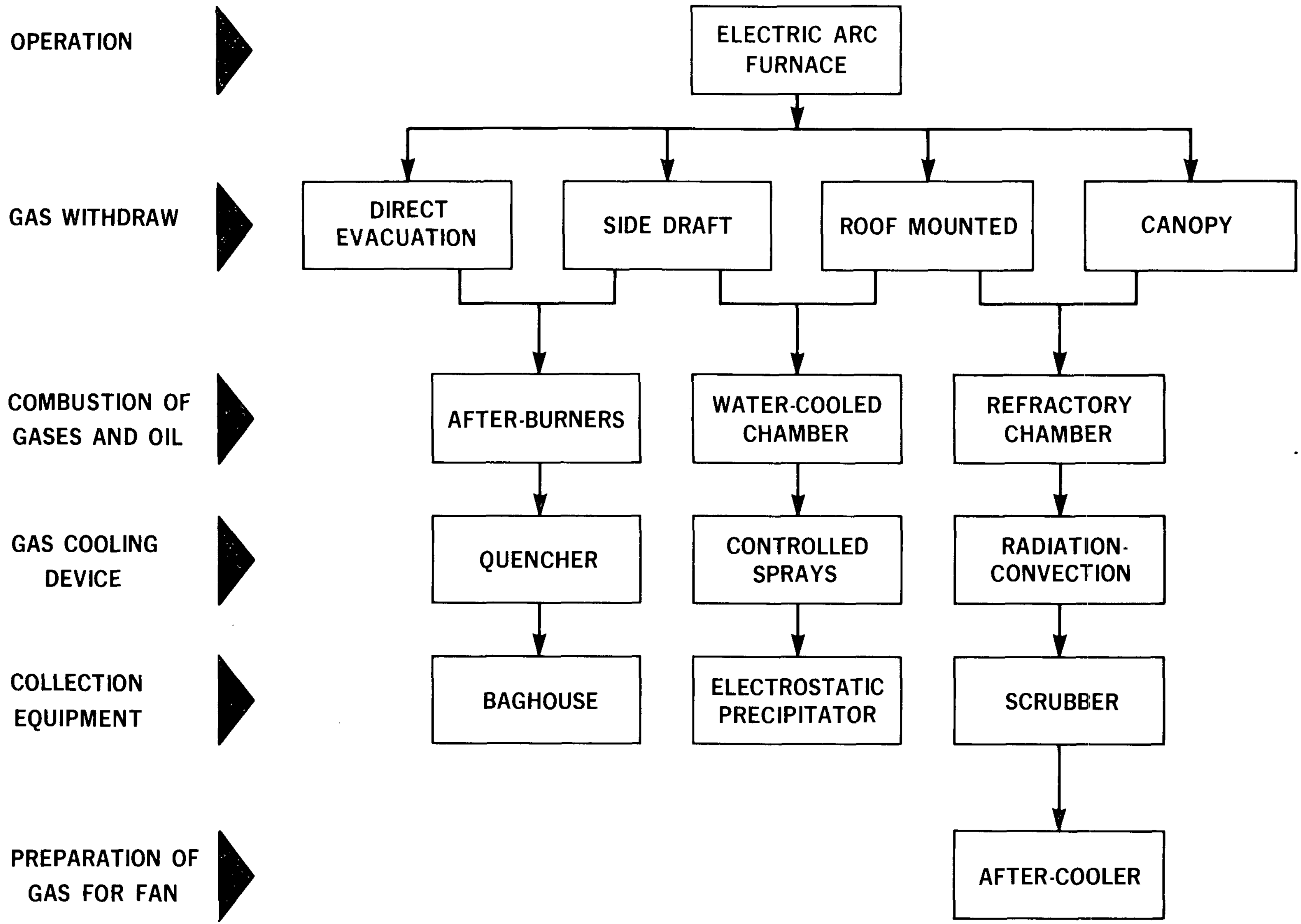



FIGURE 8 ALTERNATES FOR ELECTRIC ARC FURNACE PARTICULATE CONTROL SYSTEMS

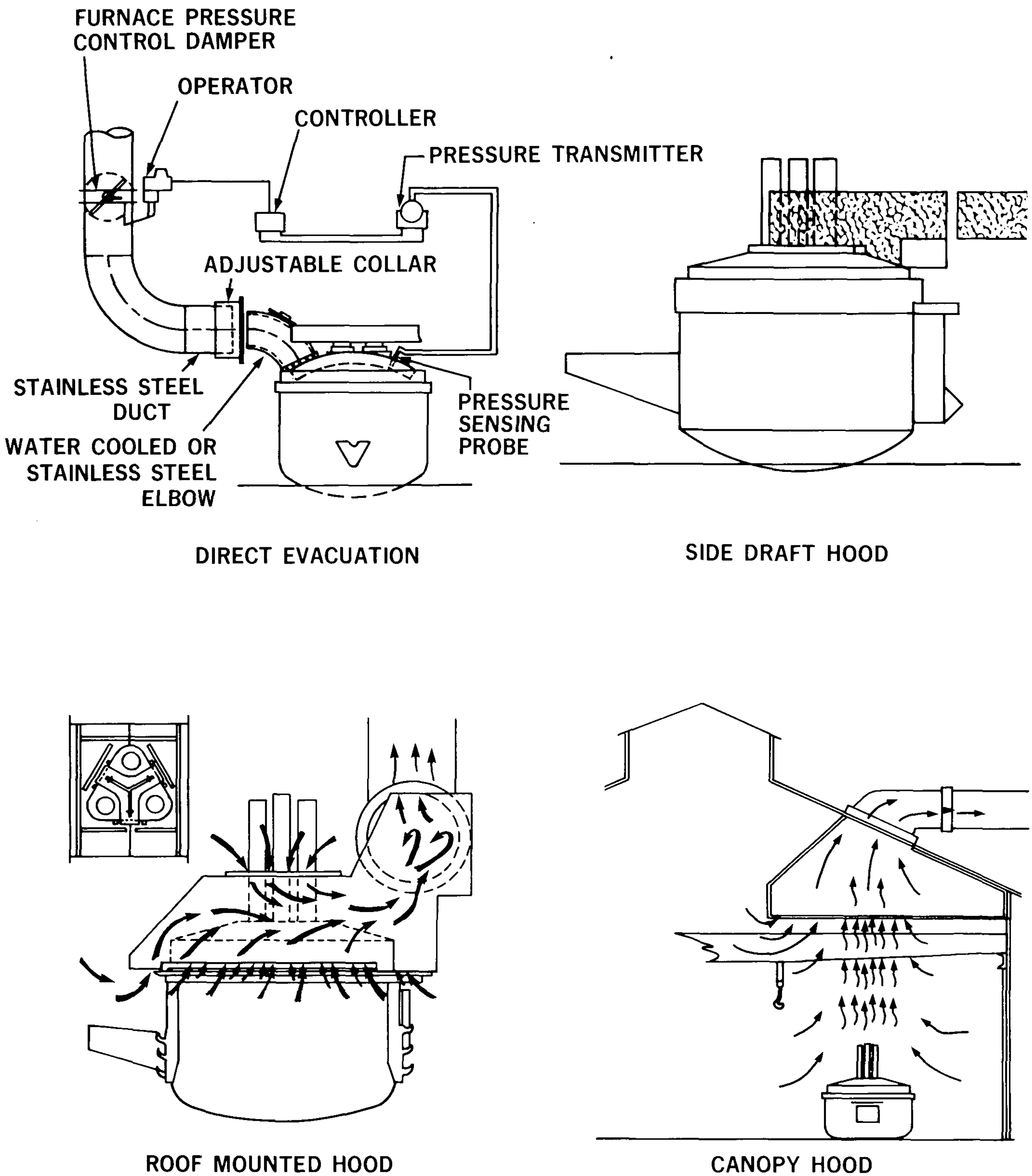



FIGURE 9 ELECTRIC ARC FURNACE EXHAUST GAS CAPTURE SYSTEMS

Wet scrubbers are used on only a few electric arc furnace installations. The high proportion of sub-micron particulates and the large volume of gas from the electric arc melting operation limit the practical use of high energy venturi scrubbers. Electrostatic precipitators are being used in Europe but not in Canada. The high electrical resistivity of the predominately sub-micron iron oxide particulate limits the electrostatic precipitator performance unless the furnace gas is properly conditioned, such as humidified with water.

**6.2.3 Induction Furnaces** (1, 20). These furnaces have recently been installed as melting and holding furnaces. Holding furnaces produce very little fume since the metal itself has had most of the impurities removed previously during the melting process. Melting furnaces normally operate with a heel of liquid metal, and for this reason metal scrap must be dry and free of oil to prevent the molten metal from splashing from the furnace. Pre-heaters are frequently used to process and prepare the scrap for induction melting. Thus, the burning of oil residue produces emissions which may require the use of afterburners and wet scrubbers, either separately or in combination. Collection of melting emissions can be accomplished by fabric filters, and the same design criteria as those for electric arc furnaces would apply. However, no pollution control equipment is used on induction furnaces in Canadian ferrous foundries.

**6.2.4 Reverberatory Furnaces.** The emissions from reverberatory furnaces come principally from the combustion of coal, oil or gas fuel, plus some slag and iron oxide which are entrained in the off-gas. The quantity of emission is relatively small compared with that of cupola and electric arc furnaces (1, 12). Emission control systems such as wet scrubbers and fabric filter collectors can be used. The one foundry in Canada using a reverberatory furnace for melting has no emission control, according to the data from the 1974 questionnaire.

## 6.3 Existing Installations for Non-Melting Operations

**6.3.1 Raw Material Storage and Charge Make-up.** Most of the emissions from this area consist of coarse particulates which are generated during transfer of the charging material. One exception might be emissions from charge pre-heating, which would be expected to contain some sub-micron size particles. In either case the emissions are very small in quantity and usually not controlled.

**6.3.2 Sand Conditioning.** The sand handling system that returns, conditions and supplies the basic ingredient in the sand mould has many points where dust is generated.

Systems usually recirculate used sand. Hoppers below the shake-outs, etc., discharge to a system of conveyors, elevators, chutes, screens, coolers, bins and mixers. Wherever the sand is disturbed, hooding may be required.

Sand is handled in three stages: shake-out sand, new sand or make-up sand, and conditioned sand. Exhaust ventilation is not required for the conditioned sand because of its high moisture. Make-up sand may or may not require ventilation, depending on its moisture level. Collectors such as low energy scrubbers, multiple cyclones and fabric filters are often used on these systems before exhausting to the outside atmosphere and appear to be quite adequate.

**6.3.3 Pattern-making.** Where woodworking equipment is used, a local exhaust system captures sawdust, chips, etc. Normally, a mechanical type of dust collector such as a cyclone is sufficient to remove the entrained particulates because the dust particles are much larger than those encountered in other foundry exhausts. The saws, planers, shapers, sanders, drills, etc., have either built-in or local hooding designed according to accepted practice.

**6.3.4 Core-making.** Particulate emission control for core-making is essentially the problem of controlling dust during transporting and mixing of sand with organic or inorganic binders, which are the basic ingredients for cores. The core-making operation using synthetic binders and heated core boxes often results in vapour and gases. A similar situation exists in some of the synthetic binders that set at room temperatures, and to a lesser degree with oil sand core-making. Oil sand cores require oven baking to dry and polymerize the oil binders. Core oven emissions can be highly odourous, which may require incineration to control them. Controlling emissions from the core-making department is done by directing the exhaust air stream to a collection ductwork and by using systems such as scrubbers and baghouses.

**6.3.5 Moulding.** In high-volume foundry installations, finished moulds are set out on continuous car-type mould conveyors, providing fixed locations for pouring, cooling and shake-out operations. However, in most jobbing foundries, completed moulds are set out on the floor, taking up a large area and creating different dust-capture problems. Moulding emissions, generated by the practice of ramming sand or some other material around a model of the pattern to be made, are primarily coarse sand and dust, most of which subsequently settle out inside the foundry building.

**6.3.6 Magnesium Treatment for Producing Ductile Iron.** There is a possibility of excess fume emission during treatment of molten iron with magnesium compounds to produce ductile iron. The emissions consist primarily of magnesium oxide, representing up to 65% of the metal injected. The high loss occurs because the boiling point of magnesium is far below the temperature of molten iron. The reaction is often violent, depending on the form of magnesium used, and shielding or enclosing of the ladle at this time may be required. The emissions are generally discharged directly to the outside atmosphere.

**6.3.7 Pouring.** In this process, molten metal is usually moved in a transfer ladle and released into a pouring ladle or directly into the moulds. Emissions from pouring are core oil vapours, organics in the moulds, and particulates. On production type conveyors, emissions are discharged from the area to local hoods. In Canadian foundries, these hoods are discharged directly to the outside atmosphere, resulting in some particulate emissions.

**6.3.8 Shake-out.** After the poured moulds are allowed to cool for a period of time, the solidified castings are removed and rough cleaned of mould material in a shake-out operation. Particulates and gases are released with varying degrees of intensity as the moulds are shaken out. The gases are often ducted and passed to low-energy scrubbers (6-inch water gauge pressure drop), multiclones, or fabric filters for control.

**6.3.9 Cleaning and Finishing.** When the castings have cooled enough to be handled, the sprues, gates, and risers are removed at a location which is exhausted to remove the dust. Further cleaning of castings is usually done by grinding, abrasive blasting, chipping or welding.

Grinding wheels need hooding designed with care since the dust tends to be thrown in the direction of rotation. The duct take-off point is usually located so that the dust can be thrown directly into the take-off. Swing frame grinders are arranged so that a local hood may be mounted on the frame and exhausted using a flexible duct. Hand grinders require bench hoods with down- and back-draft exhaust to capture the dust emissions. Most exhaust hoods are connected to either high-efficiency centrifugal collectors or fabric filters.

Abrasive cleaning produces high concentrations of metal and sand dusts. Dust collection equipment most commonly used for this application is a coarse dropout or precleaner box followed by high-efficiency fabric filters or wet scrubbers.

Surface painting requires ventilation to reduce the possibility of volatile materials being atomized in the air. Exhaust systems are used where dip painting is performed.

Heat treatment furnaces have exhaust vents into the foundry building or to the atmosphere.

### 6.4 New Technology

**6.4.1 Energy Conservation Techniques.** Of all foundry operations, the cupola is the major source of particulate and gaseous emissions. Cupolas can be modified to decrease the quantity of emissions requiring collection and/or to decrease the off-gas volumes, which will reduce the size of collection equipment required. This includes the divided blast techniques, heating of blast air and oxygen enrichment with an attendant decrease in coke or energy requirements.

**6.4.1.1 Divided blast techniques** (13). The process of introducing blast air into the furnace through double or multiple rows of tuyeres (Figure 10) is designed to obtain maximum metal tapping temperature for a given coke charge, or conversely to reduce charge coke consumption for a given metal tapping temperature. The relative amounts of blast air admitted to each of the several rows of tuyeres could be adjusted to give a maximum of carbon monoxide at the bottom and a minimum at the top of the combustion zone, thereby utilizing all the potential heat of the coke. Thus, operation of the divided blast techniques allows charge coke consumption to be reduced and the melting rate to be increased.

**6.4.1.2 Recuperative hot blast** (13, 14, 16, 17, 18, 19). The primary advantages of recuperative heating the blast air of a cupola, using the latent and sensible heat of the cupola off-gas, are a decrease in coke consumption and melting losses, and an increase in melting rate and metal tapping temperature. Another major advantage of the hot blast is reduced emissions from the cupola. This occurs because of either a reduced coke rate or blast volume. In recuperative hot blast the cupola off-gas is mixed with ambient air to provide oxygen for combustion. The gas-air mixture is afterburned to convert the CO to $CO_2$ before the mixture enters the counter-current heat exchanger (recuperator) where the ambient cupola combustion air is heated. As can be seen in Figure 11, there are four major alternatives for recuperative hot blast cupola emission control systems. They are above and below charge door take-off and pollution control before or after afterburning. Location of gas take-off below the charge door may decrease off-gas volumes. However, complexity in control equipment is a major disadvantage.

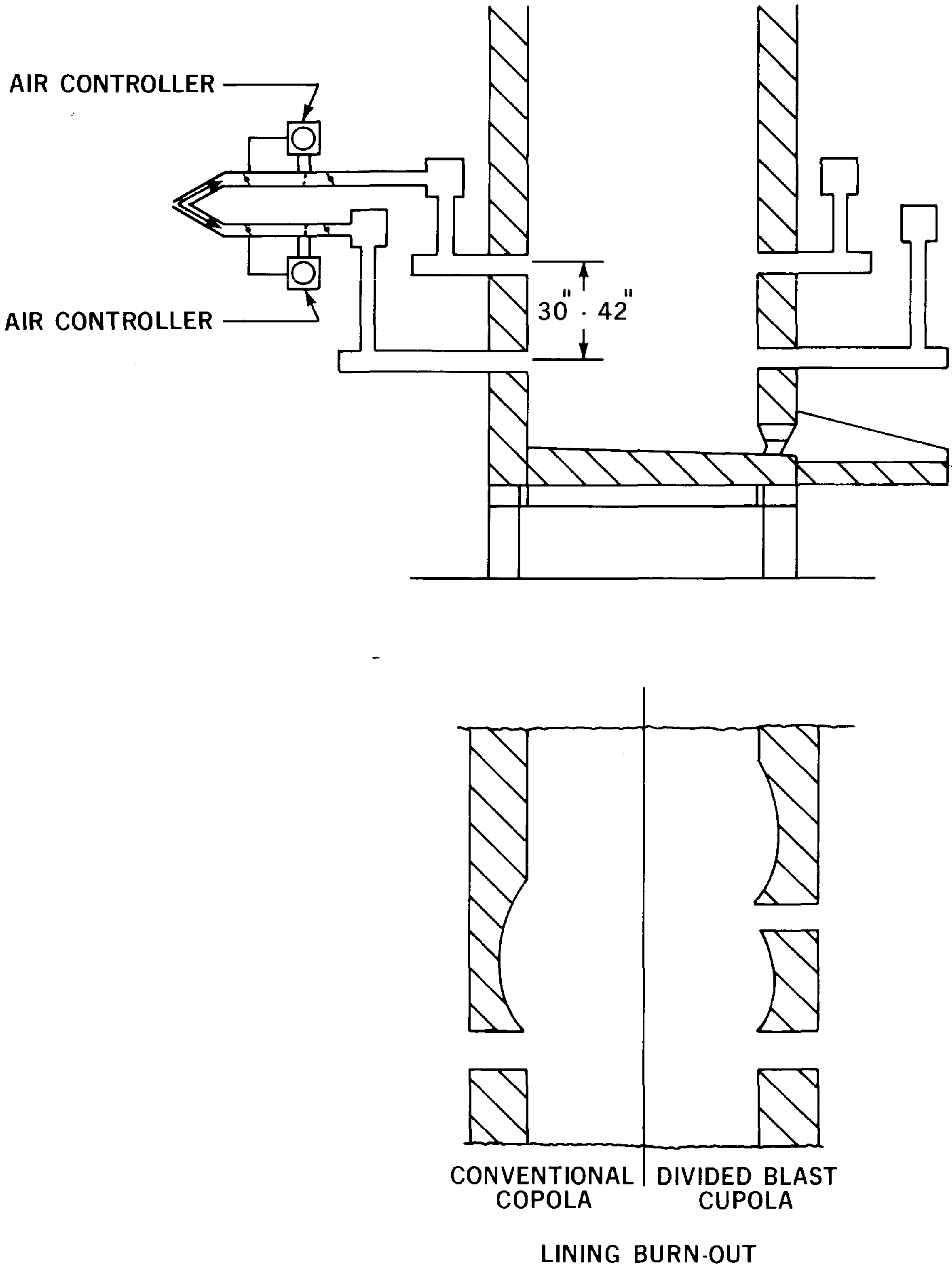



FIGURE 10 THE DIVIDED BLAST CUPOLA (14)

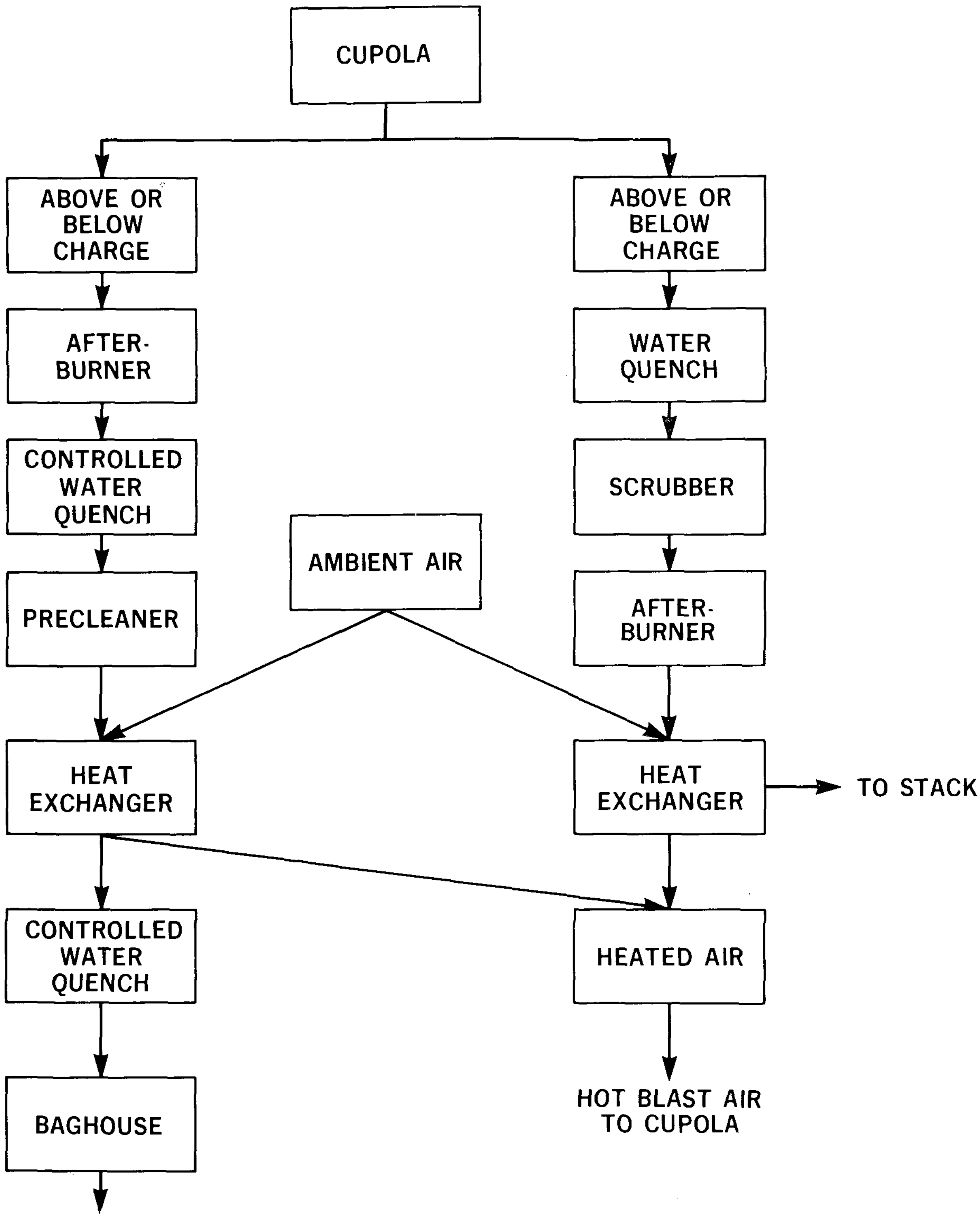



FIGURE 11 SCHEMATIC OF HEAT RECOVERY SYSTEM

**6.4.1.3 Oxygen enrichment of the cupola combustion air** (13, 15). The addition of pure oxygen enriches the combustion air in cupolas, producing a higher flame temperature and a shorter oxidation zone in the oxygen-enriched coke bed. It therefore provides a melting atmosphere richer in CO at any given metal-coke ratio without sensible heat losses from nitrogen. The important benefit of this is to melt iron with less charge coke than normal without the metal oxidation which would have occurred with conventional combustion air rates. The most common enrichment rate of 2% oxygen would result in approximately 9% blast volume reduction. A beneficial effect of oxygen enrichment is a lower gas volume in proportion to the drop in blast volume. Other beneficial effects that make oxygen injection profitable are reduction of calcium carbide addition to increase metal (tapping) temperature and increase melt rate, and substitution of lower-grade, less expensive materials such as cast scrap for a portion of the pig iron charge. These are made possible through the higher temperatures and improved heat transfer and thermal efficiency achieved in the combustion zones with oxygen enrichment.

**6.4.2 Innovative Emission Control Equipment.** Innovative pollution control equipment for further reducing control costs and improving collection efficiency has been developed. A few of the innovative developments include a scrubber system powered by the waste heat of the cupola (Steam-Hydro air cleaning system), and a dry electrostatic precipitator system in which the electrostatic field is generated by sharp needles mounted on both edges of the electrode plates.

**6.4.2.1 Steam-Hydro air cleaning system** (13). In the Steam-Hydro air cleaning system the CO-laden off-gas from the furnace is combusted in a waste heat boiler and the steam produced is used both to provide the required draft and collect the particulates. A schematic diagram of the system is shown in Figure 12. The flue gas from the waste heat boiler is first saturated with water in the atomizer chamber. Steam is then injected just ahead of the mixing tube where collision occurs between the water droplets and the particulates. A shock wave pattern is created in the mixing tube, which induces massive turbulent action for maximum scrubbing efficiency. Overall collection efficiency of more than 99% has been reported.

**6.4.2.2 United McGill electrostatic precipitator** (13). This precipitator, introduced in Japanese foundries, has an innovative design to overcome many of the inherent difficulties of conventional electrostatic precipitators applied to cupolas. The electrostatic field is generated by sharp needles mounted on both edges of the electrode plates which

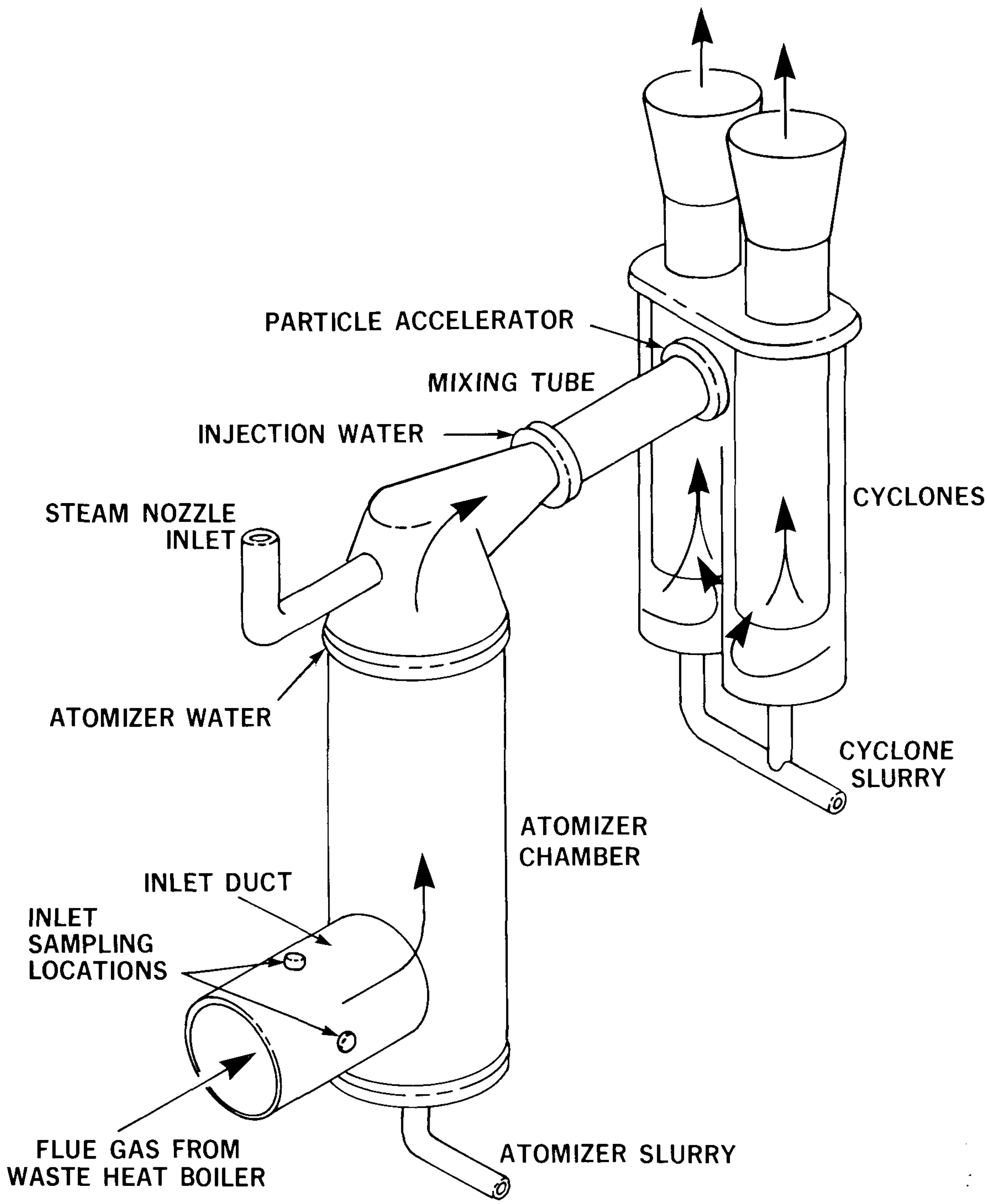



FIGURE 12 THE LONE STAR STEEL STEAM-HYDRO AIR CLEANING SYSTEM (13)

allows the precipitator to operate at a lower voltage and amperage than conventional units which use suspended wire or rigid frames as discharge electrodes. The discharge electrodes are electrically positive, which means that the positive ions used as the charge carriers build up an effective space charge. This would inhibit sparking and arcing to a large degree. As a result, the distance between the discharge plates and the collector plates can be decreased. Thus, the collection efficiency can be improved. The new design also provides twice the collection plate area since the conventional wire-plate arrangement is replaced by two plates of opposite polarity. The needle points, because of their positioning, are self-cleaning and do not need a cleaning system. Thus, re-entrainment of the collected dust is reduced.

### 6.5 Evaluation of Control Technology

**6.5.1 General.** The degree of particulate emission control for melting operations has been reported to vary between 60% and 98% depending on the control equipment installed. Cupola furnaces and electric arc furnaces controlled by high-energy venturi scrubbers and fabric filters have reported collection efficiencies of 98% and greater. The degree of control by less efficient equipment has been given at 60% for wet caps and 80%-90% for high-efficiency cyclones and centrifugal collectors. Cupola and electric arc furnaces also use high-efficiency equipment, such as combinations of spray towers and fabric filters or cyclones and venturi scrubbers. The use of spray towers and cyclones greatly reduces the load and improves the operation of the fabric filters and venturi scrubbers, making optimum efficiency possible.

**6.5.2 Cost of Pollution Control.** The cost of pollution control is estimated from in-house information and data found in the literature (9, 10, 11), supplemented by the ferrous foundry industry (11). The cost of installing pollution control equipment for the entire melting and non-melting operations has been estimated to be 8 - 11% of the capital cost of new plants. Higher costs can be expected in older plants where additional control equipment and more complicated flue systems may be needed, and where space for installation of such equipment may be limited. Part of the emission control costs, however, could be recovered from the utilization of the stack gas waste heat such as in the case of recuperative hot blast cupolas with emission control. The savings are substantial since more than 1 627 780 joules per kilogram of charge per hour (700 Btu per pound of charge per hour) or approximately 50% of the heat supplied to the furnace melting operations are lost by exhausting the stack gas to the atmosphere (13, 24).

Reliable estimates of operating costs for pollution control equipment are not available, but costs would vary from plant to plant. Factors affecting the costs are the age and size of the plant, production processes used, degree of environmental control and quality and cleanliness of raw materials. Operating costs can be reduced by establishing a good maintenance program.

**6.5.3 Control Technology.** Control technology now being used by some foundries has been described in sections 6.1 to 6.4. The emission factors attainable using this technology are shown in Table 17. An overall emission factor (115 milligrams per standard cubic metre) for non-melting operations is used to provide flexibility because many small- and medium-sized foundries in Canada collect emissions from more than one process operation in a common dust collector.

TABLE 17 EMISSION FACTORS ATTAINABLE BY CONTROL TECHNOLOGY NOW IN USE (1, 2, 9, 22, 23, 24, 25, 26)

| Operation | Emission Factor (milligrams/standard cubic metre) |
|---|---|
| MELTING OPERATIONS | |
| Cupola Furnaces (tonnes* of hot metal/hour) | |
| < 10 | 550 |
| 10-20 | 230 |
| > 20 | 115 |
| Electric Arc Furnaces | 50 |
| Induction Furnaces | To be controlled by local regulatory agency |
| NON-MELTING OPERATIONS | 115 |

* 1 tonne (1 000 kilograms) = 2 205 lb = 1.10 tons

## REFERENCES

1. Systems Analysis of Emissions and Emissions Control in the Iron Foundry Industry: Volumes I-III, A.T. Kearney and Co., Chicago, Illinois, February 1971.

2. Air Pollution Emissions and Control Technology - Iron and Steel Foundries, Hatch Associates Ltd., Toronto, Ontario. Revision 1, December 1975.

3. Report of the Canadian Ferrous Foundry Industry: 1974 National Survey, Department of Industry, Trade and Commerce.

4. Foundry Air Pollution Control, The Penton Publishing Co., Cleveland, Ohio, 1971.

5. Air Pollution Control Directorate, Nationwide Inventory of Air Pollutant Emission - Summary of Emissions for 1970. Environmental Protection Service, Department of the Environment, Ottawa, Ontario, Report EPS 3-AP-73-1, January 1973.

6. American Air Filter Bulletin No. 307.

7. Foundry Air Pollution Control Manual, American Foundrymen's Society, 1967.

8. Cupola Handbook, American Foundrymen's Society, 4th Edition, 1975.

9. A Localized Study of Gray Iron Foundries to Determine Business and Technical Commonalities Conducive to Reducing Abatement Costs, J.A. Commins and Associates, Inc., Fort Washington, Pennsylvania, January 1972.

10. Foundry Environment... Past, Present and Future, Modern Casting, December 1976.

11. Trip Reports - Ferrous Foundry Visits, August 27, 1976 and September 20-21, 1976. Kin Mah, Air Pollution Control Directorate, Environmental Protection Service, Environment Canada, Ottawa, Canada.

12. Miller, William C., Gray Iron Foundries without Cupolas: Emission Reduction and Operating Experience, Proceedings of The Third International Clean Air Congress, Dusseldorf, Federal Republic of Germany, 1973.

13. Energy Conservation Techniques for the Iron Foundry Cupola, Environmental Protection Agency, Environmental Protection Technology Series EPA-600/2-76-071, March 1976.

14. New Cupola Technology, B.J. Davies et al., Modern Casting, September 1975.

15. Rolseth, H.C.: The Effect of Oxygen Enrichment on Energy Consumption in Iron Cupola Melting, Modern Casting, September 1976.

16. Cupola Exhaust Heat Recovery, Foundry Management and Technology, August 1976.

17. Cupola Exhaust Gases Heat Foundry, Foundry Management and Technology, August 1976.

18. CFD's 138-In. Clean Gas Recuperative Cupola, Foundry Management and Technology, December 1976.

19. Recuperative Hot Blast Cupolas with Emission Control in Australia, Japan and the USA. AFS Transactions, 76-30.

20. Induction Furnaces, Preheaters, and Air Pollution, Foundry, August 1968.

21. Personal Communication from Benjamin E. White, District Engineer, Air Quality Division, Michigan Department of National Resources, Saginaw, Michigan, to Kin Mah, Air Pollution Control Directorate, Environmental Protection Service, Environment Canada, Ottawa, Canada, April 19, 1977.

22. Cupola System for Chevrolet, The Wet Scrubber Newsletter, November 30, 1976.

23. The McIlvaine Scrubber Manual, Chapter IX, Sec. 3320, p. 96.0

24. The Fabric Filter Newsletter, May 10, 1976, Vol. 1, No. 7, p. 4; July 10, 1976, Vol. 1, No. 9, p. 7.

25. Nicola, Arthur G., Fugitive Emissions Control in the Steel Industry, Iron and Steel, July 1976.

26. Advanced Melting Technology at Landore - BSC Cupola Plant Incorporates Unusual Features, Foundry Trade Journal, October 5, 1972.

**BIBLIOGRAPHY**

Copper, Hal B.H. and Green, William J., Energy Consumption Requirements for Air Pollution Equipment at an Iron Foundry, Paper 77-59.2 presented at the 70th Annual Meeting of the Air Pollution Control Association, 1977.

Wagner, Arthur J., AFS and the Energy Problem, Modern Casting, February 1976.

Bierly, James R., New Foundry Eliminates Dust Problems with Sand Cooling System, Modern Casting, April 1977.

Burden, T.E., Recycling Wet Dust Collector Waste in Green Sand Systems, Modern Casting, June 1977.

Kane, John M., In-Plant Ventilation Options for Energy Conservation, Modern Casting, December 1976.

The Cupola and its Operation, American Foundrymen's Society, 3rd Edition, 1965.

Cupola Emission Control, Gray and Ductile Iron Founder's Society, 1967.

Foundry Environmental Control, American Foundrymen's Society, Volume 2, Booklets 14, 17, 18 and 19.

Peterson, W., Wieber, E., and Engels, G., Dust Content of Cupola Top Gases for Cupolas of Different Designs and Modes of Operation, The British Foundryman, March 1972.

Horwitz, Morris, Modernization Cuts Costs, Control Pollution, Foundry, August 1973.

## APPENDIX I GLOSSARY OF TERMS

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| Additive | - | A substance added to another in relatively small amounts to impart or improve desirable qualities, or suppress undesirable qualities. As additives to moulding sand, for example, cereal, sea coal, etc. |
| Afterburner | - | A device for burning combustible materials that were not oxidized in an initial burning process. |
| Anneal | - | A heat treatment which usually involves a slow cooling for the purpose of altering mechanical or physical properties of the metal, particularly to reduce hardness. |
| Baghouse | - | A large chamber for holding bag filters used to filter gas streams from a furnace to recover metal oxides and other solids suspended in the gases. |
| Baked Core | - | A core which has been heated through sufficient time and temperature to produce the desired physical properties attainable from its oxidizing or thermal setting binders. |
| Balanced Blast | - | The arrangement of tuyeres in a cupola which provides for distributing or balancing the blast as required between upper and lower levels of the melting zone. |
| Bed | - | The initial charge of fuel in a cupola upon which the melting is started. |
| Blast Volume | - | The volume of air introduced into the cupola for the burning of fuel. This volume governs the melting rate of the cupola and approximately 30 000 cubic feet of air is required per ton of metal melted. This is equivalent to 937 cubic metres per tonne. |
| Canopy Hood | - | A metal hood over a furnace for collecting gases being exhausted into the atmosphere surrounding the furnace. |
| Centrifugal Collector | - | The dry type uses centrifugal force to throw dust particles to the periphery of an air stream whereas the wet type uses centrifugal force to accelerate the dust particles and impinges them upon a wetted collector surface. |
| Cereal Binder | - | A binder used in core mixtures and moulding sands, derived principally from corn flour. |
| Coke Breeze | - | Fines from coke screenings. |

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| Core | - | A separate part of the mould that forms cavities and openings in castings that are not possible with a pattern alone. Cores are usually made of a sand different from that used in the mould and are generally baked or set by a combination of resins. |
| Core Binder | - | Any material used to hold the grains of core sand together. |
| Core Blower | - | A machine for making cores by blowing sand into the core box by means of compressed air. |
| Core Oven | - | Specially heated chambers for the drying of cores at low temperatures. |
| Core Sand | - | Sand for making cores to which a binding material has been added to obtain good cohesion and porosity after drying. |
| Cupola | - | A cylindrical, straight-shaft furnace usually lined with refractories, for melting metal in direct contact with coke by forcing air under pressure through openings near its base. |
| Cupola, Hot Blast | - | A cupola supplied with a pre-heated air blast. |
| Ductile Iron | - | Iron of a normally gray cast type that has been suitably treated with a nodularizing agent so that all of the major portion of its graphitic carbon has a nodular or spherulitic form as cast. |
| Duplexing | - | A method of producing molten metal of desired analysis. The metal is melted in one furnace and refined in a second. |
| Dust Collector | - | A device to remove solid particles from a gas stream. |
| Electric Arc Furnace | - | A furnace used to heat materials by the energy from an electric arc. |
| 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 fibers within a baghouse for removing solid particulate matter from the air or gas stream. |

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| Fines | - | A term the exact meaning of which varies:<br>1. Those sand grains that are substantially smaller than the predominant grain size.<br>2. That portion of sieved material that passes through the mesh. |
| 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. |
| Fly Ash | - | A finely divided siliceous material, usually oxides, formed as a product of combustion of coke. A common emission from the cupola. |
| Fourth Hole Ventilation (Direct Evacuation) | - | In air pollution control, the use of a fourth hole in the roof of an electric furnace to exhaust fumes. |
| Gate | - | The portion of the runner in a mould through which molten metal enters the mould cavity. |
| Gray Iron | - | Cast iron that contains a relatively large percentage of its carbon in the form of graphite and substantially all of the remainder of the carbon in the form of eutectoid carbide. |
| Green Sand | - | A naturally bonded sand or a compounded moulding sand mixture that has been tempered with water and additives for use while still in a damp or wet condition. |
| Heat Treatment | - | A combination of heating and cleaning operations timed and applied to a metal or alloy in the solid state in a manner that will produce desired properties. |
| Heel | - | Metal left in a ladle after pouring has been completed. Metal kept in induction furnaces during standby periods. |
| Holding Furnace | - | A furnace for maintaining molten metal, from a larger melting furnace, at the proper casting temperature. |
| Inoculation | - | The addition, to molten metal, of substances designed to form nuclei for crystallization. |
| Ladle | - | A refractory lined vessel into which molten metal is poured from a furnace for the purpose of conveying hot metal and transferring into other ladles or moulds. |

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| Magnesium Treatment | - | The addition of magnesium to molten metal to form nodular iron. |
| Malleable Iron | - | A mixture of iron and carbon, including smaller amounts of silicon, manganese, sulphur and phosphorus, which, after being cast as white iron, is converted structurally by heat treatment into a matrix of ferrite containing nodules of temper carbon, and substantially free of all combined carbon. |
| Micron | - | A unit of measurement which is 1/25,000 of an inch or a millionth of a meter. Often designated by the Greek letter $\mu$. |
| Mould | - | The form, usually made of sand, which contains the cavity into which molten metal is poured to produce a casting of definite shape and outline. |
| Muller | - | A type of foundry sand mixing machine. |
| Pattern | - | A form made of wood, metal or other materials around which moulding material is placed to make a mould for casting metals. |
| Reverberatory Furnace | - | A furnace with a vaulted ceiling that reflects flame and heat toward the hearth or the surface of the charge to be melted. |
| Riser | - | An opening in the top of a mould which acts as a reservoir for molten metal and connected to the castings to provide additional metal to the casting as it contracts on solidification. |
| Runner | - | A refractory lined channel through which molten metal flows from one receptacle to another. |
| SCM | - | Standard Cubic Metre. The volume of gas measured at standard conditions, 100.87 kilopascals of pressure and 25°C. |
| Sea Coal | - | A term applied to finely ground coal which is mixed with foundry sands. |
| Shake-out | - | The operation of removing castings from a sand mould. |
| Shell Moulding | - | A process for forming a mould from thermosetting resin bonded sand mixtures brought in contact with pre-heated metal patterns, resulting in a firm shell with a cavity corresponding to the outline of the pattern. |
| Shot-blasting | - | A casting cleaning process employing a metal abrasive propelled by centrifugal force. |

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| Slag | - | A non-metallic covering which forms on the molten metal as a result of the flux action in combining impurities contained in the original charge, some ash from the fuel and silica and clay eroded from the refractory lining. |
| Spark Arrestor | - | A device over the top of the cupola to prevent the emission of sparks. |
| Sprue | - | The channel, usually vertical, connecting the pouring basin with the runner to the mould cavity. In top pour casting the sprue may also act as a riser. |
| Superheating | - | The heating of a metal to temperatures above its melting point to obtain more complete refining or greater fluidity. |
| Tapping | - | The removal of molten metal from the melting furnace by opening the tap hole and allowing the metal to run into a ladle. |
| Tuyere | - | The nozzle openings in the cupola shell and refractory lining through which the air blast is forced. |
| 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 Cap | - | A device installed on a cupola stack that collects emissions by forcing them through a curtain of water. The device requires no exhaust fan but depends upon the velocity pressure of the effluent gases. |
| Wet Scrubber | - | Dust collector which uses a liquid to achieve or assist in the removal of solid or liquid dispersoids from a carrier gas. |