

Note: This is a reference cited in AP 42, *Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources*. AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

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Section 7.10
Ref. #4
B-3

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6 pages 11-12

FINAL REPORT

on

SCREENING STUDY ON CUPOLAS
AND ELECTRIC FURNACES IN
GRAY IRON FOUNDRIES

to

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

August 15, 1975

by

¹¹⁹⁴
²⁰⁰²
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Contract No. 68-01-0611, Task No. 8

V-2111-6

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August 15, 1975

Mr. Naum T. Georgieff
United States Environmental
Protection Agency
Office of Air Quality Planning
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Research Triangle Park
Durham, North Carolina 27711

Dear Mr. Georgieff:

Screening Study on Cupolas and
Electric Furnaces in Gray Iron Foundries
(EPA Contract No. 68-02-0611, Task No. 8)

Enclosed are 25 copies of our report, "Screening Study on Cupolas and Electric Furnaces in Gray Iron Foundries". Basically, it consists of writeups of specific sections for use in the Standards Support Document and independent writeups for certain subtasks.

Battelle's assignment included only selected portions of the Standards Support Document. Therefore, this report is an incomplete document composed of various assigned subtasks and sections. Subtask 2 is included in Section III (Subtask 4). Subtasks 3, 7, 8, 9, 13, and 1 are submitted as independent writeups that have been designated Subtasks A, B, C, D, E, and F, respectively. The references specified in Subtask 15 are included at the end of each subtask writeup or section. In addition to Section III, mentioned previously, this document also contains Sections IV, V, XII, XIII, and XIV. Brief descriptions of the various subtasks follow:

- (1) Prepare a list of gray iron foundries in the United States giving the plant name, location, capacity, and product line, to the extent available.
- (2) Provide quantitative information on past and current production by the industry, and an estimate of future production over the next 5 years. Estimate, also, the number of new plants to be constructed and the number of existing plants to be significantly modified during the 5-year period.

- (3) Prepare a list of individuals and/or firms having expertise in the gray iron-founding industry.
- (4) Prepare a draft Section III, "Cupolas and Electric Furnaces in Gray Iron Foundries", of the Standards Support Document.
- (5) Prepare a draft Section IV, "Emission Control Technology", of the Standards Support Document.
- (6) Prepare a draft Section V, "Environmental Effects", of the Standards Support Document.
- (7) Prepare an estimate of nationwide air-contaminant emissions from each of the sources (furnace types) dealt with in this task.
- (8) Prepare a list of plants and their locations that are judged to use the best systems of emission reduction. Also provide a brief description of the control systems and supply the name, title, and telephone numbers of plant personnel whom EPA could contact at each location.
- (9) List the potential emission-control systems that could be used as a basis for defining "the best systems of emission reduction taking cost into account" and the advantages and disadvantages of each system.
- (10) Prepare a draft Section XII, "Modifications", of the Standards Support Document.
- (11) Prepare a draft Section XIII, "Unresolved Issues", of the Standards Support Document.
- (12) Prepare a draft Section XIV, "Anticipated Reaction of the Public and Industry", of the Standards Support Document.
- (13) Summarize the available methods for testing and analysis of air-contaminant emissions for each process (furnace type) covered in this task.
- (14) Make use of references suggested by EPA.
- (15) Provide a detailed list of all references.

Mr. Naum T. Georgieff

3

August 15, 1975

Since this is an incomplete document, no summary or conclusions sections were prepared.

Yours very truly,

A handwritten signature in cursive script that reads "J. A. Davis". The signature is written in dark ink and is positioned above the typed name and title.

J. A. Davis
Task Leader

JAD:lls

Enc. (25)

TABLE OF CONTENTS

| | <u>Page</u> |
|-----------------------------------------------------------------------------------------------------------------|-------------|
| SECTION III | |
| CUPOLAS AND ELECTRIC FURNACES IN GRAY IRON FOUNDRIES. | III-1 |
| Background Description of the Domestic Gray Iron-Foundry Industry | III-1 |
| Introduction. | III-1 |
| Gray Iron-Foundry Products. | III-2 |
| Number, Size and Location of Plants | III-4 |
| Some Major Trends in the Gray Iron-Foundry Industry . . . | III-5 |
| Contribution of the Foundry Industry to Air Pollution When the Industry Was Not Controlled. | III-7 |
| Introduction. | III-7 |
| Pollution Contributed to the Air by Foundry Melting Equipment if Uncontrolled | III-9 |
| Emissions From Melting Units for Which Standards Are Not Recommended | III-11 |
| Emissions From Foundry Operations Other Than Melting for Which Standards Are Recommended | III-12 |
| Gray Iron-Foundry Processes. | III-12 |
| Raw-Materials Receiving, Preparation, Storage, and Preheating. | III-12 |
| Iron Melting. | III-17 |
| Sand Receiving and Preparation. | III-24 |
| Molding, Pouring, and Shakeout. | III-25 |
| Cleaning and Finishing. | III-28 |
| Heat Treatment. | III-28 |
| Sources, Types, and Mass Rate of Uncontrolled Atmospheric Emissions and Process Factors That Affect the Rate | III-30 |
| Raw Materials as a Source of Emissions. | III-30 |
| Melting as a Source of Emissions. | III-30 |

TABLE OF CONTENTS
(Continued)

| | <u>Page</u> |
|-----------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Molding and Coremaking as Sources of Emissions. | III-40 |
| Tapping, Metal Treatment, Pouring, Cooling, Shakeout, and Cleaning as Sources of Emissions. | III-41 |
| Examples of Air-Pollution Rates When Restricted by Both Typical and Most-Restrictive State Emission-Control Regulations | III-44 |
| References | III-56 |

SECTION IV

| | |
|----------------------------------------------------------------------------------------|-------|
| EMISSION-CONTROL TECHNOLOGY | IV-1 |
| Introduction | IV-1 |
| Water Scrubbers. | IV-1 |
| Wet Caps. | IV-2 |
| Low-Energy Scrubbers. | IV-3 |
| High-Energy Scrubbers | IV-3 |
| Baghouse Filtration. | IV-5 |
| Electrostatic Precipitators. | IV-8 |
| Cyclone-Type Cleaners. | IV-10 |
| Combustion Systems for Controlling Carbon Monoxide and Organic Vapors | IV-11 |
| Preheaters for Scrap. | IV-11 |
| Afterburners for Cupola Top Gases and Other Foundry Waste Gases | IV-12 |
| Catalytic-Combustion Systems for Mold Gases and Coremaking Fumes. | IV-13 |
| Emission-Control Technology Used in Other Industries | IV-13 |
| Effect of Operating Conditions on Emission-Control-Equipment Requirements | IV-15 |
| Molding and Coremaking. | IV-15 |
| Charge Materials. | IV-15 |

TABLE OF CONTENTS
(Continued)

| | <u>Page</u> |
|------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Melting Operation | IV-16 |
| Metal Treating, Pouring, Mold Cooling, Shakeout, Cleaning, Sand Preparation, Mixing and Handling, and Coremaking. | IV-18 |
| Performance of Commonly Used Emission-Control Devices. | IV-21 |
| Performance of the Best Systems to Control Emissions from Foundries | IV-23 |
| References | IV-26 |
| SECTION V | |
| ENVIRONMENTAL EFFECTS OF VARIOUS AIR-POLLUTION-CONTROL SYSTEMS. . . . | V-1 |
| Air-Pollution Emission When Using the Best Systems of Control. | V-1 |
| Iron-Melting Air-Pollution-Control Equipment. | V-1 |
| Tapping the Furnace and Treating the Iron With Magnesium to Make Ductile Iron. | V-4 |
| Pouring and Cooling of Molds and Shakeout of Castings | V-5 |
| Sand Transportation and Mixing, and Casting Cleaning and Finishing | V-6 |
| Coremaking. | V-7 |
| Estimate of the Reduction in the Emission When Using the Above Best Systems Over the Average State Emission Requirements | V-7 |
| Total Particulate Emission from Melting Operations With Best and <u>Average</u> Systems | V-8 ✓ |
| Total Carbon Monoxide Emission from Melting Operations With Best System and Average State Emission Code. | V-9 |
| Possible Benefits to Health and Welfare Due to the Decrease in Emission from the Controlled Plants | V-11 |
| Impact on Potential Water Pollution and Solid-Waste Disposal When Employing the Best Control System | V-12 |
| Increase in Pollutant Emissions from the Power Sources that Provide the Energy for the Best Emission-Control System. . . . | V-14 |

TABLE OF CONTENTS
(Continued)

| | <u>Page</u> |
|-----------------------------------------------------------------------------------------------------------------------------|-------------|
| Reducing the Emission from Iron-Foundry Melting Units by Changing the Melting Equipment | V-15 |
| References | V-17 |
| SECTION XII | |
| MODIFICATIONS | XII-1 |
| Standards of Performance for New Stationary Sources. | XII-1 |
| Changes in Melting Equipment That Could Increase the Amount of Air Pollution. | XII-1 |
| Changes in Melting Procedures That Could Increase the Amount of Pollution. | XII-2 |
| Changes in Plant Operations Other Than Melting That Could Increase the Amount of Pollution | XII-3 |
| Reference. | XII-4 |
| SECTION XIII | |
| UNRESOLVED ISSUES | XIII-1 |
| Emissions From Foundry Melting Furnaces That Are Not Controlled in the Recommended Best Emission-Reduction System | XIII-1 |
| The Level to Which Pollutants Should be Controlled | XIII-2 |
| The Problem of Disposal of Particulates from Air-Cleaning Systems. | XIII-3 |
| Effect of the Emission-Control System for Carbon Monoxide on the Consumption of Fuel | XIII-4 |
| Restriction of Air Flow. | XIII-5 |
| Foundry Emissions from Sources Other Than Melting That Are Not Included in This Document. | XIII-6 |
| Reverberatory Furnaces | XIII-7 |

TABLE OF CONTENTS
(Continued)

| | <u>Page</u> |
|-------------------------------------------------------------------------------------------------------------------------------------|-------------|
| SECTION XIV | |
| ANTICIPATED REACTION OF THE PUBLIC AND INDUSTRY TO THE STANDARDS SUPPORT DOCUMENT. XIV-1 | |
| Introduction | XIV-1 |
| Anticipated Public Reaction to the Proposed Emission Standards. | XIV-2 |
| Anticipated Reaction of the Iron-Foundry Industry to the Revised Emission Standards | XIV-3 |
| Particulates. | XIV-3 |
| Carbon Monoxide, Hydrocarbons, and Organic Fumes. | XIV-3 |
| Nitrogen Oxides | XIV-5 |
| Sulfur Expressed as Sulfur Dioxide. | XIV-5 |
| References | XIV-6 |
| SUBTASK A | |
| INDIVIDUALS AND FIRMS THAT HAVE EXPERTISE ABOUT THE IRON-FOUNDRY INDUSTRY AND HAVE BEEN HELPFUL IN THE BATTELLE PROGRAM. | A-1 |
| SUBTASK B | |
| ESTIMATE OF THE NATIONWIDE AIR-CONTAMINANT EMISSIONS FROM GRAY IRON FOUNDRIES. | B-1 |
| References | B-7 |
| SUBTASK C | |
| LIST OF PLANTS THAT HAVE EXEMPLARY AIR-POLLUTION-CONTROL SYSTEMS. . . | C-1 |
| SUBTASK D | |
| ALTERNATIVES FOR THE BEST SYSTEM OF EMISSION CONTROL IN IRON FOUNDRIES | D-1 |
| Control of Particulate | D-1 |
| Fabric Filters. | D-1 |
| High-Energy Scrubbers | D-2 |
| Hoods | D-4 |

TABLE OF CONTENTS
(Continued)

| | <u>Page</u> |
|-------------------------------------------------------------------------------------------------------------|-------------|
| Control of Carbon Monoxide and Other Combustible Gases | D-4 |
| Afterburners. | D-5 |
| Catalytic Combustors. | D-5 |
| Control of Emissions by Changing Melting Equipment | D-6 |
| Effect of Emission-Control Systems on In-Plant Occupational Safety and Health Act Requirements | D-7 |
| References | D-8 |

SUBTASK E

| | |
|--------------------------------------------------------------------------------------------------|-----|
| TESTING AND ANALYSIS METHODS FOR AIR-CONTAMINANT EMISSIONS FROM GRAY IRON FOUNDRIES | E-1 |
| Measurement of Particulate | E-1 |
| Measurement of Carbon Monoxide | E-3 |
| Measurement of Hydrocarbons. | E-4 |
| Measurement of Sulfur Dioxide. | E-4 |
| Measurement of Nitrogen Oxides | E-5 |
| References | E-5 |

SUBTASK F

| | |
|---------------------------------------------------------------|-----|
| GRAY AND DUCTILE IRON FOUNDRIES IN THE UNITED STATES. | F-1 |
|---------------------------------------------------------------|-----|

SUBTASK G

| | |
|-----------------------------|-----|
| GLOSSARY OF TERMS | G-1 |
|-----------------------------|-----|

SECTION III

CUPOLAS AND ELECTRIC FURNACES IN GRAY IRON FOUNDRIES

Background Description of the Domestic Gray Iron-Foundry Industry

Introduction

The gray iron-foundry industry as here defined includes all foundries that produce primarily gray or ductile iron castings or malleable iron. Excluded from this definition are foundries that produce primarily steel castings, and, of course, nonferrous castings. Malleable iron originally was excluded from the study, but later was included after a computer list of U. S. foundries had been prepared. The final listing includes all malleable iron foundries that make some gray or ductile iron castings, and includes all malleable iron foundries that are members of the Malleable Founders Society. Foundries that produce such castings as molds for steel ingots from blast-furnace metal also are excluded because the melting system (blast furnaces) used to produce such castings requires the same air-pollution controls as do blast furnaces in integrated iron and steel plants. However, foundries that produce ingot molds with cupola or electric-furnace melting methods are included. Unfortunately, it has not been possible to effect a statistical separation of ingot molds produced by these two melting sources.

Metal casting is a huge industry, the size of which is not generally appreciated by the public nor even by many industrialists. With annual "value added" in excess of \$6 billion per year, the metal-casting industry ranks sixth among all American manufacturing industries.(1)* Metal casting is exceeded in "value added" only by (1) motor vehicles, (2) the steel industry, (3) aircraft and parts, (4) industrial chemicals, and

* References are listed at the end of the section.

(5) communications equipment; in turn, the casting industry exceeds (7) the beverage industries, (8) fabricated metal products, (9) newspapers, and (10) drugs and pharmaceuticals in value added. Some background statistics are given in Table III-1.

Gray Iron-Foundry Products

Gray iron-foundry castings have a Product Class Code of 3321. A breakdown of the value of gray iron-foundry products for 1970 is as follows:⁽²⁾

| Product Class Code | Product Class | Total Shipments, mkg (1,000 short tons) | | Total Value of Shipments, million dollars ⁽³⁾ |
|--------------------|----------------------------------------------------|-----------------------------------------|------------------|----------------------------------------------------------|
| 33210 | Gray iron castings, n.s.k. (not specified by kind) | -- | X ^(a) | 22 |
| 33211 | Molds for heavy steel ingots | 3,080 | (3,396) | 257 |
| 33212 | Cast iron pressure pipe and fittings | 1,534 | (1,691) | 332 |
| 33213 | Cast iron soil pipe and fittings | 864 | (953) | 136 |
| 33214 | Miscellaneous gray iron castings | 7,170 | (7,905) | 2,300 |
| | Total | 12,648 | (13,945) | 3,047 |

(a) X = not applicable.

The value of all gray iron-foundry products (including ductile iron products) shipped in 1972 was \$3,888 million.⁽⁴⁾ Other statistics on the value impact of the foundry industry in 1972 are as follows:⁽⁴⁾

| | |
|-------------------|------------------|
| All employees | 138,000 |
| Payroll | \$1,400 million |
| Cost of materials | \$1,644 million |
| Value added | \$2,272 million. |

Thus, the gray iron-foundry industry exerts an enormous impact on the economy of the United States through the value of the products it produces, through the number of people employed, and through its total payroll.

TABLE III-1. ANALYSIS OF THE FOUNDRY INDUSTRY

| Number of Employees | Major Metal Cast | Number of U. S. and Canadian Plants, for Indicated Years | | | | | | |
|---------------------------------------|-----------------------|----------------------------------------------------------|-------|-------|-------|-------|-------|-------|
| | | 1973 ^(a) | 1971 | 1969 | 1967 | 1965 | 1963 | 1961 |
| <u>Grouped by Number of Employees</u> | | | | | | | | |
| Over 1,000 | -- | -- | 49 | 47 | 49 | 37 | 28 | 28 |
| 500 to 999 | -- | -- | 73 | 83 | 109 | 82 | 81 | 86 |
| 250 to 499 | -- | 166 ^(b) | 210 | 224 | 223 | 191 | 195 | 212 |
| 100 to 249 | -- | -- | 606 | 610 | 593 | 547 | 533 | 540 |
| 50 to 99 | -- | 595 ^(c) | 711 | 749 | 788 | 701 | 728 | 741 |
| 20 to 49 | -- | 534 ^(d) | 1,169 | 1,181 | 1,155 | 1,195 | 1,211 | 1,216 |
| Under 20 | -- | 178 ^(e) | 2,436 | 2,472 | 2,478 | 2,729 | 2,898 | 3,056 |
| <u>Grouped by Major Metal Cast</u> | | | | | | | | |
| -- | Gray and ductile iron | 1,473 ^(f) | 1,530 | 1,638 | 1,724 | 1,771 | 1,896 | 2,040 |
| -- | Malleable iron | -- | 70 | 77 | 80 | 83 | 90 | 92 |
| -- | Steel | -- | 427 | 416 | 393 | 370 | 367 | 360 |
| -- | Nonferrous metals | -- | 3,227 | 3,235 | 3,198 | 3,258 | 3,321 | 3,387 |
| -- | All plants | | 5,254 | 5,366 | 5,395 | 5,482 | 5,674 | 5,879 |

(a) U. S. gray and ductile iron plants only, as of January, 1974.

(b) Over 250 employees.

(c) 50 to 249 employees.

(d) 10 to 49 employees.

(e) Less than 10 employees.

(f) The Penton Foundry Survey lists 1473 foundries that produce gray or ductile iron either as a primary or secondary metal.

Number, Size, and Location of Plants

The Penton Publishing Company supplied a computer printout that listed all of the gray and ductile iron foundries in the United States. The foundries, arranged alphabetically by state and by city in each state, are listed in Subtask F. The list contains 1473 foundries from the Penton Foundry Survey list. It also includes 23 malleable iron foundries (added at the end of the listing) from the Malleable Founders Society membership list. Data on employment and melting equipment are not available for these 23 foundries. Malleable iron foundries that are not members of the Malleable Founders Society and that do not make gray or ductile iron are not included. The Malleable Founders Society has 32 members, and 23 of these members were not included in the Penton Publishing Company list, presumably because they do not make gray or ductile iron in addition to malleable iron.

The 1473 gray and ductile iron foundries listed in the Penton Publishing Company computer printout have the following furnaces:

| <u>Furnace Type</u> | <u>Number of Units</u> | <u>Companies</u> | <u>Capacity, tons/hour</u> |
|-----------------------|------------------------|------------------|----------------------------|
| Cupola | 1804 | 1092 | 14,213 |
| Channel induction | 408 | } 397 | 2,362 |
| Coreless induction | 726 | | |
| Arc | 371 | 187 | 2,555 |
| Air and reverberatory | 159 | -- | -- |

Of the total foundries listed, 381 do not operate cupola furnaces.

For the 1473 foundries that produce gray and ductile iron, those foundries that listed the major metal produced in the area of interest in this report were as follows:

| <u>Major Metal</u> | <u>Number of Foundries</u> |
|--------------------|----------------------------|
| Gray iron | 1226 |
| Ductile iron | 74 |
| Malleable iron | 40(a) |
| Total | 1340 |

(a) Includes 32 foundry members of Malleable Founders Society.

May foundries that produce gray and ductile iron consider other metals to be their major metal, as is shown in Table F-1 (Subtask F).

The 1473 foundries listed in Table F-1 had employment in the following ranges:

| <u>Employment</u> | <u>Number of Foundries</u> |
|-------------------|----------------------------|
| Over 250 | 166 |
| 50 to 249 | 595 |
| 10 to 49 | 534 |
| Less than 10 | 178. |

Most gray and ductile iron foundries employ between 10 and 249 people.

No melting equipment or capacity was given for 29 of the foundries. These foundries apparently are all of those engaged primarily in the production of gray iron ingot molds for the steel industry.

Some Major Trends in the Gray Iron-Foundry Industry

The general level of total output of gray iron foundries in the United States has remained about the same for the past 25 years. For example, the average output of gray iron foundries from 1965 to 1972 was about 15 million tons per year. This is almost identical with the average annual production in the 1950 period. The 1973 output increased to 16.4 million tons; however, output is expected to decrease about 3 percent for 1974.⁽⁶⁾ This decrease will be the result of a slightly lower demand in the automotive and basic steel industries, although the demand in most other major markets will continue to be strong. After 1974 and on through 1980, the production of gray iron castings is expected to increase at a moderate rate as the demand for automotive and basic steel castings is restored as a result of easing of the oil shortage. However, continued shortages of scrap iron and steel, coke, and pig iron might retard or even prevent the expected growth. The proposed expansion plans shown in Figure III-1⁽⁷⁾ should provide the gray iron-foundry industry with sufficient capacity to meet the increased demand.

Ductile iron castings represent only about 12 percent of total gray iron shipments at present. However, since 1967, ductile iron production has been growing at a rate of about 15.6 percent per year.⁽⁶⁾ In fact, it is the continued growth in this type of casting that will account for most of the growth of the gray iron-foundry industry through 1980. The

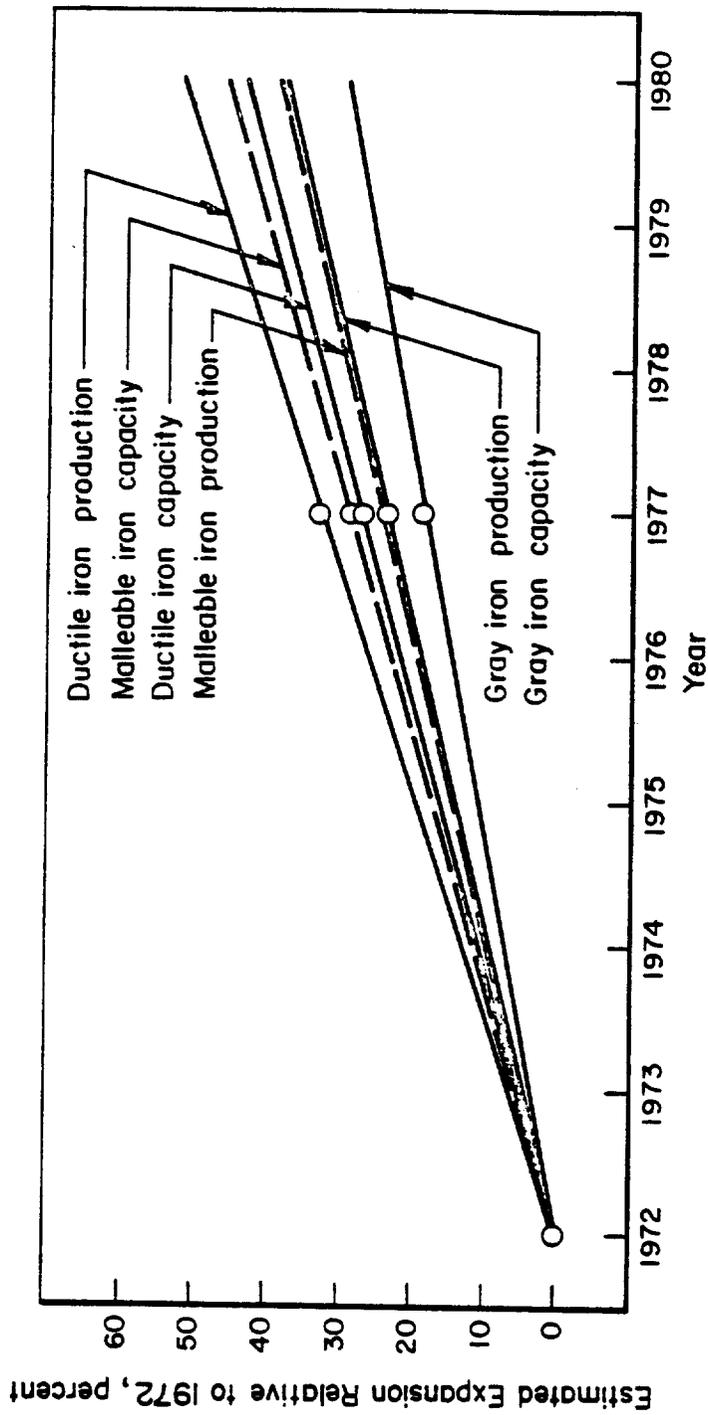


FIGURE III-1. ESTIMATED PERCENTAGE EXPANSION OF PRODUCTION AND CAPACITY FOR GRAY, DUCTILE, AND MALLEABLE CAST IRON (1970-1980) (*)

expansion in ductile iron production is the direct result of replacement of steel fabrications, steel and malleable iron castings, and, to a lesser extent, gray iron castings by ductile iron castings. The ductile iron production is expected to increase 50 percent between 1972 and 1980⁽⁷⁾ (see Figure III-1).

Malleable iron represents only about 7 percent of the gray iron production. Malleable iron production is expected to increase at about the same rate as gray cast iron through 1980 (see Figure III-1).

The total production in 1973 was⁽⁸⁾:

| | | |
|----------------|----------------|--------------------------|
| Gray iron | 13,466,714 kkg | (14,844,494 short tons) |
| Ductile iron | 2,038,867 kkg | (2,247,464 short tons) |
| Malleable iron | 934,437 kkg | (1,030,039 short tons) |
| Total | 16,440,018 kkg | (18,121,997 short tons). |

The estimated production in 1977 and 1980 and actual production for 1972 are as follows:

| Metal | Production for Indicated Years, Millions | | | | | |
|----------------|------------------------------------------|------------|------|------------|------|------------|
| | 1972 ⁽⁹⁾ | | 1977 | | 1980 | |
| | Kkg | Short tons | Kkg | Short tons | Kkg | Short tons |
| Gray iron | 12,241 | (13.494) | 15.1 | (16.7) | 16.9 | (18.6) |
| Ductile iron | 1.665 | (1.835) | 2.2 | (2.4) | 2.5 | (2.8) |
| Malleable iron | 0.871 | (0.960) | 1.1 | (1.2) | 1.2 | (1.3) |
| Total | 14.777 | (16.289) | 18.4 | (20.3) | 20.6 | (22.7). |

Contribution of the Foundry Industry to
Air Pollution When the Industry Was Not Controlled

Introduction

The foundry industry contributed significantly to air pollution in the United States during the years when it operated without controls. The most apparent contributions to air pollution were the volumes of smoke and grit that were emitted from the stacks of cupolas. The smoke often could be seen for miles and would drift for miles before it would disperse.

The coarse particles settled rapidly near the stack, sometimes collapsing roofs in the area*, and the finer particles drifted further and settled over a much wider area. Very dusty atmospheres generally are irritating to the human respiratory system. Therefore, there is little doubt that these particulates were irritants and contributed to poor air quality in the community. The fine particles often contribute to degradation of property.

Carbon monoxide is generated by the combustion of coke in the cupola. Part of the time, carbon monoxide was emitted from the cupola stacks, along with the particulate. At other times, almost all of the carbon monoxide was converted to harmless carbon dioxide when it was burned in the stack when the normal combustion zone extended above the charging door. The contribution of the carbon monoxide emitted by foundries to the degradation of the total quality of the air is not known.

Other pollutants that would have been present in the cupola-stack discharge part of the time include vaporized or partially burned organic matter, sulfur dioxide, metal oxides, and chlorides or fluorides. The concentration of these pollutants was probably too low most of the time to have a significant detrimental effect on the air quality at ground levels.

Arc furnaces emit considerably less particulates than do cupolas, and induction furnaces emit considerably less particulates than do arc furnaces. Both of these types of furnace are relatively new in the foundry industry and, inasmuch as very few of these furnaces were used, they probably made a small contribution to the total air pollution in the nation before the installation of air-cleaning equipment. However, the effluent from arc furnaces is visible, and it is an irritant; therefore, it must be controlled. Most of the arc-furnace particulate is composed of iron oxide. The amount of effluent from induction furnaces, mostly iron oxide, may be small enough that air-pollution controls might not be needed. However controls may be needed with some installations.

Prior to the enactment of the Williams-Steiger Occupational Safety and Health Act of 1970 (OSHA), most foundries discharged very little in the way of pollutants directly to the outside atmosphere, other than the discharge from the cupola stacks. Emissions from most foundry operations other than melting were discharged into the atmosphere inside the foundry buildings and

* Personal observation by one of the authors.

eventually the finer particles were discharged through roof fans or vents. Without forced ventilation, there may have been a significant quantity of emissions from these other operations, although the amount is not quantifiable. However, OSHA requirements for clean air inside foundry buildings have made it necessary for most foundries to install hoods over the dirtiest operations and to remove the fumes and dusts from work areas with suction fans. In most cases, the dirty air thus removed from the foundry must be cleaned before it can be discharged to the outside atmosphere.

In summary, before 1970 when OSHA went into effect, gray iron foundries contributed significantly to air pollution, including both the emissions produced by cupola melting operations, the most common melting practice, and, to a lesser extent, the emissions from other plant operations. As forced ventilation of foundry work areas and foundry operations became necessary to meet OSHA requirements, the emission of large particles probably increased and the emissions were likely to be much more noticeable. In most cases, it also became necessary to clean the air effectively before it was discharged either back into the foundry atmosphere or outside the foundry buildings.

Pollution Contributed to the Air by Foundry Melting Equipment if Uncontrolled

The gray, ductile and malleable iron foundries produced 16.44 million kkg (18.12 million short tons) of castings in 1973. Assuming an average yield of 60 percent good castings, then the total weight of metal melted was 27.40 million kkg (30.2 million short tons). About 3.7 million kkg (4.1 million short tons) of the total gray iron was ingot molds. Again at 60 percent yield, about 6.2 million kkg (6.8 million tons) was melted to make the ingot molds. Based on capacity according to furnace type, an estimated breakdown of the metal melted in 1973 by the various methods follows (See Subtask B):

| Furnace Type | Weight of Metal Melted in 1973 | | | | | |
|---------------|-----------------------------------------------|--------|----------------------------------------------------------------|---------|-----------------------------------------|---------|
| | Ingot Molds, million kkg (million short tons) | | Gray, Malleable, and Ductile, million kkg (million short tons) | | Total, million kkg (million short tons) | |
| Blast furnace | 4.32 | (4.76) | -- | -- | 4.32 | (4.76) |
| Cupola | 1.85 | (2.04) | 17.02 | (18.76) | 18.87 | (20.80) |
| Arc | -- | -- | 2.10 | (2.32) | 2.105 | (2.32) |
| Induction | -- | -- | 2.10 | (2.32) | 2.105 | (2.32) |
| Total | 6.17 | (6.80) | 21.22 | (23.40) | 27.40 | (30.20) |

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total
work

The metal melted in blast furnaces is properly included in the iron-and-steel industry and is not included in the foundry industry insofar as this report is concerned.

The unit weight of pollutants emitted by the various types of foundry melting furnaces is as follows:

| Furnace Type | Unit Weight of Pollutants | | | |
|--------------|--------------------------------------------------|---------------|-------------------------------------|--------------|
| | Particulate ⁽¹⁰⁾ , kg/kkg (lb/ton) | | Carbon Monoxide, kg/kkg (lb/ton) | |
| Cupola | 8.5 | (17) | 75 | (150)(10) |
| Arc | 5.0 | (10) | 18.5 | (37)(a) |
| Induction | 0.8 | (1.5) | ~0 | (~0) |
| Total | 14.3 | (28.5) | 93.5 | (187) |

(a) Calculated from 12,000 scf of ventilation air per ton of iron melted, which contains an estimated 4 percent carbon monoxide.

The contribution of the iron-foundry industry to air pollution for 1973, calculated from the above data on production and pollution, was as follows:

| Furnace Type | Weight of Iron Melted, million kkg (million short tons) | | Weight of Pollutants for 1973 If Uncontrolled | | | |
|--------------|---------------------------------------------------------------|----------------|-----------------------------------------------|----------------|------------------------------------------------|-----------------|
| | | | Particulate, million kg (million lb) | | Carbon Monoxide, million kg (million lb) | |
| Cupola | 18.87 | (20.80) | 160.4 | (353.6) | 1,415 | (3,120) |
| Arc | 2.10 | (2.32) | 10.5 | (23.2) | 39 | (86) |
| Induction | 2.10 | (2.32) | 1.6 | (3.5) | ~0 | (~0) |
| Total | 23.07 | (25.44) | 172.5 | (380.3) | 1,454 | (3,206). |

The major particulate pollutant from cupolas is coke ash, but considerable unburned coke also is emitted. In addition, dirt from the yard, loose rust, and scale that may be present on the scrap or foundry returns, and, also, limestone fines, sand, and metal oxides generally are emitted by either cupolas or arc furnaces. Iron and zinc oxides are the most common metal oxides. The major constituent of particulates emitted by electric-arc furnaces is iron oxide.

Emissions From Melting Units for
Which Standards Are Not Recommended

Metal oxides in the cupola or arc-furnace discharge will be controlled, along with the other particulates. Fluorides are seldom found in appreciable amounts in the cupola discharge, but they also should be controllable by suitable particulate-emission-control equipment. These materials should not be controlled separately, but should be included with the performance standards for particulates.

Control of sulfur emissions (generally present as sulfur oxides, or hydrogen sulfide in certain other industries) is not necessary in foundries, because the sulfur content of the charge materials must be selected to give low-sulfur molten metal and, as a result, the effluent gases are very low in sulfur compounds. Sulfur enters the cupola in the coke. An average coke that contains 0.8 percent sulfur would contribute about 1.78 pounds of sulfur to each ton of metal melted, assuming that the metal-to-coke ratio is 9 to 1. Half or more of the sulfur charged is dissolved in the metal, and about 20 percent is dissolved in the slag. The remaining sulfur is given off in the stack gases, chiefly as sulfur dioxide (SO₂). The sulfur emission from the stack is generally less than 20 percent of the sulfur charged⁽¹¹⁾ (or less than 0.356 pound of sulfur per ton of metal charged). Based on 35,000 scf of gas from the melting of 1 ton of iron in the cupola, which is diluted to 70,000 scf with plant air, this amount of sulfur would correspond to 0.0057 volume percent SO₂ or 57 ppm by volume. This concentration is well below the permissible limit of 500 ppm SO₂ by volume specified by most states for most stationary fuel-burning installations. State regulations do not limit sulfur emissions from foundries, as is shown later in Section III in the part entitled "Sources, Types, and Mass Rate of Uncontrolled Atmospheric Emissions and Process Factors that Affect the Rate".

Only very small amounts of sulfur compounds are emitted from arc or induction furnaces.

Therefore, sulfur compounds should not be candidates for emission standards of performance for iron foundries.

Emissions From Foundry Operations Other Than
Melting for Which Standards Are Recommended

Smoke, fume, and particulate are produced during metal tapping, metal treatment to desulfurize or inoculate with magnesium, metal pouring, mold cooling, casting shakeout, sand distribution and preparation while dry, and the cleaning and grinding of castings. All these sources should be controlled to prevent the discharge into the foundry atmosphere or to the outside air of particulate or of the carbon monoxide from cooling molds. Fumes from metal cutting or incineration during the preparation of scrap charges also should be controlled. Organic vapors or smoke from coremaking, curing, or baking, generally should be controlled.

Particulates from metal preparation by cutting or incineration, metal pouring, metal treatment, mold cooling, casting shakeout, sand handling, and metal cleaning should be controlled to the same level as for metal melting, probably with bag-type filters or high-energy scrubbers. Particulates from chipping and grinding generally can be controlled with cyclone-type collectors, because the particulates are coarse. Carbon monoxide is emitted from cooling molds, and it should be burned in the stack with an afterburner. Organic smoke and vapors from the coremaking and core-baking operations should be incinerated with a catalytic-combustion system. Gutow⁽¹²⁾ estimated that 5.83 pounds of particulate per ton of iron melted was released to the atmosphere from nonmelting foundry operations. (See Tables III-2 and III-3.)

All or part of the polluted ventilation air collected within the foundry buildings can be used to cool the hot gases from the melting equipment before they enter the baghouse filters, when this type of melting-pollution control is employed.

No other sources of gaseous or particulate pollutants normally are encountered in foundries.

Thus, the development of standards is recommended for the above operations.

Gray Iron-Foundry Processes

Raw-Materials Receiving, Preparation,
Storage, and Preheating

Introduction. The raw materials used for gray, ductile, and malleable iron production fall into the following classifications:

TABLE III-2. PARTICULATE-EMISSION FACTORS FROM NONMELTING FOUNDRY OPERATIONS (12)

| Department | Operation | Emissions Generated, lb/ton melted | Normal Collection, percent | Emissions to Foundry Environment, lb/ton melted | Settling Factor, percent | Emissions Released to Atmosphere, lb/ton melted |
|--------------------------------|-----------------------------------------|------------------------------------|----------------------------|-------------------------------------------------|--------------------------|-------------------------------------------------|
| Scrap yard | Raw-material handling | 0.20 | 0 | 0.20 | 80 | 0.04 |
| | Charge makeup | 0.15 | 0 | 0.15 | 80 | 0.03 |
| | Charge preheating | 0.20 | 10 | 0.18 | 40 | 0.11 |
| Molding, pouring, and shakeout | Molding | 0.50 | 0 | 0.50 | 90 | 0.05 |
| | Magnesium treatment | 5.00 | 10 | 4.50 | 75 | 1.12 |
| | Pouring | 5.10 | 10 | 4.59 | 60 | 1.84 |
| | Cooling | 10.30 | 10 | 9.27 | 90 | 0.93 |
| | Shakeout | 32.20 | 60 | 12.80 | 90 | 1.28 |
| Cleaning and finishing | Shot blasting | 15.50 | 99 | 0.16 | 80 | 0.03 |
| | Grinding | 1.60 | 95 | 0.08 | 80 | 0.02 |
| | Annealing | 0.10 | 0 | 0.10 | 30 | 0.07 |
| | Painting | 0.02 | 95 | -- | 40 | -- |
| Sand conditioning | Dry-sand handling | 10.30 | 10 | 9.27 | 90 | 0.93 |
| | Prepared-sand handling | 0.50 | 0 | 0.50 | 90 | 0.05 |
| | Screening | 10.00 | 20 | 8.00 | 90 | 0.80 |
| | Mulling | 20.60 | 60 | 8.24 | 90 | 0.82 |
| | Drying and sand reclamation | 1.50 | 60 | 0.60 | 80 | 0.12 |
| Core department | Oil-sand core baking | 0.10 | (a) | 0.05 | 0 | 0.05 |
| | Shell, hot-box, and cold-set sand cores | 1.02 | 0 | 1.02 | 0 | 1.02 |
| Pattern shop | Wood pattermaking | 0.01 | 80 | -- | 50 | -- |
| | Metal pattermaking | <u>0.02</u> | 80 | <u>--</u> | 50 | <u>--</u> |
| Total | | 114.92 | | 60.21 | | 9.31 |

(a) Apparently 50 percent, but the original article listed 5 percent, which is inconsistent with the emission values listed.

TABLE III-3. DATA ON EMISSIONS FOR A REPRESENTATIVE GROUP OF
ELECTRIC-ARC-MELTING FURNACES (13)

| Furnace- Shell Diameter, feet | Furnace Charge, tons | Furnace Cycle, hours | Emissions Produced, lb/ton charge | Emissions-Control System | |
|----------------------------------------|----------------------------|----------------------------|-----------------------------------------|--------------------------|-----------------------|
| | | | | Capacity, cfm | Gas Temperature, F |
| 11.0 | 15 | 1.15 | 12.0 (est.) | 50,000 | 250 |
| 12.0 | 20 | 1.5 | 6.0 | 65,000 | 120 |
| 8.0 | 5 | 1.0 | 20.0 | 17,000 | 120 |
| 12.0 | 20 | 2.5 | 18.3 | 32,000 | 250 |
| 7.0 | 3 | 1.75 | 10.0 | 26,000 | 225 |
| 12.0 | 25 | 4.0 | 4.0 | 63,000 | 200 |
| 8.0 | 5 | 1.0 | 40.0 | 20,000 | 150 |
| 7.0 | 3 | 1.75 | 12.7 | 20,000 | 220 |
| 7.0 | 2 | 2.0 | 10.7 | 19,000 | |
| 7.0 | 2 | 1.2 | 13.4 | | |
| 7.0 | 3 | 2.0 | 5.3 | | |
| 9.0 | 6 | 2.3 | 15.3 | | |
| 9.0 | 6 | 2.0 | 12.8 | | |
| 11.0 | 18 | 3.0 | 6.1 | | |
| 9.0 | 6 | 1.2 | 29.4 | | |
| 9.0 | 6 | 1.75 | 12.7 | | |
| 8.0 | 4 | 2.0 | 11.0 | 13,000 | 130 |
| 11.0 | 14 | 1.75 | 7.5 | 19,000 | 190 |
| 12.0 | 19 | 1.7 | 15.0 | 42,000 | 170 |

- (1) **Metallics**
 - (a) Pig iron
 - (b) Cast iron scrap
 - (c) Steel scrap
 - (d) Turnings and borings (loose or briquettes)
 - (e) Foundry returns
 - (f) Ferroalloys
 - (g) Inoculants, including magnesium alloys
- (2) **Carbon additive**
- (3) **Fluxes**
 - (a) Carbonate type (limestone, dolomite, soda ash)
 - (b) Fluoride type (fluorspar)
 - (c) Carbide type (calcium carbide)
- (4) **Fuels**
 - (a) Coke for cupolas
 - (b) Electricity and electrodes for arc furnaces
 - (c) Electricity for induction furnaces
- (5) **Refractories**
- (6) **Sand, sand additives, and binders**
- (7) **Water.**

Among the metallics, foundry returns recirculate within the foundry. The other materials are purchased and (with the exception of electricity) are shipped to the foundry by railroad car or truck, usually are unloaded by crane, and are stored in the foundry stockyard. Although open stockyards are still common, the value of protecting raw materials from the weather is becoming increasingly appreciated, and, hence, covered areas are becoming more popular.

Scrap Preparation. Most foundries purchase scrap that is of a size suitable for charging into their furnaces. The maximum dimension of the scrap should be no larger than one-third of the diameter of the melting furnace. Very fine scrap, such as borings and turnings, generally are purchased in the form of briquettes. Most other scrap is purchased in loose form, though occasionally in bundles. Scrap that contains excessive amounts of oil and grease sometimes is degreased with solvents, or by centrifuging, more often is charged "as is" into a cupola, or preferably is degreased by centrifuging then treating it in an externally fired incinerator or preheater.

Furnace-Charge Preparation. Charge make-up varies widely, from hand charging in small shops, to mechanized systems in intermediate shops, to essentially automatic charging with computerized controls in some of the new, larger installations. Most shops attempt to weigh the various ingredients as well as to balance the ingredients in the charge so as to produce the desired grade of iron. In cupola melting, the coke weight is vitally important. Excess coke reduces the melting rate and increases the cost of the charge. On the other hand, too little coke will result in rapid melting, low temperatures, and an iron that is low in carbon and silicon contents.⁽²⁰⁾

The cupola is capable of adjusting to minor discrepancies in charges and will satisfactorily melt a wider range of metallic scrap materials and convert them into a suitable gray iron than will arc or induction furnaces. However, considerably more care is necessary in the selection of scrap and melting conditions when ductile iron is made in a cupola.

All scrap that is charged into a molten heel of metal in electric furnaces, either induction or arc furnaces, must be dry and free from organic materials so as to prevent explosions when the scrap becomes submerged under the molten metal. Scrap charges for electric furnaces commonly are loaded into metal preheating buckets or conveyors and heated with gas or oil flames to insure a dry charge material and to provide some residual heat in the metal. This operation may generate organic fumes and carbon monoxide, especially if the preheating station is poorly designed and the burners are not adjusted properly. The preheated scrap charge should be added to the furnace while it is still hot, because moisture could again condense on cold scrap, and less electrical energy is required to melt hot scrap. Auto motor blocks or other closed containers suspected of containing liquids, especially water, must be broken, cut open, or perforated to prevent explosions on heating. Scrap must be selected carefully when making ductile iron so as to avoid introduction of undesirable elements, such as sulfur, titanium, tin, lead, and aluminum, and so as to control the alloy content (manganese, chromium, molybdenum, nickel, and similar alloys) within the desired limits. Arc furnaces use scrap similar to that used in induction furnaces, but will tolerate more borings.

Iron Melting

The types of melting equipment in use in gray and ductile iron foundries are as follows:

- Cupola
- Induction furnace
- Arc furnace
- Others

Of primary importance are the cupola, induction-melting equipment, and arc furnaces. Other types of furnaces are used only to a limited extent.

Cupola. The classical cupola is a vertical, refractory-lined, cylindrical, steel shell, or shaft, which is charged at the top with alternate additions of metal, coke, and fluxing materials. The iron in the charge is melted by burning the coke with a blast of air introduced under pressure through tuyeres placed around the shaft and just above the bottom. The required air pressure is developed by blowers. The charge and molten metal are held in the shaft by means of hinged bottom doors, propped shut and lined with bottom sand. Metal may be tapped continuously or intermittently from a tap hole in the side of the shaft just above the bottom sand. At the conclusion of each day's melting, the hinged bottom is dropped to permit removal of unmelted materials.

Cupola furnaces generally range in size from a Number 0, which has a shell diameter of 27 inches, an inside diameter of 18 inches, and a melting capacity of less than 1 ton per hour, to a Number 12, which has a shell diameter of 108 inches, an inside diameter of 84 inches, and a melting capacity of 22 to 27 tons per hour.⁽¹⁴⁾ Recent trends have been toward still larger furnaces, up to 150 inches in outside diameter, with melting capacities greater than 100 tons per hour.

The small furnaces are refractory lined, generally use a cold-air blast (that is, not preheated), and often operate one shift or less per day. The refractories in refractory-lined furnaces are patched after each heat; thus, two shells are necessary when metal is melted each day. Intermediate-size furnaces generally are lined with a regular (9-inch thick) or thin (3-inch thick) refractory lining, and operate with either a cold or a preheated blast. Furnaces with a thin lining generally use a preheated air blast and are

externally cooled with a curtain of water. The larger furnaces generally are unlined in the melting zone, use a preheated air blast, and are cooled with a steady flow of cooling water from beneath the charging doors to the tuyeres. The tuyeres of the larger furnaces that use preheated air are water cooled. The well area is lined with carbon blocks.

In contrast to the small furnaces that generally operate less than 8 hours per day, drop bottom for clean-out, and are relined after each day's melting, the larger furnaces often operate 18 to 24 hours per day, 5 to 6 days per week, and drop bottom for inspection and repair only at the end of the week's campaign. If they operate less than 24 hours per day, they are banked with extra coke and sealed during the shut-down period. Typical lined and water-cooled furnaces are shown in Figure III-2.

Induction Furnaces. In the induction furnace, electrical energy supplied to the melting vessel or crucible is converted to heat directly in the charge. The conversion occurs this way: a coil, embedded in the vessel so as to surround the metal to be melted, is energized with an alternating electric current. The coil thereupon acts as the primary of a transformer, setting up an alternating magnetic field in the charge (the secondary) at a high flux density. This magnetic field induces eddy currents in the charge that are converted to heat by the electrical resistance of the metal.

Two types of induction furnaces are commonly used to melt, hold, and/or superheat cast iron: channel and coreless furnaces. Both utilize line-frequency (60-hertz) current.

A coreless induction furnace generally consists of a drum-shaped crucible that contains a helical copper coil embedded within it, the axis of the helix being the same as the vertical axis of the vessel. The copper coil is water cooled and is insulated from the metal charge by a thin layer of refractory. Heating is started slowly, the initial charge consisting of starting blocks of solid iron (molten iron may be used if available). Charging of pig iron, scrap, and ferroalloys is continued as melting progresses, until the furnace is full. The cover of the furnace is kept closed except when charging, skimming, or tapping. After the molten metal is adjusted to the desired chemical composition and temperature, about two-thirds of the melt is tapped into the pouring ladle. This is the

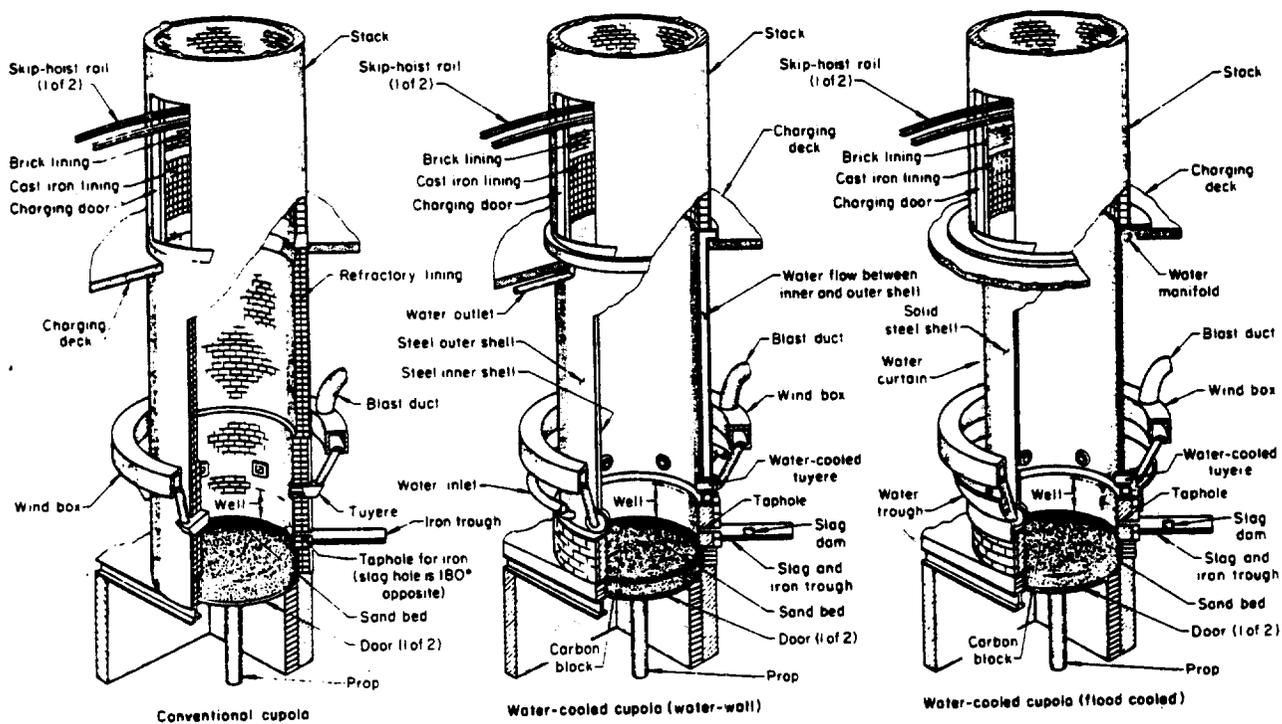


FIGURE III-2. SECTIONAL VIEWS OF CONVENTIONAL AND WATER-COOLED CUPOLAS (15)

(Reproduced by permission, from Metals Handbook Volume 5, American Society for Metals, 1970.)

first heat. The initial charge for the second heat is then added to the molten heel remaining in the furnace. Charge materials must be clean and dry to prevent explosive reactions. The presence of the molten heel in the crucible greatly improves the electrical coupling and, hence, the efficiency and speed of melting. A molten heel, or even a full crucible of metal, generally is held over from day to day until the furnace is scheduled for inspection and lining repair. Minor upper-crucible or pouring-lip repair can be performed with a heel of metal in the furnace.

The channel-type induction furnace closely resembles the ordinary step-down transformer, that is, a transformer with primary and secondary windings that is used to reduce voltage. It utilizes a complete-magnetic-circuit core, a primary or furnace coil, and a single-turn, molten-metal secondary, which is channeled in refractory around the primary winding. The primary winding is capable of carrying 2000 amperes at 600 volts. The transformer ratio is approximately 30 to 1. Therefore, the single-turn, molten-metal secondary is induced with 20 volts and carries some 60,000 amperes. One unit, which consists of a primary metal core and windings, a secondary metal loop, the refractory, and the metal shell, is called an inductor. The resistance of the molten metal to the electrical current results not only in the generation of heat to do the melting but also in violent stirring of the molten metal above the inductor. Because of the latter phenomenon, the furnace must be at least one-third full to prevent ejection of the metal from the furnace when full power is on.

The secondary molten-metal loop and the lower section of the furnace must contain molten metal at all times for the channel-type induction furnace to operate. Therefore, this means that, to get the furnace started, some molten metal must be added to the furnace from another source. A heel of metal (approximately one-third of the furnace's vertical height) must be maintained above the inductor at all times until the furnace is emptied and shut down for repairs.

Channel furnaces may be any desired shape that meets the electrical requirements. They may be barrel shaped with a vertical axis, barrel shaped with a horizontal axis, or dish shaped. The channel-type induction furnace may contain one or more 500 kVA inductors. A few of the more recent installations employ even larger inductors. To conserve heat, such furnaces are always covered, except when charging, skimming, or tapping. The cover also greatly reduces oxidation of the melt and the formation of fumes.

Induction furnaces are supported on pedestal-type structures with pivot bearings for tilting the furnace during tapping. The charging platform is normally at or near the top of the furnace to permit easy access for charging, slagging, and making additions. Examples of coreless and channel furnaces are shown in Figures III-3 and III-4.

Arc Furnaces. The direct-arc electric furnace consists of a refractory-lined, cup-shaped, steel shell with a refractory-lined roof through which three graphite electrodes are inserted. Charging may be accomplished in one of three ways: (1) the roof may be lifted and swung laterally out of the way and the furnace charged from the top, (2) the furnace may be charged by means of a chute inserted through a hole in the roof, or (3) the furnace may be charged through a door in the side of the shell. The metal charge is melted by the heat generated by arcs established between the metal and the three electrodes. The electrodes are so dimensioned as to properly carry the electrical power (three-phase alternating current) supplied to the furnace. Arc furnaces vary in capacity from less than 1 ton to about 65 tons and in melting rate from a few pounds to over 20 tons per hour.

Direct-arc furnaces are fairly efficient melters of loose turnings, borings, and other fine iron or steel scrap. A typical arc furnace is shown in Figure III-5.

Other Melting Furnaces. A small percentage of the total gray, ductile, and malleable iron produced is melted in miscellaneous types of furnaces, including air furnaces, reverberatory furnaces, pot furnaces, indirect-arc furnaces, and electrical-resistance furnaces. Air furnaces, reverberatory furnaces, and pot furnaces are indirectly fired with gas, oil, or powdered coal; efficiency is low. Indirect-arc and resistance furnaces are not often used in iron foundries.

Air furnaces are covered, rectangular, refractory-lined furnaces with a shallow hearth. The air furnace is a reverberatory furnace similar in shape to an open-hearth furnace. Formerly, all air furnaces were fired with powdered coal. Most of the air furnaces that are still in operation are fired with fuel oil and/or natural gas. The bulk of them are being replaced with other systems, because they are very inefficient and consume large quantities of oil and/or natural gas.

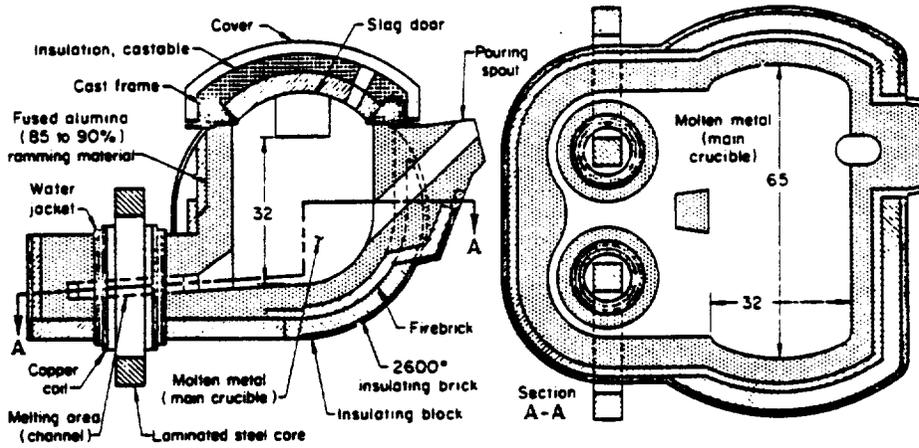


FIGURE III-3. SECTIONAL VIEWS THROUGH A CHANNEL-TYPE INDUCTION-MELTING FURNACE (16) *

Dimensions are in inches.

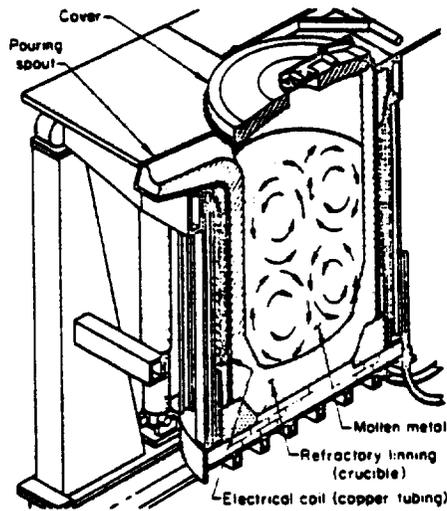


FIGURE III-4. SECTIONAL VIEW THROUGH A CORELESS INDUCTION-MELTING FURNACE (16) *

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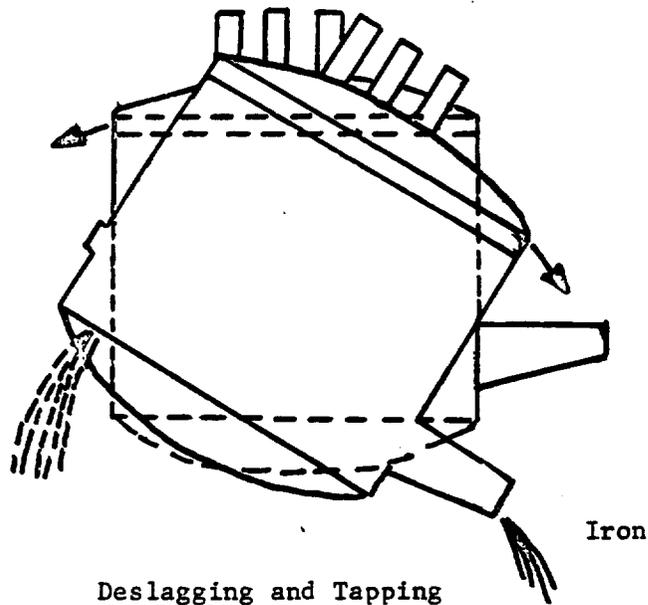
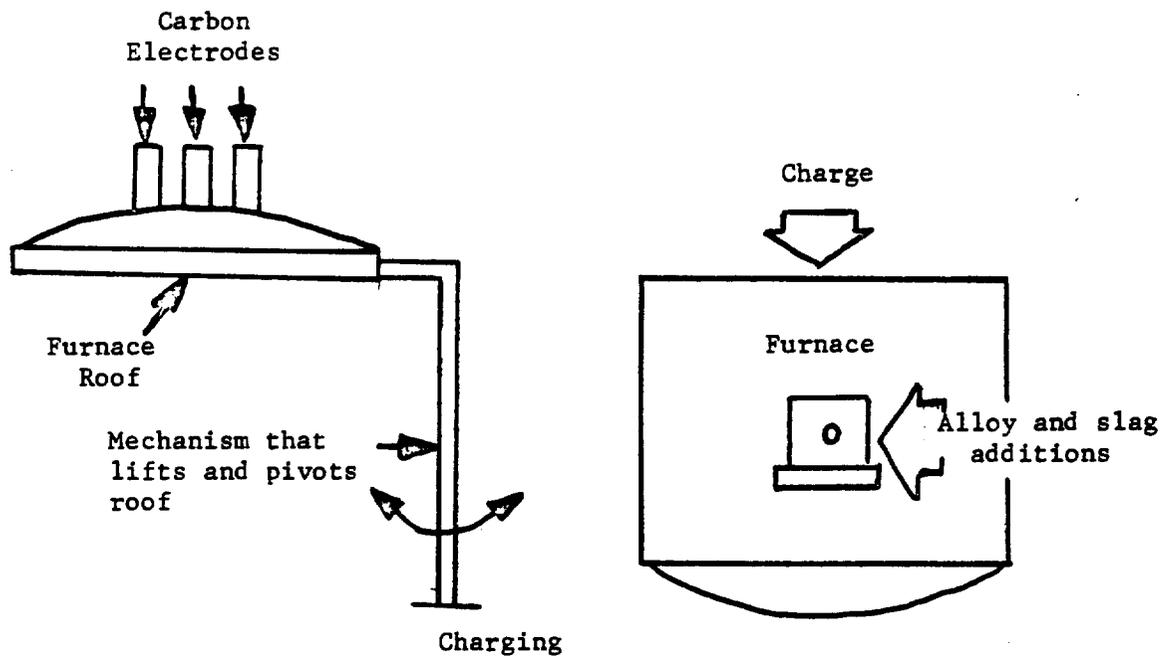


FIGURE III-5. SCHEMATIC VIEWS OF AN ARC-MELTING FURNACE

At one time, a few small, malleable iron shops melted cold charges in air furnaces. More recently, an interest in oil- or gas-fired, air furnaces (or reverberatory furnaces) has developed for melting gray or ductile iron for small foundries, because the furnaces are cheap to install, and, in most communities, they require no air-pollution-control equipment. This trend should be discouraged, because these inefficient furnaces are very wasteful of scarce fuel supplies. If oil or gas again becomes available for melting iron, a very clean and economical gas-fired cupola that duplexes with an induction furnace, a recent development⁽¹⁷⁾, may come into use.

Duplexing. Many of the larger foundries commonly duplex the metal, thus utilizing the best features of various melting units. For example, metal is melted in a cupola and continuously tapped into an induction furnace where it is adjusted as to temperature and chemical composition before it is poured. In this system, the cupola is used to melt a variety of scrap charges efficiently, while the induction furnace is used as a mixer, holding furnace, and superheater.

Again, cupola metal often is duplexed with an arc furnace, particularly if alloying materials are to be added. The cupola melts efficiently, and the arc furnace is excellent for alloying, mixing, and superheating the metal to the desired pouring temperature.

Most malleable iron formerly was made by duplexing cupola iron with an air furnace in which it was superheated and adjusted to the desired composition for pouring.

Sand Receiving and Preparation

New molding and core sands are ordered to a desired screen-mesh size for a specific use. Most of the sands are primarily clean (sharp) silica sand with very low contents of fine silica sand, silt, or clay. However, most sands do contain a few percent of fines which may escape into the atmosphere at transfer points during delivery, storage, and mixing. Transfer of the sand with front-end loaders, bucket elevators, or belt conveyors tends to release fine dust at all transfer points. Dust can be essentially eliminated by using closed systems or pneumatic conveyors.

Molding, Pouring, and Shakeout

Production of Cores. Most new sand enters the foundry molding-sand system through the core room. The clean sand is mixed with one or more organic binders and then is formed into cores of the desired shape that are cured and inserted into the molds. Cores are necessary to make internal cavities in castings. Most cores are formed in a metal core box, then are removed from the core box and cured (hardened) by baking in an oven. Shell cores or hot-box cores, on the other hand, are heated for curing while still in the metal core box, and then they are ejected after they have been cured. Some cores are cured cold (cold set) by mixing a two-part resin and hardener with the sand, making the cores before the reaction takes place, and permitting the cores to cure in the core box without an external source of heat. Certain other resin systems use a gas to cure the cores. For example, the Isocure process uses isocyanate gas to cure the resin binder, and the "CO₂ process" uses carbon dioxide to cure the sodium silicate binder. After the casting is poured, the organic binder in the core breaks down, thereby permitting the free-flowing sand grains to flow out of the internal casting cavity. This used core sand normally becomes mixed with the molding sand and replaces all or most of the molding sand lost in the casting cleaning and finishing operations.

Core sands are formulated and cured as follows:

| <u>Type of Core</u> | <u>Typical Binder Addition, percent</u> | <u>Method of Curing</u> | <u>Curing Time</u> |
|---------------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------|
| Oil core | 1.0 core oil 1.0 cereal 0 to 1 pitch or resin | Baked in an oven at 204 to 316 C (400 to 600 F) | 1 to 2 hours |
| Shell core | 3 to 5 phenolic and/or urea formaldehyde; hexamine activator | Cured as a thin layer on a heated metal pattern at 204 to 316 C (400 to 600 F) | 1 to 3 minutes |
| Hot-box core | 3 to 5 furan resin; phosphoric acid activator | Cured as a solid core in a heated metal pattern at 204 to 316 C (400 to 600 F) | 1/2 to 1-1/2 minutes |
| Cold-set core | 3 to 5 furan resin; phosphoric acid activator, or 1 to 2 core-oil; phosphoric acid activator | Hardens in the core box | 1/2 to 3 hours |

| <u>Type of Core</u> | <u>Typical Binder Addition, percent</u> | <u>Method of Curing</u> | <u>Curing Time</u> |
|---------------------------|---------------------------------------------------------------------|----------------------------------------------------------------------------------|--------------------|
| Cold-box "Isocure" core | 1 to 3 each of two resins; activator is a gas diluted with nitrogen | Hardens when the green core is gassed in the core box with polyisocyanate in air | 10 to 30 seconds |
| CO ₂ sand core | 2 to 4 sodium silicate; activator is CO ₂ gas | Hardens when the green core is gassed in the box with carbon dioxide | 20 to 60 seconds. |

The "CO₂ process" is seldom used in iron foundries, because the cores do not break down well after being subjected to the casting temperatures employed.

Ventilation of the coremaking area and the casting-pouring and cooling areas is essential because of the complex organic fumes that are produced when the complex binders break down.

Green-Sand Molding. Medium-size and small gray iron castings generally are made in green-sand molds.

Sand Preparation. Green molding sand (sand that contains appreciable amounts of moisture, as opposed to dry sand or core sand) normally is composed of silica sand bonded with a moist clay. The clay content of the sand mixture normally is 4 to 6 percent bentonite, and the water content is normally 4 to 6 percent. All or part of the bentonite may be replaced with fireclay. Molding sands for gray, ductile, or malleable iron castings always contain organic materials that have been added to minimize casting defects caused by expansion of the silica sand during the casting process. The most common organic additive is 4 to 6 percent sea coal (a pulverized, high-volatile bituminous coal). Instead of sea coal, the sands may contain pulverized cereals, wood flour, oat hulls, corn-cob flour, pitch, or similar organic materials.

Hot molding sands from the casting-shakeout operation are cooled, crushed, and screened, tramp iron is removed with a magnetic separator, and the sand is remixed with water and other additives in a sand muller. The prepared sand is delivered to the molding stations. The sand may be transported with front-end loaders, or the entire system may be automatically controlled as a closed circuit.

Molding. The prepared molding sand is used to make molds at the molding stations. The molds may be made by hand. In this method, molding sand is shovelled into a flask that contains the pattern, the sand is rammed by hand, the pattern is removed, cores are set, and the mold is closed and is carried to the pouring area. In contrast, in some foundries molds are made automatically whereby metered amounts of sand are added to the flask, the sand is pressed to the desired hardness, the mold is stripped from the pattern, the cores are set, the mold is closed and set on a conveyor, and the mold is poured, all without manual assistance. Most foundries have some automatic equipment to assist in making and transporting the molds. Some automatic molding machines make molds that do not require flasks.

Other Molding Materials. Although medium and small gray iron castings generally are made in green-sand molds, a few small castings are made in shell and/or core-sand molds. Shell sands and core sands were described in the previous section. Large castings generally are made in dry-sand molds. Dry-sand molds are produced by drying green-sand molds with hot air or with heat supplied by burners or electric heaters. The process requires many hours before the cores can be set, the mold closed, and the mold filled with molten metal. There has been a recent trend toward making large castings with a cold-set molding sand (similar to cold-set core sand) to eliminate the need for the slow, expensive drying operation.

Pouring and Cooling. Molten metal of the proper composition and temperature is treated, if necessary, to control the internal structure of the resulting casting and then is poured into the molds. The metal may be poured manually by carrying the metal to the molds or poured manually or automatically as the molds pass by a pouring station on a conveyor. Most foundries transport the molds on a conveyor past a pouring station and cool the molds on a conveyor with good ventilation at all stages of the operation.

Very large flask molds or floor molds cannot be moved, and both types must be poured in place. In this situation, fumes developed during pouring and cooling are difficult to collect and exhaust.

Shakeout. When the liquid metal has solidified in the mold and the casting has cooled for a sufficient time, it is removed from the sand and cooled in air. The shake-out operation can be carried out manually. Generally, however, castings are removed from the sand on a shakeout device that consists of a vibrating and impacting metal grid. The hot sand falls through the grid and subsequently is returned to the molding-sand-preparation area. The castings are stored for further cooling or are transported on a conveyor through a controlled cooling tunnel to the cleaning-and-finishing area.

Cleaning and Finishing

Most gates and risers of gray iron castings are broken off in the shakeout operation. Gates and small risers may be broken off manually just after shakeout. Even ductile iron gates and risers (which are tougher than gray iron) can be broken off manually if the castings are small, if the gates and risers are properly designed, and if the metal temperature is in the right range. Large risers must be cut off (generally with a refractory cutoff wheel), and the connecting stub of metal, along with fins or rough spots, is ground smooth so as to blend with the contour of the casting. All castings are cleaned by grit or shot blasting to remove remaining molding sand and scale that adheres to the casting. Finally the castings are inspected and shipped. A simple, process-flow diagram for the production of iron castings is shown in Figure III-6.

Heat Treatment

Gray iron and ductile iron castings may be given various heat treatments, including stress relieving, annealing, normalizing, and quenching and tempering. If required, ductile iron castings also may be given a special heat treatment called a ferritizing anneal.

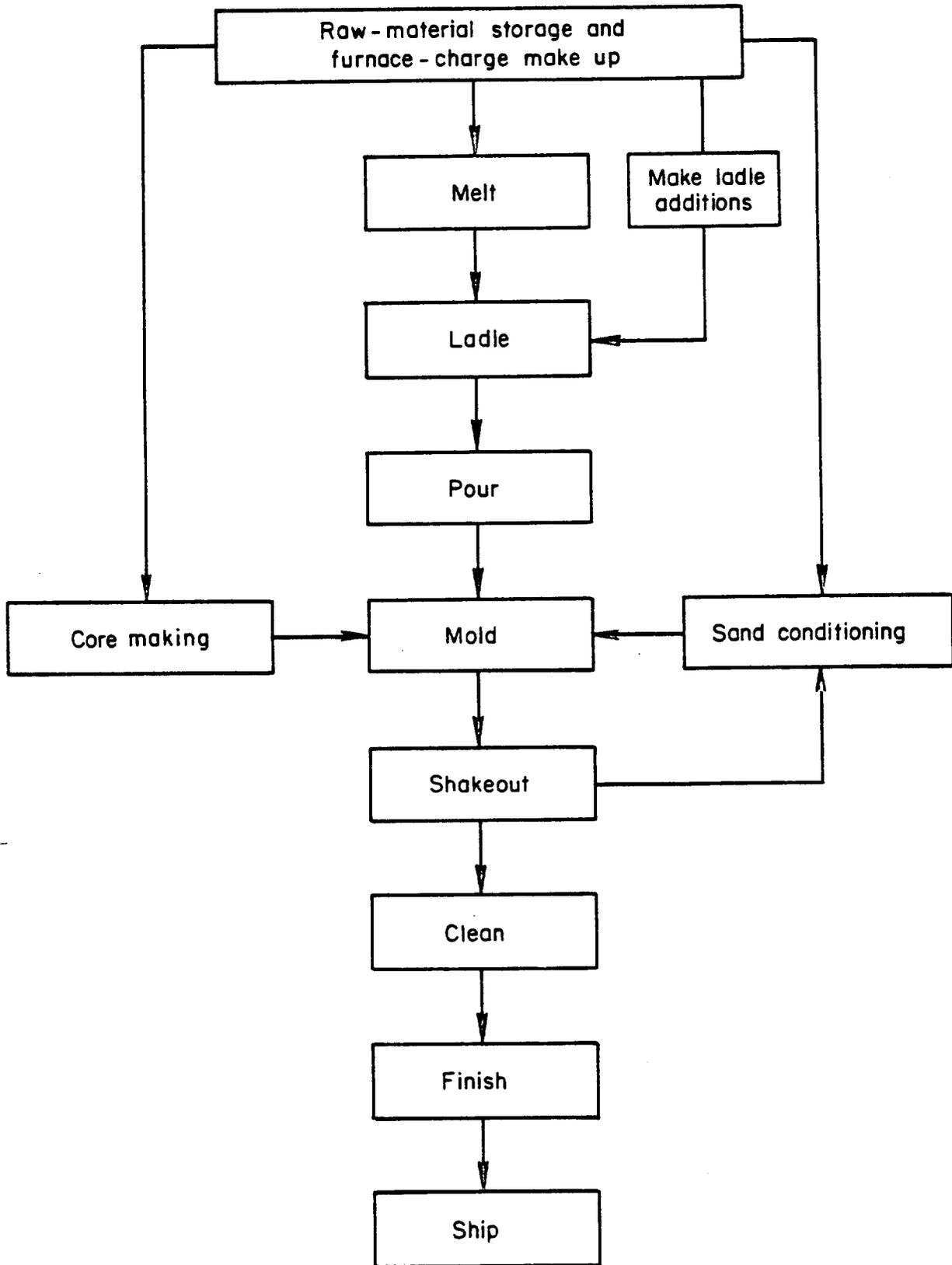


FIGURE III-6. PROCESS-FLOW DIAGRAM FOR THE PRODUCTION OF IRON CASTINGS

Sources, Types, and Mass Rate of Uncontrolled
Atmospheric Emissions and Process Factors
That Affect the Rate

Raw Materials as a Source of Emissions

The unloading, distribution, and preparation of foundry raw materials on the premises of the foundry may produce moderate amounts of particulate emissions. Transfer of coke, limestone, fluorspar, scrap iron and steel, in-plant iron returns, sand, sand binders and additives, and refractories at the foundry site may create some dust (particulates) at every transfer point. However, the particulate concentrations that are generated by these operations generally are not great, but frequently pollution-control devices are needed.

Preparation of scrap charges that involves cutting to reduce the size of the pieces in the charge or incineration operations to remove paint, oil, or other contaminants may create excessive amounts of smoke and particulates.

Melting as a Source of Emissions

Melting operations normally create the major amount of foundry emissions, and the melting department constitutes the most difficult area to control.

The nature of the charge materials has a very great effect on the amount and composition of the emissions from foundry melting units. For example, in cupola melting, the reactivity of the coke will affect the amount of carbon monoxide in the stack gases; the ash content, hardness, and size of the coke will affect the amount and composition of the particulates in the stack gases; and the sulfur content of the coke will have some effect on the sulfur content of the stack gases. Low-sulfur coke must be used in cupolas so as to maintain a low sulfur content in the iron that is produced. Fortunately, most metallurgical cokes are low in sulfur. The type and conditions of the metallic charge materials greatly affect the amount and composition of the effluent from foundry melting furnaces. All organic materials in or on the scrap must eventually be burned to carbon dioxide and water, either in the preheating process, the melting process, or with after-burners in the off-gas system. Rust, dirt, and mud from the yard, along with nonferrous materials, mixed in with the scrap greatly increase the

amount and, at the same time, reduce the average size of the particulates emitted. Particulates from the metallic charge, principally oxides that generally are submicrometer in size and are very difficult to collect, are derived mainly from rust, dirt, zinc, lead, magnesium, and aluminum in the scrap charge.

Cupola. The cupola is the largest single source of foundry emissions. It produces smoke, fume, particulate matter, and gases.

Cupola Particulate Emissions. The amount of particulate emitted by the cupola is affected by the cleanliness of the metallic-charge materials, the size and amount of coke used, the size and amount of flux materials added, the air-blast rate, the use of auxiliary fuels (such as natural gas or oil), the use of oxygen enrichment of the blast, the melting-zone temperature, the height of the charge in the stack, and the progress of the daily campaign (start, middle, or blow-down). Oxygen enrichment of the blast reduces the total volume of blast required and the total volume of stack emissions. The cost of cleaning stack emissions is related to the total volume of such emissions.

The amount of particulate emitted by a cupola varies widely; according to one source, it may range between 2.5 and 14.5 kg/kkg (between 5 and 29 lb/ton) of charge⁽¹⁸⁾. Patterson and coworkers⁽¹¹⁾ found a range of particulate loadings from 3 to 67 kg/kkg (6 to 134 lb/ton) of charge. The high reading was obtained at a gas takeoff below the charge door. All but one of the 35 cupolas evaluated had particulate loadings between 3 and 17 kg/kkg (between 6 and 34 lb/ton).⁽¹¹⁾ The amount of particulate emission was observed to vary with the iron-to-coke ratio and the specific blast rate in scfm per square foot of cupola area⁽¹⁹⁾; the relationship is shown in Figure III-7. The particles-size distribution of emissions from various cupolas is shown in Table III-4, and typical compositions of particulates are shown in Table III-5. The particulates are derived mainly from coke ash, unburned particles of coke, limestone, rust and dirt on return metal, and rust, dirt, and nonferrous metals in the scrap charge.

The particulate emissions from cupolas range in size from 1/4 inch pieces to particles less than 1 micrometer (0.00004 inch) that are carried in a gas stream the temperature of which may be as high as 1093 C (2000 F).⁽²⁰⁾

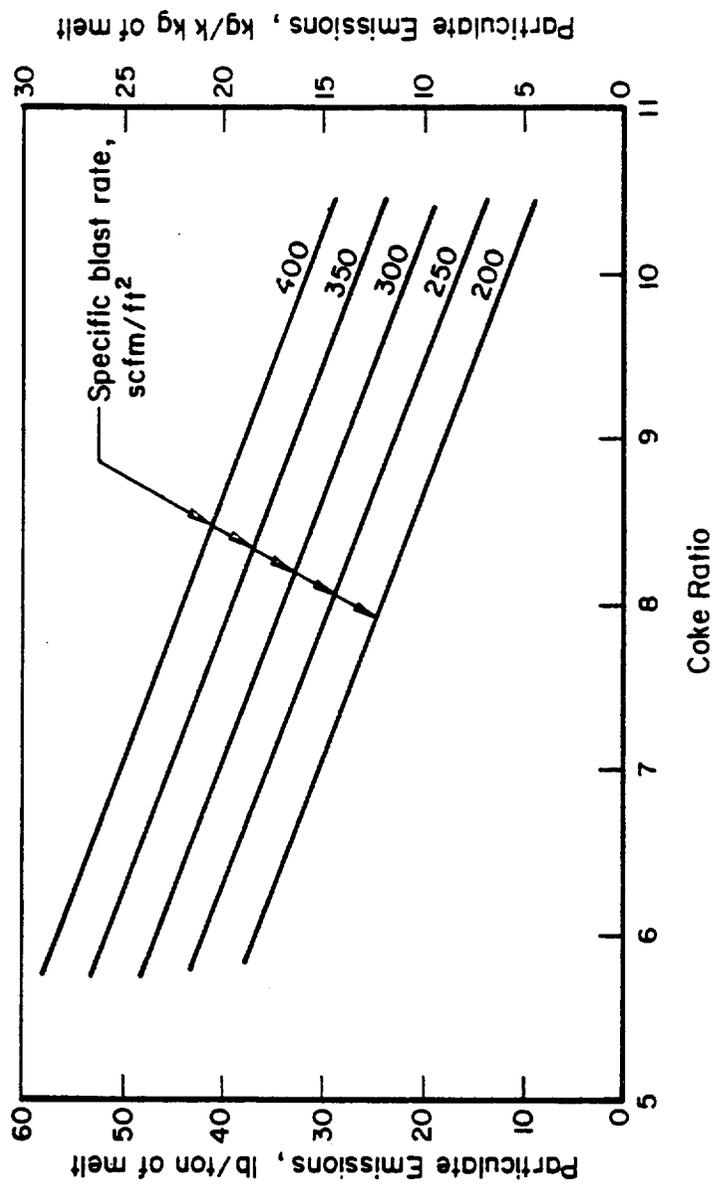


FIGURE III-7. EFFECT OF BLAST RATE AND COKE RATE ON PARTICULATE EMISSIONS FROM UNLINED CUPOLAS (19)

TABLE III-4. PARTICLE-SIZE DISTRIBUTION OF CUPOLA EMISSIONS
(AFTER REFERENCE 19)

| Foundry | Cumulative Percent by Weight for Particles Less Than the Indicated Particle Diameter, micrometers | | | | | | | | | | | | Reference |
|---------|------------------------------------------------------------------------------------------------------|-----|------|------|----|------|------|----|------|-----|------|------|-----------|
| | 1 | 2 | 5 | 10 | 20 | 25 | 44 | 50 | 75 | 100 | 150 | 200 | |
| 9 | | 30 | 50 | 65 | 82 | | | 90 | | 99 | | | 19 |
| 14 | | 64 | 82 | 98 | 99 | | | | | | | | 19 |
| 18 | | | 2 | 12 | 34 | | | 92 | | 99 | | 99 | 19 |
| 26 | | 13 | 28 | 45 | 55 | | | 60 | | | | | 19 |
| 32 | | | 54 | 86 | 98 | | | 99 | | 99 | | 99 | 19 |
| 67 | | | 14 | 15 | 15 | | | 21 | | 99 | | | 19 |
| 67 | | | | | 19 | | | 25 | | 99 | | | 19 |
| 146 | | | | | | | | 99 | | 99 | | | 19 |
| 151 | | 0.6 | 2 | 3 | 8 | | | 99 | | 99 | | | 19 |
| A | | | 4.1 | 5.5 | -- | 8.9 | 13.7 | -- | 58.8 | -- | 74.3 | 77.3 | 20 |
| B | | | 10.6 | 23.9 | -- | 39.8 | 53.0 | -- | 65.5 | -- | 83.9 | 89.7 | 20 |
| C | | | 8.3 | 12.5 | -- | 20.8 | 27.7 | -- | 59.3 | -- | 76.2 | 82.8 | 20 |
| 1 | | | 18 | 25 | 38 | | | 62 | | | | | 21 |
| 2 | | | 17 | 26 | 36 | | | 53 | | | | | 21 |
| 3 | | | 24 | 28 | 23 | | | 42 | | | | | 21 |
| 4 | | | 26 | 30 | 32 | | | 44 | | | | | 21 |
| A | | 0 | 7 | 25 | 32 | 34 | | 41 | | 56 | | 61 | 21 |
| B | | 0 | 7 | 24 | 41 | 47 | | 32 | | 69 | | 81 | 21 |

TABLE III-5. CHEMICAL COMPOSITION OF CUPOLA PARTICULATE EMISSIONS (19)

| Foundry Number | Content in Cupola Effluent (a), percent by weight | | | | | | | | Combustibles |
|-------------------|---------------------------------------------------|--------------------|--------------------|---------------|-------------------|---------------|--------------------|------------------|--------------|
| | Iron Oxide | Magnesium Oxide | Manganese Oxide | Lead Oxide | Aluminum Oxide | Zinc Oxide | Silicon Dioxide | Calcium Oxide | |
| 66 | 11.1 | | | | | | 12.3 | | |
| 85 | 14.7 | 1.3 | | 1.4 | | | 28.7 | | 24.0 |
| 90 | | | | | | | 56.3 | 42.0 | 0.9 |
| 113 | 8.6 | | 3.7 | | 0.05 | | 31.8 | 3.1 | 27.0 |
| 116 | 10.0 | 5.0 | 10.0 | | 5.0 | 1.0 | 10.0 | 3.0 | 5.0 |
| 146 | 33.0 | | 1.0 | 5.0 | | 38.0 | 20.0 | 1.0 | |
| 150 | 11.6 | 1.0 | 5.5 | 20.0 | 1.4 | 14.7 | 30.1 | 1.1 | |

(a) Quantities listed are as reported. They do not add up to 100 percent.

The total discharge of particulate in uncontrolled cupola emissions is of only academic interest, because most state air-pollution-control regulations limit the particulate effluent on a basis of maximum allowable pounds of particulate per ton of material processed per hour. (The process-weight formulas are all graduated to decrease the allowable discharge per ton as the production rate per hour increases.) Coke-fired cupola furnaces melting more than about 2 tons per hour always exceed the allowable particulate discharge rate if uncontrolled, and particulate discharge must be controlled by very efficient particulate collectors. The proportions of the various metallic oxides appearing in the emissions from different cupolas are related to the amount and vapor pressure of the various metals present in the melting zone. Contamination of ferrous scrap by nonferrous metals may result from the presence of alloying elements, coatings, or inserts, or it may be due to improper sorting of the scrap. Coatings of zinc, lead, tin, cadmium, aluminum, chromium, and copper, or metal-oxide paints generally result in the presence of increased amounts of nonferrous metal-oxide emissions. Lead bearings, nonferrous metal inserts, and bimetal scrap sections will promote the presence of non-ferrous metal oxides in the particulate. The presence of iron oxide in the emissions results when charges contain much rusty scrap or when high temperatures and oxidizing conditions prevail in the melting zone.

In cupola melting, the amount of particulate in the emissions per ton of metal melted is decreased by (1) reducing the amount of coke and limestone and the amount of dirt on return metal and scrap, (2) reducing the blast rate, and (3) using some auxiliary fuel, such as natural gas or fuel oil, in place of part of the coke.

Cupola Emission of Carbon Monoxide. Cupola gas emissions contain between 12 and 25 percent (typically 16 percent) carbon monoxide (CO), before dilution by air infiltration at the charging door.⁽²²⁾ The amount of CO in the gas depends on the reactivity of the coke, the amount of coke charged, and the temperature of the melting zone. These CO emissions must be controlled. If the top gases are removed below the charging door, the gas volume will be reduced.

Cupola Emission of Sulfur Dioxide. Sulfur emissions originate from the sulfur in the coke. United Kingdom coke averages 0.8 percent sulfur. Half or more of this sulfur enters the metal and about 10 percent

enters the slag.⁽²²⁾ The remaining 40 percent of the sulfur charged ends up in the stack gases. Thus, with a metal-to-coke charge of 9 to 1 and a sulfur content in the coke of 0.8 percent, about 0.89 kg of sulfur would be charged for each kilokilogram of metal (1.78 lb/ton). For these conditions, the sulfur charged per unit weight of metal would be partitioned about as follows:

| | kg/kkg | (lb/ton) |
|----------------|--------|----------|
| Melt | 0.44 | (0.89) |
| Slag | 0.09 | (0.18) |
| Emission gases | 0.35 | (0.71) |

Similar amounts of sulfur in the coke and similar partitioning of the sulfur in the products would be expected in the United States.

The amount of sulfur as sulfur dioxide emitted in the gas in the example is less than the maximum permissible discharge limits of most communities. Therefore, sulfur emissions from foundries are not controlled per se.

Arc Furnaces. Electric-arc furnaces produce considerably less particulate than do cupola furnaces because, unlike cupolas, coke and limestone, which contribute greatly to particulate-emission production, are not a part of the charge. The particulate is derived from organic or non-ferrous impurities in the charge, from iron oxides produced near the start of the heat, and from additions such as carbon riser. Iron oxide emission may be intense during oxygen lancing, on the rare occasions when this operation is performed in the production of cast iron. Particulate amounts, size distribution, and chemical composition are shown in Tables III-6, III-7, and III-8.

Sulfur dioxide normally is not present in appreciable quantities in the effluent from arc furnaces. If air is available, the arc will ignite at least part of the carbon monoxide formed from burning the electrodes and convert it to carbon dioxide. Uncontrolled effluent gases contain about 6 pounds of CO per ton of metal melted.⁽²³⁾

TABLE III-6. EMISSIONS DATA FOR ELECTRIC-ARC-MELTING FURNACES
(AFTER REFERENCE 19)

| | Furnace Shell Diameter, meters (feet) | Furnace Charge, kkg (short tons) | Furnace Cycle, hours | Emissions Produced Per Unit Charge, kg/kkg (lb/ton) |
|----|---------------------------------------------|-------------------------------------|-------------------------|-----------------------------------------------------------|
| 1 | 3.35 (11.0) | 13.6 (15) | 1.15 | 6.0 (12.0) (est.) |
| 2 | 3.66 (12.0) | 18.1 (20) | 1.5 | 3.0 (6.0) |
| 3 | 2.44 (8.0) | 4.5 (5) | 1.0 | 10.0 (20.0) |
| 4 | 3.66 (12.0) | 18.1 (20) | 2.5 | 9.2 (18.3) |
| 5 | 2.13 (7.0) | 2.7 (3) | 1.75 | 5.0 (10.0) |
| 6 | 3.66 (12.0) | 22.7 (25) | 4.0 | 2.0 (4.0) |
| 7 | 2.44 (8.0) | 4.5 (5) | 1.0 | 20.0 (40.0) |
| 8 | 2.13 (7.0) | 2.7 (3) | 1.75 | 6.4 (12.7) |
| 9 | 2.13 (7.0) | 1.8 (2) | 2.0 | 5.4 (10.7) |
| 10 | 2.13 (7.0) | 1.8 (2) | 1.3 | 6.7 (13.4) |
| 11 | 2.13 (7.0) | 2.7 (3) | 2.0 | 2.7 (5.3) |
| 12 | 2.74 (9.0) | 5.4 (6) | 2.3 | 7.7 (15.3) |
| 13 | 2.74 (9.0) | 5.4 (6) | 2.0 | 6.4 (12.8) |
| 14 | 3.35 (11.0) | 16.3 (18) | 3.0 | 3.1 (6.1) |
| 15 | 2.74 (9.0) | 5.4 (6) | 1.2 | 14.7 (29.4) |
| 16 | 2.74 (9.0) | 5.4 (6) | 1.75 | 6.4 (12.7) |
| 17 | 2.44 (8.0) | 3.6 (4) | 2.0 | 5.5 (11.0) |
| 18 | 3.35 (11.0) | 12.7 (14) | 1.75 | 3.8 (7.5) |
| 19 | 3.66 (12.0) | 17.2 (19) | 1.7 | 7.5 (15.0) |

2000 CFH

TABLE III-7. CHEMICAL ANALYSIS OF ELECTRIC-ARC-FURNACE PARTICULATE EMISSIONS (19)

| Constituent | Proportion of Total Particulate, percent | | |
|------------------|------------------------------------------|-----------|-----------|
| | Foundry A | Foundry B | Foundry C |
| Iron oxide | 75-85 | 75-85 | 75-85 |
| Silicon dioxide | 10 | 10 | 10 |
| Magnesium oxide | 2 | 0.8 | 1 |
| Manganese oxide | 2 | 2 | 2 |
| Lead oxide | 1 | 2 | 0.5 |
| Alumina | 0.5 | 1 | 0.5 |
| Calcium oxide | 0.3 | 0.2 | 0.8 |
| Zinc oxide | 0.2 | 2 | 0.3 |
| Copper oxide | 0.04 | 0.03 | 0.01 |
| Lithium oxide | 0.03 | 0.03 | 0.03 |
| Tin oxide | 0.03 | 0.3 | 0.02 |
| Nickel oxide | 0.02 | 0.03 | 0.01 |
| Chromium oxide | 0.02 | 0.07 | 0.02 |
| Barium oxide | 0.02 | 0.07 | 0.01 |
| Loss on ignition | 8.87 | 3.1 | 0 |
| Ash | 91.93 | 96.9 | 100 |

TABLE III-8. PARTICLE-SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS
FROM THREE ELECTRIC-ARC-FURNACE INSTALLATIONS⁽¹⁹⁾

| Particle Size, micrometers | Cumulative Percent by Weight for Indicated Particle Diameter | | |
|-------------------------------|-----------------------------------------------------------------|-----------|-----------|
| | Foundry A | Foundry B | Foundry C |
| Less than 1 | 5 | 8 | 18 |
| Less than 2 | 15 | 54 | 61 |
| Less than 5 | 28 | 80 | 84 |
| Less than 10 | 41 | 89 | 91 |
| Less than 15 | 55 | 93 | 94 |
| Less than 20 | 68 | 96 | 96 |
| Less than 50 | 98 | 99 | 99 |

Induction Furnaces. Very little fume is produced by induction furnaces. The scrap material in the charge normally is preheated outside the furnace so as to remove organic material and water; thus, very little, if any, organic material is charged to the furnace. The lid is kept closed as much as possible, which further limits the release of fume. A small amount of iron oxide fume, about 0.8 kilogram of emission per kilogram of metal (1.5 lb/ton) is evolved during the charging, skimming, and pouring operations. (19)

Other Furnaces. Reverberatory, or air, furnaces that are fired with natural gas or oil generally do not require gas-cleaning equipment. If oxygen injection of the bath is a part of the practice, considerable particulate emission may be expected in that portion of the heat cycle.

Reverberatory furnaces that are fired with powdered coal emit considerable flyash.

Pot furnaces, electrical-resistance furnaces, and indirect-arc furnaces are seldom used in iron foundries. In any case, when they are used, they are so small as to have very little effect on the environment. Air-cleaning equipment probably would not be required with such units.

Molding and Coremaking as Sources of Emissions

Molding and Molding-Sand Preparation. Considerable dust is generated when dry sands are mullied in the preparation of molding sands, and this dust should be controlled. Additions of dry sea coal, clays, cereal, pitch, or other addition agents will increase the amount of dust generated. The use of slurries to make the necessary additions reduces the emissions. Molding itself creates very little dust, because the damp (tempered) molding sand employed is essentially dust free.

Coremaking. Coremaking often produces fumes that are very difficult to control. When oil-sand cores are baked, the ovens emit fumes composed of the partially decomposed core oil. Other coremaking systems often

emit furfuryl alcohol, ethyl alcohol, methyl alcohol, urea, carbon monoxide, silica dust, free phenol, formaldehyde, hexamethylenetetramine⁽¹⁹⁾, Novalak, melamine, polyisocyanate⁽²⁴⁾, and other resins and decomposition products, or acids that are either injurious to the body or are irritants.

Tapping, Metal Treatment,
Pouring, Cooling, Shakeout, and
Cleaning as Sources of Emissions

Tapping and Metal Treatment. Some metal-oxide fumes normally are evolved when molten iron is tapped from the furnace into a pouring ladle. However, when the molten metal is treated with magnesium alloys (generally an alloy of silicon and magnesium) to make ductile iron, dense clouds of magnesium oxide fume often are produced. This magnesium oxide fume is produced when magnesium vapor escaping from the surface of the molten metal comes in contact with the air and burns. In this way, some 1 to 4 kilograms of magnesium oxide are produced per kilokilogram of ductile iron treated (2 to 8 lb/ton).⁽¹⁹⁾ Actually, the fume produced from the magnesium treatment contains 60 to 80 percent magnesium oxide, the balance being iron oxide plus some silica. This operation usually is performed in the ladle, but occasionally it is performed in the molds.

Many systems have been devised to improve the efficiency with which the magnesium is recovered in the melt and, in so doing, greatly decrease the fume produced.

Some foundries must desulfurize the molten iron before it is suitable for conversion to ductile iron or low-sulfur gray irons. Desulfurizers consisting of soda ash, lime, or calcium carbide generally are placed in the bottom of a ladle, and the molten metal is poured on top of them. (Calcium carbide may be plunged into the metal in a metal basket). The resulting reaction products are skimmed off the metal bath before the iron is poured. This operation creates considerable dust, and some sulfur dioxide is evolved.

Pouring and Cooling Molds. Some fume is evolved from the surface of the molten metal in the ladle as well as from the pouring stream. Most of the fume is iron oxide. Use of refractory ladle covers greatly reduces the amount of fume discharged from the metal in the ladle. In any event, the amount of fume produced from this source is not great.

When the molten metal is poured into molds, the heat from the metal vaporizes part of the organic material present in the molding sand (sea coal, cereal, synthetic binders, and core binders) and vaporizes part of the water contained in the sand, giving off a mixture of steam (or water vapor), organic fumes, carbon monoxide, carbon dioxide, up to about 1 percent hydrogen, and dust. Part of the carbon monoxide, hydrogen, and organic fumes will burn to harmless carbon dioxide and water vapor as they emerge from vents in the molds, if the temperature is high enough to start the ignition and the moisture level is low enough to permit combustion to continue. Eventually, the flames at the mold vents will be extinguished as the mixture of gases being emitted becomes too lean in combustible materials. The emission of carbon monoxide and organic fumes is at a maximum at the start of pouring and after the casting has cooled for some time.

The actual compositions of the molding-sand gases produced within the mold cavity in various types of molding sands after pouring are shown in Table III-9. The compositions become altered considerably before the gases reach the collection-hood system, by combustion at the mold vents and by dilution with foundry air.

Shakeout. The shakeout operation is dirty. The molds that contain the castings normally are fed onto a vibrating and impacting metal grid that removes most of the molding sand and the core sand from the mold flask and the casting. The sand drops through the grid onto a conveyor below, where it is returned to the sand-cooling and remixing area. The castings, still very hot, are separated from the flasks. The flasks return to the molding machines, and the castings are further cooled in preparation for the cleaning operation.

The heat in the castings normally has vaporized much of the water from the molds by the time they reach the shakeout station. Therefore, during shakeout, the dry mold materials create much dust, which consists of organic materials that are partially burned, clay binders, and fine silica sand, and some water vapor also is evolved. The dust may exceed 6.86 g/m^3 (3 grains/ft³).⁽¹⁹⁾ The shakeout operation also is very noisy.

TABLE III-9. COMPOSITION OF MOLDING-SAND GASES INSIDE THE MOLD CAVITY DURING FILLING OF THE MOLD(25)

| Molding-Sand Gas Analyses (percent by volume) and CO/CO ₂ Ratio for Various Molds (A Through L) | | A | B | C | D | E | F |
|------------------------------------------------------------------------------------------------------------|--|-----------------------------------|-------------------------------------|------------------------|--------------------------------|------------------------------------------------|--------------------------------------------------|
| Constituent | | 4% Bentonite, Oven Dried | 4% Bentonite, 2.5% H ₂ O | 4% Bentonite, 5% Water | 4% Bentonite, 1% Cereal, Dried | 4% Bentonite, 1% Cereal, 3.4% H ₂ O | 1.5% Cereal, 1.0% Core Oil, 1.0% Kerosene, Dried |
| CO ₂ | | 4.9 | 3.3 | 2.0 | 6.5 | 2.8 | 5.0 |
| O ₂ | | 9.2 | 6.2 | 2.9 | 7.4 | 1.7 | 5.2 |
| CO | | 2.4 | 6.3 | 11.3 | 10.8 | 11.5 | 30.4 |
| H ₂ | | 0.9 | 33.0 | 46.1 | 2.5 | 50.3 | 25.6 |
| Paraffins | | 0 | 1.2 | 0 | 0.4 | 2.9 | 2.2 |
| N ₂ | | 82.6 | 49.7 | 37.7 | 72.4 | 30.8 | 31.6 |
| CO/CO ₂ | | 0.49 | 1.91 | 5.7 | 1.66 | 4.10 | 6.08 |
| | | | | | | | |
| Constituent | | G | H | I | J | K | L |
| | | 4% Cereal, 4% Bentonite, 4% Water | 4% Cereal, 4% Bentonite, Dry | Oil-Sand Drag | Oil Sand | Oil-Sand Cope | Cavity & Sprue for Steel Casting |
| CO ₂ | | 2.5 | 2.3 | 6.4 | 6.4 | 6.8 | 5.0 |
| O ₂ | | 3.0 | 6.2 | 4.3 | 5.5 | 8.9 | 9.4 |
| CO | | 30.5 | 28.7 | 7.9 | 11.1 | 2.5 | 4.1 |
| H ₂ | | 46.0 | 24.8 | 2.6 | 7.5 | 0.6 | 0.5 |
| Paraffins | | 4.6 | 0.6 | 0.1 | 0 | 0 | 0.2 |
| N ₂ | | 13.2 | 37.4 | 78.7 | 69.5 | 81.2 | 80.8 |
| CO/CO ₂ | | 12.2 | 12.5 | 1.23 | 1.73 | 0.37 | 0.82 |

Cleaning. After the castings have cooled from the shakeout operation, the gates and risers are removed by tumbling or sawing. Then the castings are grit blasted or shot blasted to remove any adhering sand and scale. The castings are next ground to remove excess metal where the gates and risers were attached, or to remove fins; then they are inspected, heat treated if necessary, grit blasted again, and shipped.

Dust and dirt developed during cleaning originates in the grit- or shot-blasting machines and the grinders. The dust from grit blasting may exceed 6.86 g/m^3 (3 grains/ft^3).⁽¹⁹⁾

Finishing and Shipping. Some castings are finished in the foundry by machining. The finishing and shipping operations are relatively clean activities and do not require any air-pollution controls.

Examples of Air-Pollution Rates When Restricted by Both Typical and Most-Restrictive State Emission-Control Regulations

The state air-pollution codes were examined for information relevant to foundry operations. From this information, a summary table, Table III-10, was prepared. This summary table of state air-pollution laws as they pertain specifically to foundries includes (1) the maximum particulate emissions permitted as calculated for gray iron production rates of 5, 10, 20, or 50 tons per hour, (2) the maximum permissible emission of carbon monoxide or the treatment specified for controlling carbon monoxide in the stack, and (3) the maximum amount of sulfur dioxide emission permitted from any combustion or manufacturing process.

The states with the most restrictive codes were selected on the basis of the data given in Table III-10. Information from these codes that pertains to pollution from foundries is listed in Table III-11.

The most restrictive states relative to particulate emissions are New Jersey, New Mexico, Washington, and Illinois. The particulate emission codes of those states relate to all manufacturing processes; those states do not have separate codes for iron foundries. In the case of New Jersey and Washington, the maximum allowable emissions are expressed

TABLE III-10. SUMMARY OF STATE AIR-POLLUTION LAWS AS THEY PERTAIN TO FOUNDRIES SPECIFICALLY
 (Tons/hr x 0.907 = kkg/hr; lb/hr x 0.454 = kg/hr)

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Maximum Effluent or Specified Treatment | Sulfur Dioxide; Maximum Effluent for any Combustion Process | |
|-----------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|---------------------|--------------------------------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | | |
| Alabama (1973) | 16.65 <i>15.5 = 7.5 tpy</i> | (For foundries) 25.10 | 37.0 | 32.28 ^(a,c) 44.47 ^(b,d) | Burn at 1300 F for 0.3 second in a direct-flame after- burner | 1.8 to 4.0 pounds/ million Btu heat input; County Classes 1, 2, 3 | |
| Alaska (1972) | | None | | | None | None | |
| Arizona (1973) | 12.0 | (Process industries) ^(d) 19.2 | 30.5 | 44.6 | Secondary combustion required | (e) | |
| Arkansas (1973) | 9.73 | (Manufacturing processes) ^(c) 14.99 | 22.3 | 32.24 | -- | -- | |
| California (1973) | | (None specifically for foundries) (Must meet ambient-air-quality standards) | | | | | |
| Colorado (1973) | 9.73 | (Manufacturing processes) ^(c) 14.99 | 22.3 | 32.24 | -- | 500 ppm or 5 tons/day | |
| Connecticut (1973) | | (For iron-foundry cupolas) 85% efficient cleaner, not to exceed 0.8 lb/1000 lb gas 9.3 ^(f) | 18.6 ^(f) | 37.2 ^(f) | 93.0 ^(f) | Burn at 1300 F for 0.3 second in a direct- flame afterburner | 500 ppm |
| Delaware (1972) | 7.5 | (Secondary metals) 15 | 30 | 75 | -- | -- | |
| District of Columbia (1973) | 10.0 | (Process industries) 16.2 | 28.3 | 40.0 | -- | 0.05 percent by volume; 500 ppm | |
| Florida (1972) | 9.73 | (Process industries) ^(c) 14.99 | 22.3 | 32.24 | -- | -- | |
| Georgia (1972) | 16.65 | (Ferrous foundries) ^(d) 25.10 (6.0 pounds per ton if any cupola melts less than 10 tons in 24 hours) | 33.76 | 44.6 | -- | (New fuel-burning sources) 1.2 lb SO ₂ /1,000,000 Btu heat input | |
| Hawaii (1972) | | (Ambient air quality) | | | -- | -- | |

TABLE III-10. (Continued)

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Maximum Effluent or Specified Treatment | Sulfur Dioxide; Maximum Effluent for any Combustion Process |
|----------------------|------------------------------------------------------------------------------|----------------------------|---------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | |
| Idaho (1973) | 12.0 | 19.2 | 30.5 | 44.6 | (Ambient-air-quality standards) | -- |
| Illinois (1973) | | (Industrial processes) (d) | | | Cupola gases burned with an afterburner to less than 200 ppm corrected to 50 percent excess air. Cupolas with a melt rate of less than 5 tons/hour excluded | 2000 ppm |
| | 16.65 | 25.10 | -- | -- | | |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| | 6.0 | 8.7 | 12.5 | 20.5 | | |
| Indiana (1973) | 16.65 | 24 | 36 | 52.6 | (For processes) Greater than 10 ton/hr must use afterburner | (Meet formula for process operation) |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Iowa (1972) | 16.65 | 25.10 | -- | -- | -- | 500 ppm by volume |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Kansas (1974) | 12.0 | 19.2 | 30.5 | 44.6 | Burn in a direct-flame afterburner at 1300 F for at least 0.3 second | -- |
| Kentucky (1972) | 12.0 | 19.2 | 30.5 | 44.6 | Burn in a direct-flame afterburner at 1300 F for at least 0.3 second | 2000 ppm in Priority I regions |
| Louisiana (1973) | 12.0 | 19.2 | 30.5 | 44.6 | (Ambient-air-quality standards) | (Ambient-air-quality standards) |
| Maine (1973) | 9.73 | 14.99 | 22.3 | 32.24 | (Ambient-air-quality standards) | (Ambient-air-quality standards) |
| Maryland (1974) | (Ambient-air-quality standards) | | | | (Ambient-air-quality standards) | -- |
| Massachusetts (1973) | (Ambient-air-quality standards) | | | | (Ambient-air-quality standards) | -- |

TABLE III-10. (Continued)

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Maximum Effluent or Specified Treatment | Sulfur Dioxide; Maximum Effluent for any Combustion Process |
|----------------------|----------------------------------------------------------------------------------------|------------------------|---------------|---------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | |
| Michigan (1974) | 24 | (Small jobbing cupola) | | | -- | -- |
| | | -- | -- | -- | | |
| | | (Other cupolas) (h) | | | | |
| | 4.6 | 5.8 | 7.0 | 17.4 | | |
| Minnesota (1971) | (Cleaning equipment 85% efficient or 0.4 grain per scf gas) | | | | Burn all cupola top gases at 1200 F for 0.3 second | -- |
| | (Calculated particulate) (i) | | | | | |
| | 8.2 | 16.4 | 32.8 | 82.0 | | |
| Mississippi (1972) | (Manufacturing processes) | | | | -- | Existing process equipment = 2000 ppm by volume. New process equipment = 500 ppm by volume |
| | 12.0 | 19.2 | 30.5 | 56.4 | | |
| Missouri (1972) | (Same as Minnesota) | | | | Burn all cupola top gases at 1200 F for 0.3 second | -- |
| | (Cleaning equipment 85% efficient or 0.4 grain per scf gas, whichever most stringent.) | | | | | |
| | (Calculated particulate) (i) | | | | | |
| | 8.2 | 16.4 | 32.8 | 82.0 | | |
| Montana (1974) | (Process operation) (d) | | | | -- | -- |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Nebraska (1973) | (Process operation) (d) | | | | -- | -- |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Nevada (1973) | (Industrial sources) (d) | | | | Meet ambient-air-quality standards | (Combustion-units standards) Less than 250 million Btu/hr = 0.71 lb SO ₂ per million Btu. Over 250 million Btu/hr = 0.105 lb SO ₂ per million Btu |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| New Hampshire (1974) | (Ferrous foundries) | | | | Meet ambient-air-quality standards | Meet ambient-air-quality standards |
| | (Existing) (j) | | | | | |
| | 14.85 | 23.62 | 31.46 | 53.29 | | |
| | (New) (d) | | | | | |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |

TABLE III-10. (Continued)

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Maximum Effluent or Specified Treatment | Sulfur Dioxide; Maximum Effluent for any Combustion Process |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|------------------|------------------|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | |
| New Jersey (1972) | (Manufacturing processes) (based on 0.02 grain/scf gas) (k) | | | | -- | 2000 ppm by volume |
| | 0.41 | 0.82 | 1.64 | 4.1 | | |
| New Mexico (as of Dec. 31, 1974) | (Manufacturing processes) Particulate = 0.05 pound per million Btu heat input. Particulate less than 2-micrometer diameter = 0.02 pound per million Btu heat input (1) | | | | -- | (Manufacturing processes) Not to exceed 1 lb SO ₂ per million Btu heat input |
| | 0.55 | 1.10 | 2.20 | 5.50 | | |
| New York (1973) | (Jobbing foundries) | | | | -- | Less than 50 grains of sulfur compounds (measured as H ₂ S) per 100 scf of gas |
| | 16.65 | 25.10 | 37.0 | -- | | |
| | or 80% collection efficiency, whichever is least restrictive | | | | | |
| | (Production foundries) (m) | | | | | |
| | 10.8 | 17.0 | 27.0 | 50.0 | | |
| North Carolina (1972) | (Existing jobbing foundries) | | | | -- | Existing: 2.3 lb SO ₂ /million Btu input New: 1.6 lb SO ₂ /million Btu input |
| | 16.65 | 25.1 | -- | -- | | |
| | (Production or new foundries) (d) | | | | | |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| North Dakota (1972) | (Industrial processes) | | | | -- | Must meet ambient air-quality standards |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Ohio (1972) | (Industrial processes) (d) | | | | Burned at 1300 F for 0.3 second in a direct-flame afterburner | Existing: 2000 ppm New: 500 ppm |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Oklahoma (1972) | (Existing jobbing foundries) | | | | Removal of 93% of the CO with an afterburner | Existing: meet ambient-air-quality standards New: 2.0 lb per million Btu |
| | 16.65 | 25.1 | -- | -- | | |
| | (Production or new foundries) (d) | | | | | |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Oregon (1972) | (Manufacturing processes) | | | | -- | -- |
| | 10.0 | 16.2 | 28.3 | 44.6 | | |

TABLE III-10. (Continued)

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Maximum Effluent or Specified Treatment | Sulfur Dioxide; Maximum Effluent for any Combustion Process |
|-----------------------|------------------------------------------------------------------------------|---------------|---------------|---------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | |
| Pennsylvania (1972) | (Process -- iron-foundry melting) (n) | | | | -- | 500 ppm |
| | 12.26 | 10.34 | 13.83 | 20.32 | | |
| Rhode Island (1972) | (Process operation) (d) | | | | -- | -- |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| South Carolina (1974) | (Process operation) (d) | | | | Must meet ambient-air standards | Must meet ambient-air standards |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| South Dakota (1973) | (Process operation) (d) | | | | -- | 3.0 lb SO ₂ per million Btu heat input |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| Tennessee (1973) | (Existing jobbing cupolas) | | | | -- | (After 7/1/75) Class IA county = 500 ppm Class I or II county = 1000 ppm Class III county = 2000 ppm |
| | 16.65 | 25.10 | -- | -- | | |
| | (Existing foundries) (d) | | | | | |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |
| | (New after 8/9/69) (c) | | | | | |
| | 9.7 | 15.0 | 23.0 | 32.4 | | |
| Texas (1974) | (Manufacturing processes) (o) | | | | Burn at 1300 F for at least 0.25 second in a direct-flame afterburner | -- |
| | 15.2 | 30.1 | 59.7 | 78.1 | | |
| Utah (1973) | (Manufacturing processes) Maintain at least 85% efficiency of controls. | | | | -- | If potential is greater than 250 tons sulfur per year, control to 80% efficiency |
| Vermont (1973) | (Industrial processes) | | | | -- | Use fuel that is less than 1.0% sulfur by weight or control to discharge no more than 1.0% of fuel by weight |
| | 10.0 | 16.19 | 28.3 | 40.0 | | |
| Virginia (1974) | (Process operation) (d) | | | | Burn at 1300 F for at least 0.3 second in a direct-flame afterburner | 2000 ppm by volume |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |

TABLE III-10. (Continued)

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Maximum Effluent or Specified Treatment | Sulfur Dioxide; Maximum Effluent for any Combustion Process |
|----------------------|------------------------------------------------------------------------------|---------------|---------------|---------------|----------------------------------------------------------------------|-------------------------------------------------------------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | |
| Washington (1972) | (General Processes) | | | | Meet ambient-air-quality standards | Meet ambient-air-quality standards |
| | Existing (0.20 grain per scf) (p) | | | | | |
| | 4.1 | 8.2 | 16.4 | 41.0 | | |
| | New After 7/1/75 (0.10 grain per scf) | | | | | |
| | 2.05 | 4.1 | 8.2 | 20.5 | | |
| West Virginia (1971) | (Manufacturing processes) | | | | -- | (6/30/75) 2000 ppm |
| | Existing before 7/1/70 | | | | | |
| | 19.0 | 26.0 | 36.0 | 54.0 | | |
| | New after 7/1/70 | | | | | |
| | 10.0 | 16.0 | 28.0 | 33.0 | | |
| Wisconsin (1973) | (Cupolas) | | | | Burn at 1300 F for at least 0.3 second in a direct-flame afterburner | Meet ambient-air-quality standards |
| | (0.45 lb dust/1000 lb gas) (q) | | | | | |
| | 5.23 | 10.10 | 20.92 | 52.30 | | |
| Wyoming (1973) | (Process operation) | | | | Meet ambient-air-quality standards | Meet ambient-air-quality standards |
| | Existing before 4/9/73 (c) | | | | | |
| | 9.73 | 14.99 | 22.29 | 32.24 | | |
| | New processes after 4/9/73 (d) | | | | | |
| | 12.0 | 19.2 | 30.5 | 44.6 | | |

(a) Class 1 county.

(b) Class 2 county.

(c) $P \leq 30$ tons/hr $E = 3.59 P^{0.62}$
 $P > 30$ tons/hr $E = 17.31 P^{0.16}$.

In Footnotes (c), (d), (g), (j), and (o), but not (m): P = process weight per hour, in tons/hour, that is, tons of iron melted per hour in the case of foundries. E = maximum particulate emission permitted, in pounds/hour.

(d) $P \leq 30$ tons/hr $E = 4.10 P^{0.67}$
 $P > 30$ tons/hr $E = 55.0 P^{0.11} - 40$.

(e) Uncertain whether the code applies to foundries.

(f) The average undiluted-top-gas discharge per cupola from 12 cupolas was 28,765 scf/ton of iron melted.⁽²⁶⁾ Thus, $28,765 \div (359 \text{ ft}^3 \text{ per lb-mole}/29 \text{ lb-mole}) = 2,324 \text{ lb gas/ton of iron} \times (0.8/1000) = 1.86 \text{ lb particulate/ton with no dilution}$.

(g) $P \leq 450$ tons/hr $E = 2.54 P^{0.534}$
 $P > 450$ tons/hr $E = 24.8 P^{0.16}$.

Footnotes to Table III-10 to be continued on next page.

Footnotes to Table III-10 (Continued)

- (h) Michigan specifies: 5 tons/hr - 0.4 lb particulate/1,000 lb gas
 10 tons/hr - 0.25 lb particulate/1,000 lb gas
 20 tons/hr or over - 0.15 lb particulate/1,000 lb gas.
 Based on 2,324 lb gas/ton of iron melted (see (f)), the indicated particulate in pounds per hour was calculated.
- (i) The volume of undiluted top gas per ton of iron was estimated to be 28,765 scf. (26)
 7,000 grains = 1 pound. Thus, $28,765 \times 0.4 \div 7,000 = 1.64$ pounds of particulate per ton of iron processed. Then $1.64 \text{ lb/ton} \times \text{number of tons/hr} = \text{lb/hr}$.
- (j) $P \leq 30 \text{ tons/hr}$ $E = 5.05 p^{0.67}$
 $P > 30 \text{ tons/hr}$ $E = 66.0 p^{0.11} - 48$.
- (k) The tabulated values were calculated as follows: *No good!* average volume of undiluted top gas per ton of iron was estimated to be ~~28,765~~ scf. (26) The allowable emission of 0.02 grain/scf = $28,765 \times 0.02 = 575.3$ grains/ton $\div 7,000$ grains/lb = 0.082 lb/ton of iron melted. Then $0.082 \text{ lb/ton} \times \text{number of tons/hr} = \text{lb/hr}$.
- (l) Calculated particulate emission permitted in melting gray iron. Heat required to melt 1 ton of iron and superheat to 2700 F = 1,096,000 Btu. (27) Estimated melting efficiency = 50%. Total heat required = 2,192,000 Btu. 2.192 million Btu $\times 0.05 = 0.110$ pound of particulate per ton of iron melted. Then $0.110 \text{ lb/ton} \times \text{number of tons/hr} = \text{lb/hr}$.
- (m) P = process weight per hour in pounds/hour,
 E = emissions in pounds/hour
 $P \leq 100,000$ $E = 0.024 p^{0.665}$
 $P > 100,000$ $E = 39 p^{0.082} - 50$.
- (n) The values tabulated were calculated from the equation $A = 0.76 E^{0.42}$, where A = allowable emission in lb/hr, E = emission index = F x W lb/hr, F = process factor, and W = production rate in tons/hr. F = 150 for 5 tons/hr or less; F = 50 for more than 5 tons/hr.
- (o) $P \leq 20 \text{ tons/hr}$ $E = 3.12 p^{0.985}$
 $P > 20 \text{ tons/hr}$ $E = 25.4 p^{0.287}$.
- (p) The tabulated values were calculated as follows: average volume of undiluted top gas per ton of iron melted was estimated to be 28,765 scf. (26) The allowable emission of 0.20 grain/scf = $28,765 \times 0.20 = 5,753$ grains/ton $\div 7,000$ grains/lb = 0.82 lb/ton of iron melted. Then $0.82 \text{ lb/ton} \times \text{number of tons/hr} = \text{lb/hr}$.
- (q) The tabulated values were calculated as follows: the average undiluted cupola-top-gas discharge is 2,324 lb/ton of iron melted (see Footnote (f)). Then $0.45 \text{ lb dust} \times 2,324 / 1,000 = 1.046$ lb dust per ton of iron melted. Taking $1.046 \text{ lb/ton} \times \text{number of tons/hr} = \text{lb/hr}$.

TABLE III-11. MOST RESTRICTIVE STATE AIR-POLLUTION CODES

| State | Particulate (pounds per hour) Based on Indicated Process Weight in Tons/Hour | | | | Carbon Monoxide; Treatment Required | Sulfur Dioxide; Maximum Effluent for any Manufactur- ing Process |
|--------------|---------------------------------------------------------------------------------|------------------|------------------|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| | 5 Tons/ Hour | 10 Tons/ Hour | 20 Tons/ Hour | 50 Tons/ Hour | | |
| New Jersey | (Manufacturing processes) (a) | | | | -- | 2000 ppm by volume |
| | 0.41 | 0.82 | 1.64 | 4.1 | | |
| New Mexico | (Manufacturing processes) (b) | | | | -- | 1.0 pound SO ₂ per million Btu input |
| | 0.55 | 1.1 | 2.2 | 5.5 | | |
| Pennsylvania | (Iron foundries) | | | | -- | 500 ppm by volume |
| | 12.26 | 10.34 | 13.83 | 20.32 | | |
| Washington | (General processes new after 7/1/75) (c) | | | | -- | -- |
| | 2.05 | 4.1 | 8.2 | 20.5 | | |
| Wisconsin | (For cupolas) (d) | | | | Burn at 1300 F for at least 0.3 second in a direct-flame after- burner | -- |
| | 4.83 | 9.66 | 19.32 | 48.31 | | |
| Oklahoma | (Foundries) (Does not apply) | | | | Remove 93% of the carbon monoxide with an after- burner | -- |
| Illinois | (New processes) (e) | | | | Cupola gases burned with an afterburner to less than 200 ppm CO cor- rected to 50 percent excess air. (Cupolas with a melt rate of less than 5 tons/hour excluded.) | 2000 ppm |
| | 6.0 | 8.7 | 12.5 | 20.5 | | |

(a) Calculated from 0.02 grain per scf of gas discharged.

(b) Calculated from 0.05 pound per million Btu input.

(c) Calculated from 0.10 grain per scf of gas discharged.

(d) Calculated from 0.45 pound of dust per 1000 pounds of gas.

(e) Includes iron foundries.

in grains per scf* of gas emitted, whereas New Mexico states the emission limits in pounds of particulate per million Btu introduced. The values for particulate emissions shown in Tables III-10 and III-11 were calculated on the basis of undiluted gas from a cupola. The New Jersey code states that the measurement must be made before the gases are diluted, whereas the Washington code specifies that the off gases must be corrected to 7 percent oxygen. Among the state codes that prescribe limits for particulate emissions specifically for iron foundries, the two most restrictive are those of Pennsylvania and Wisconsin (see Table III-11).

Fourteen states specify that the carbon monoxide in the off gases from foundry melting furnaces be burned to carbon dioxide with an afterburner. Most of the 14 states specify that the off gases be subjected to the direct flame of an afterburner operating at or above 704 C (1300 F) for a time of at least 0.3 second. Oklahoma has specified further that at least 93 percent of the carbon monoxide be burned with the afterburner, and Illinois has specified that the carbon monoxide in the off gases be reduced to less than 200 ppm with an afterburner when the total gas volume is corrected to 50 percent excess air. The Illinois code is the most restrictive.

An average cupola produces 1,162 kilograms of undiluted top gas per kilokilogram of iron melted (2,324 pounds per ton**). At 50 percent excess air, this would be 1,743 kilograms per kilokilogram ($1.5 \times 2,324 = 3,486$ pounds of diluted gas per ton). If this gas contained a maximum of 200 ppm (0.02 percent) carbon monoxide in accordance with the Illinois code, then the maximum amount of CO emitted to the atmosphere would be 0.340 kg/kg of iron melted ($3,486 \text{ pounds of gas} \times 200/1,000,000 = 0.679 \text{ lb/ton}$).

None of the states specifically limit the sulfur dioxide (SO₂) in the effluent from cupola furnaces or other foundry melting equipment. Instead, foundries are required to meet the sulfur dioxide emission limits for manufacturing or combustion processes. These limits vary

* scf = standard cubic foot (see Glossary).

** The average volume per cupola of undiluted top gas discharged from 12 cupolas was 28,765 scf/ton of iron melted.⁽²⁶⁾ Thus, $28,765 \div \left(\frac{359}{29}\right)$ scf/lb for air = 2,324 lb/ton melted.

from 2000 to 500 ppm SO₂ in the off gases to 0.71 pound of SO₂ per million Btu of heat input. An average cupola produces 1,162 kilograms of undiluted top gas per kilokilogram of iron melted (2,324 pounds per ton⁽²⁶⁾). The most restrictive codes for combustion processes specify 500 ppm of sulfur dioxide in the top gases. Thus, the top gases could contain a maximum of 0.58 kilogram) of sulfur dioxide per kilokilogram of iron melted (2,324 x $\frac{500}{1,000,000} = 1.16$ lb/ton). About 1,100,000 Btu are required to melt and superheat 1 ton of iron.⁽²⁷⁾ On this basis, the Nevada code (see Table III-10) would permit the discharge of 0.39 kilogram of SO₂ per kilokilogram of iron melted (1.1 million Btu x 0.71 lb SO₂/million Btu = 0.78 lb/ton). Again, where a maximum sulfur dioxide concentration in the off gases is specified, the restrictiveness of the codes could be reduced by diluting the gases. However, the value from the Nevada code of 0.71 pound of sulfur dioxide emitted per million Btu input is a precise quantity, not a concentration, and dilution of the off gases is of no aid in meeting the code requirements. Most state codes include a statement to the effect that merely diluting the effluent so as to meet the code is prohibited.

Typical State Air-Pollution Codes. The foundry-particulate-emission codes for 23 states are similar and could be considered as typical state air-pollution codes. The states are Arizona, Idaho, Illinois for existing foundries, Indiana, Iowa, Kansas, Kentucky, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Hampshire for new foundries, North Carolina, North Dakota, Ohio, Oklahoma for production or new foundries, Rhode Island, South Carolina, South Dakota, Tennessee for existing foundries, Virginia, and Wyoming for new processes. The maximum amount of particulate that can be emitted under these codes is based on process weight and is as follows:

| Maximum Particulate (pounds per hour) That Can Be Emitted Based on Process Weight in Tons Per Hour | | | |
|-------------------------------------------------------------------------------------------------------|-------------------|-------------------|-------------------|
| <u>5 Tons/Hr</u> | <u>10 Tons/Hr</u> | <u>20 Tons/Hr</u> | <u>50 Tons/Hr</u> |
| 12.0 | 19.2 | 30.5 | 44.6. |

These particulate amounts were taken from charts calculated from the formula, $E = 4.10 P^{0.67}$, where E equals the maximum particulate emission permitted, in pounds per hour, and P equals a process weight of 30 tons per hour or less. If P equals a process weight of over 30 tons per hour, the maximum particulate emission permitted, in pounds per hour, is based on the formula, $E = 55.0 P^{0.11} - 40$.

The typical state laws limit visible emissions for new installations to a maximum of Ringlemann No. 1 (20 percent opacity) except for 3 minutes per hour and not to exceed 20 minutes per day when the visible emissions can exceed a Ringlemann No. 1 (20 percent opacity) but must not exceed a Ringlemann No. 2 (40 percent opacity).⁽²⁹⁾

Typical carbon monoxide regulations require that the top gases be burned in a direct-flame afterburner for at least 0.3 second at 704 C (1300 F) or above. Treatment for the minimum time at the minimum temperature would be expected to remove carbon monoxide to a level of 2 to 4 percent in the effluent.⁽²⁸⁾ Thus, if the undiluted top gases weighed 1,162 kilograms per kilokilogram of iron melted (2,324 lb/ton; from preceding subsection) and contained 16 percent carbon monoxide, the treatment would remove all but 34.9 kilograms of carbon monoxide per kilokilogram of iron melted (69.7 lb/ton), based on a concentration of 3 percent in the effluent from the afterburner.

A typical maximum allowable sulfur dioxide emission based on state regulations for combustion processes is about 2000 ppm in the effluent gases. Again if the total weight of undiluted top gases from a cupola is 1,162 kilograms per kilokilogram of iron melted (2,324 lb/ton), the maximum permissible emission would be 2.32 kilograms of SO₂ per kilokilogram of iron melted (4.65 lb/ton). If the gases were diluted 10 fold, the permissible emission would be increased 10 times to 23.2 kg/kkg (46.5 lb/ton).

Impact of the Most-Restrictive State Regulations on New-Foundry Operations. New foundries operating cupolas or arc furnaces probably could meet a strict interpretation of the particulate-effluent limits shown in Table III-11 for New Jersey, New Mexico, or Washington. Foundry cupolas probably could not meet the carbon monoxide (CO) effluent limitations of Illinois. The best afterburner is capable of reducing the CO to less than 0.1 percent or 1000 ppm, a level up to 5 times the 200 ppm maximum set by Illinois. (The CO can be reduced to 0.1 percent by subjecting the top gases to the direct flame of a suitable afterburner for at least 1.0 second at 816 C (1500 F) or above.) New foundries probably will not be built in these very restrictive states.

References

- (1) "Survey of Manufacturers", U. S. Department of Commerce (1970).
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SECTION IV

EMISSION-CONTROL TECHNOLOGY

Introduction

Foundries have used and continue to use a large number of devices to remove some portion of the pollutants that their operations discharge to the atmosphere.

In the melting of cast iron in cupola furnaces, many installations have used spark-arrester screens or wet caps to trap large sparks and particles. Both devices rely on the natural draft of the stack to conduct the stack gases through a screen, in the case of the spark arrester, or through one or more curtains of water or water sprays, in the case of the wet cap. As the water-cleaning devices become more efficient, some power is required to force the furnace gases through the water sprays or water-scrubbing devices. The energy required to force or pull the stack gases through the water-cleaning system is used to classify these cleaning devices as either low- or high-energy water scrubbers.

Filter bags, somewhat similar to ordinary household-vacuum-cleaner bags, have long been used to remove particulates (coarse and fine dusts) from industrial atmospheres. Some energy must be used to operate fans to push or pull the gases through the bags and the rest of the system. An installation that contains a multiplicity of fabric-bag filters is called a baghouse.

Electrostatic precipitators remove solid particles from foundry gases by electrically charging the particles in the gases and then collecting the charged particles on oppositely charged metal plates. The resistance to the flow of the gases is low, but considerable energy is required to charge the particles and the collecting plates.

Cyclone dust collectors operate by causing the dust-laden gases to swirl in a cylindrical vessel so that centrifugal force drives the particles to the outer surface of the vessel where they can be collected. Water sprays or curtains may be used in cyclones to improve the particle-collection efficiency. Within limits, the collection efficiency increases as the energy that forces the gases through the cyclone increases.

Combustion systems may be very effectively used to remove and consume organic impurities in furnace-charge materials and organic fumes or carbon monoxide produced in metal melting, mold cooling, or coremaking. Properly designed scrap preheaters with afterburners can effectively remove and consume organic materials on the scrap. Properly designed afterburners in cupola stacks can effectively consume almost all of the organic fumes and carbon monoxide in the stack gases.

Very large burners or catalytic-combustion systems are necessary to effectively remove organic fumes and carbon monoxide from gases emitted during coremaking or from gases emitted from molds during cooling after pouring. The reason is that these operations tend to be performed over large areas, which necessitates processing substantial amounts of air with the fumes and gaseous pollutants.

Water Scrubbers

Water scrubbers vary from wet caps through low-energy scrubbers to high-energy scrubbers.

Wet Caps

Wet caps are cone-shaped devices installed on the top of cupola stacks for the purposes of removing the very coarsest particles in the off-gas stream and extinguishing most of the sparks. Water introduced on the top surface of the metal cone forms a curtain as it falls around the periphery of the cone. The natural draft of the cupola stack induces the stack gases to flow through the water curtain. On passing through one or more such curtains of water, the stack gases lose much of the coarse particulate they are carrying, and most of the sparks are extinguished. The particulate is collected in the water, which must then go to a settling basin where the solid matter settles out and is removed; the overflow water generally is recirculated.

Wet caps are not efficient collectors of fine particulates. They are used to extinguish sparks, remove some of the coarse particulate, and cool the gases before they are introduced into baghouse filters.

Low-Energy Scrubbers

A low-energy scrubber as defined here is any of a number of wet scrubbers in which the gas-pressure drop through the system is less than 12.44 kilopascals (50 inches of water), or 12.44 kN/m² or 0.00127 kg/mm². These low-energy scrubbers include multiple-spray towers, wet-impingement scrubbers, disintegrator gas washers, packed-bed washers, and many others^{(1)*}. Although these scrubbers can be fairly efficient at removing particles larger than 5 micrometers** (about 0.00020 inch), none of the low-pressure washers are efficient at removing particles less than 5 micrometers (about 0.00020 inch) in size.

High-Energy Scrubbers

High-energy scrubbers are herein defined as wet scrubbers in which the pressure drop through the unit is more than 12.44 kilopascals (50 inches of water). Of the scrubbers, only the high-energy venturi scrubber has been used extensively in cleaning the stack gases discharged from cupolas. Typical arrangements of the elements of a venturi scrubber are shown in Figure IV-1.

The horsepower of the exhaust blowers necessary to pull the gases through a venturi scrubber can be calculated from the following equation:⁽²⁾

$$HP = \frac{1.575}{10,000} \times \frac{\left(\begin{array}{c} \text{Pressure Drop in} \\ \text{inches of water} \end{array} \right) \times \left(\begin{array}{c} \text{Cubic feet of} \\ \text{gas per minute} \end{array} \right)}{\left(\text{Efficiency of the blower} \right)} \quad (1)$$

Properly designed, plant-size, high-energy, venturi scrubbers are capable of a maximum efficiency of 97 percent for 1-micrometer (approximately 0.00004-inch) particles, 99.6 percent on 5-micrometer (approximately 0.00002-inch) particles, and 99.7 percent overall, when evaluated in a controlled test with a standard silica dust and a pressure drop in excess of 50 inches of water.⁽¹⁾ It is assumed that similar efficiencies can be achieved in the foundry with a properly installed and properly maintained high-energy scrubber,

* References are listed at the end of the section.

** One micrometer equals 1 micron.

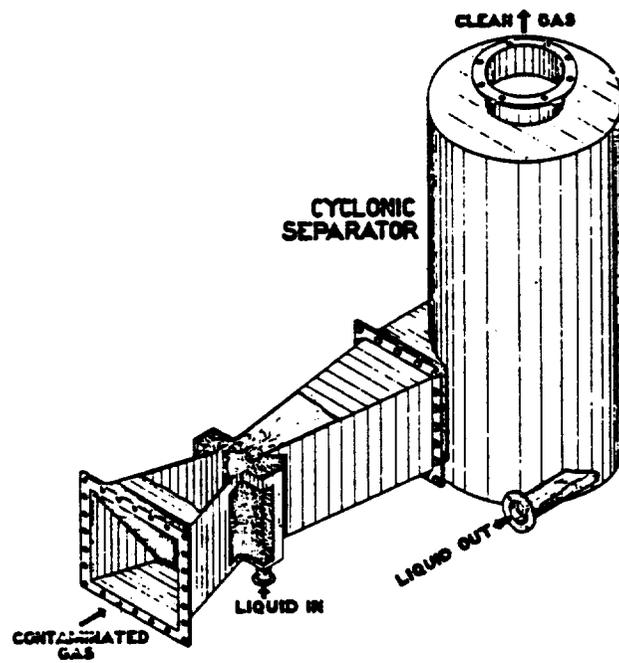


FIGURE IV-1. VENTURI SCRUBBER (3)

so long as the particulate in the effluent being treated does not contain a higher proportion of very fine particles than did the standard silica dust (12 percent less than 2-1/2 micrometers). However, as was shown in Table III-8, the particulate emissions from foundry electric-arc-melting furnaces may be much finer than the standard silica dust.

Many scrubbers require settling ponds of appreciable size in which the solids can separate from the water and a recirculating system to reuse the water. Raw overflow from the scrubber system cannot be discharged into streams or sewers.

Baghouse Filtration

As was indicated earlier, a baghouse is an installation comprising a group of cylindrical fabric filters through which particulate-bearing gases are passed. On the way through, the gases leave particulates behind on the filtering surfaces of the bags. Baghouses are the most commonly used devices for removing particulates from gas streams in iron foundries.

The dust collected on the filtering surface of the bags is removed periodically by diverting the flow of dirty gas from a portion of the bags, and removing the dust from those idle bags with reverse-air jets, by shaking the bags, or by other means. The dust from the bags drops down into cone-shaped or pyramidal receivers in the bottom of the baghouse chamber. The dust from the chamber normally is discharged into paper bags or closed containers for disposal. Most state air-pollution regulations hold foundries responsible for the dust created during and after disposal. Two typical baghouse-cleaning arrangements are shown in Figure IV-2.

The filter bags are made of fabric woven from cotton, wool, synthetic fibers, or glass wool. The glass-wool fabrics generally are treated with a silicone to improve particle retention. The cotton, wool, and synthetic fibers cannot be used at gas temperatures above about 93 C (200 F); glass fibers will operate up to about 288 C (550 F). The fibers are woven with main strands about 500 micrometers (about 0.02 inch) in diameter, the strands being spaced up to 100 to 200 micrometers (about 0.004 to 0.008 inch) apart. The result is a sieve. The apertures in the sieve are criss-crossed with fine "hairs" of the individual fibers that effectively close the apertures.⁽¹⁾ The filter does not operate effectively

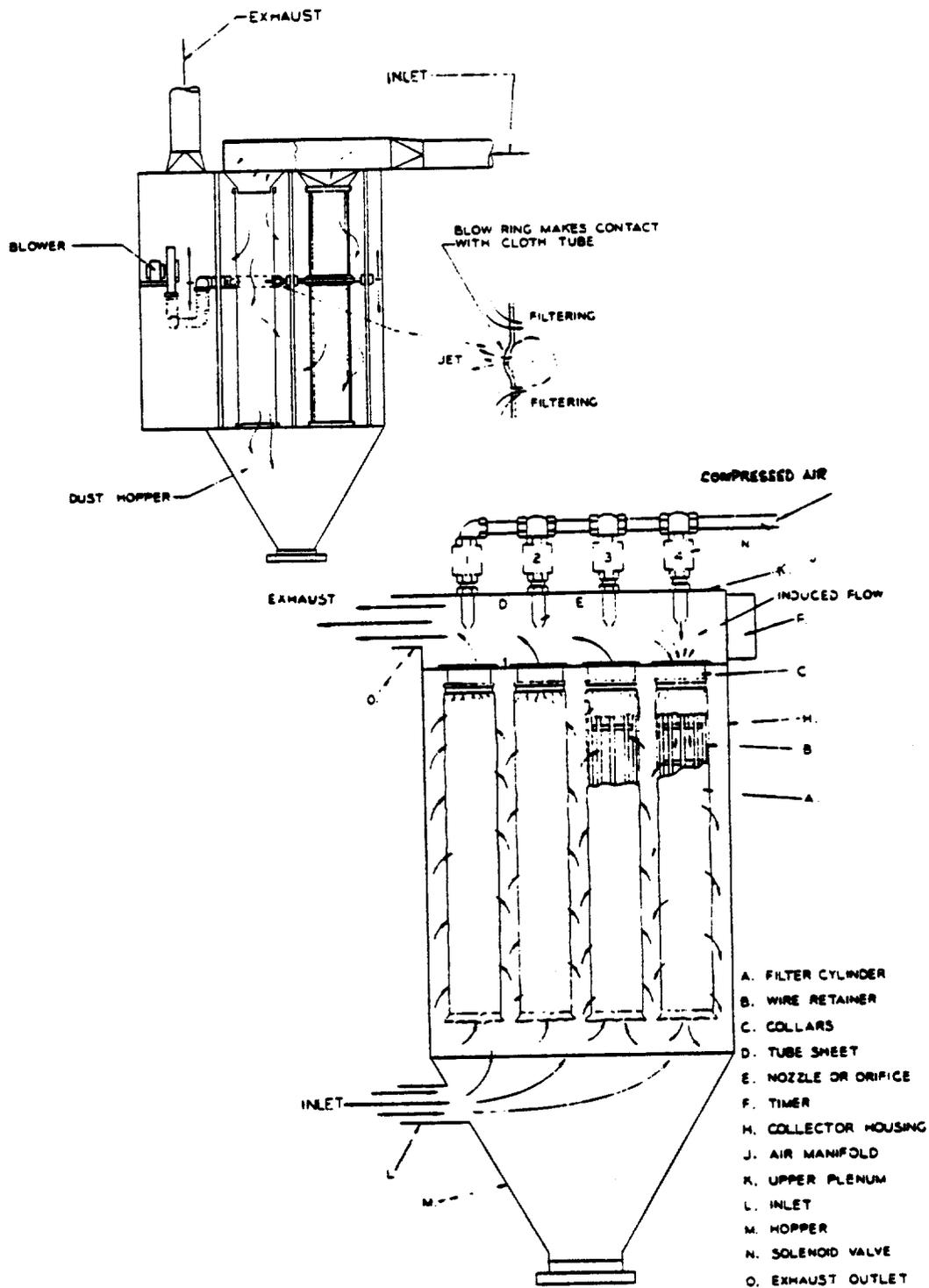


FIGURE IV-2. BAGHOUSE FILTER SHOWING TWO METHODS OF CLEANING THE BAGS BY REVERSE AIR FLOW (3)

until a loose "floc" of particulate builds up on the fabric and provides an effective filter bed. The floc may be dislodged each time the filter is cleaned. Therefore, all fabric filters in a given baghouse do not perform at maximum efficiency at all times, although, if the filter area is properly sized and the cleaning periods are short, the efficiency should approach 100 percent.⁽¹⁾ Normal fabric filters should not be operated with gas velocities through the filters exceeding about 0.3 to 1.8 m/min (about 1 to 6 ft/min) to avoid excessive packing of the floc, which would result in an excessive pressure drop and local breakdown of the filter beds.⁽¹⁾

Most larger scale fabric filters installed in industrial plants are less than 50 percent efficient in filtering particles between about 0.1 and 1.4 micrometers (about 4 to 55 microinches) and, in fact, are least efficient (10 percent efficient) in removing particles of about 0.9 micrometer (35 microinches).⁽¹⁾ However, in such installations they are almost 100 percent effective in filtering particles larger than about 2 micrometers (about 79 microinches), except during cleaning or when a bag breaks down.

Some form of gas cooling is necessary with fabric filters. Cupola top gases generally are ignited with afterburners operating at 704 C (1300 F) or above, so that the temperature of the off gases will be at least 704 C (1300 F). The off gases from other melting furnaces, which may or may not require afterburners, also must be cooled. One way to cool melting-furnace off gases is to dilute them with dirty off gases from other foundry operations, such as metal treating, metal pouring, mold cooling, cleaning, sand handling or mixing, or coremaking.

The off gases often are cooled with water sprays, either in the gas stream or on the outside surface of the gas duct. This method of cooling the furnace off gases will reduce the volume of gases appreciably, rather than increase the volume as occurs when they are cooled by dilution with air or dirty off gases from other operations as was described above. A smaller volume of gases to be cleaned will permit use of smaller and less expensive pollution-control equipment. Internal water sprays must be controlled so as to prevent the gas temperature from falling below the dew point, as the resultant condensation of water would "blind" the bags and prevent them from operating. Because cotton or wool bags cannot handle gas above 93 C (200 F), the gas temperature may be below the dew point, so internal sprays are not practicable for use with these bag materials. On the other hand,

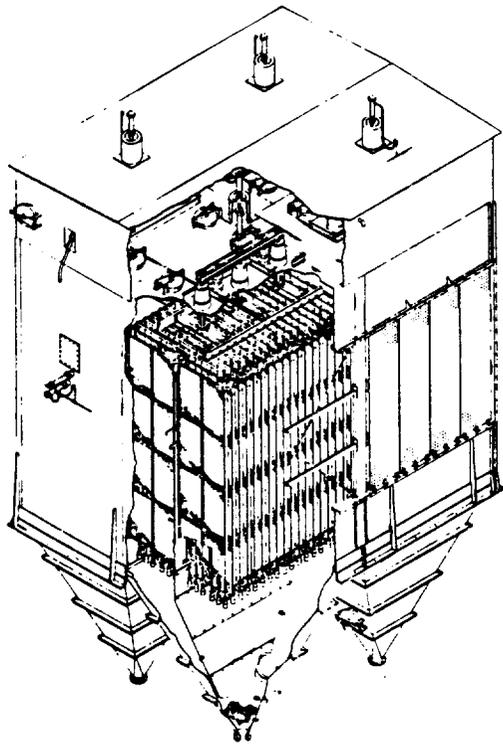
external cooling of the gas ducts is much less efficient. However, water used to cool the outside of gas ducts can be recirculated or discharged into sewers or waterways, because, being noncontact cooling water, it is not polluted. In contrast, water used inside the ducts, if not completely consumed, must be settled and filtered before it can be discharged; of course, it can be settled and recirculated.

All sparks large enough to carry to the bags must be arrested to prevent them from burning the bags. Screens or water sprays generally are effective spark arresters.

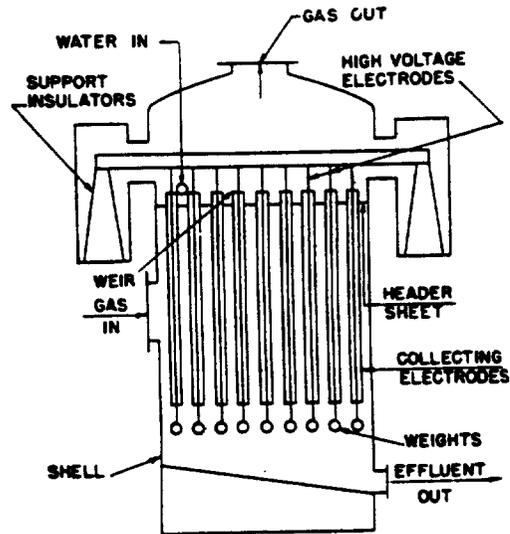
Electrostatic Precipitators

Electrostatic precipitators remove solid particles from foundry gases by electrically charging the particles in the gas and then collecting the charged particles on oppositely charged metal plates. The dust collected on the plates must be periodically removed by diverting the flow of dirty gas from a section of the collecting plates, grounding the plates to remove the charge, and cleaning the plates either by vibrating them dry or washing them with water. If water is used, it must be cleaned before it can be recirculated or discharged.

In large-scale, industrial-plant applications, electrostatic precipitators are about 92 percent efficient in removing 5-micrometer (197-microinch or 0.000197-inch) dust dry and 98 percent efficient in removing 5-micrometer (197-microinch) dust by wet cleaning.⁽¹⁾ Electrostatic precipitators are not efficient enough in removing small particles to permit their use in most U. S. foundries. Also, they cost much more to install and maintain than do high-energy venturi scrubbers or baghouses of similar capacity. For these reasons, electrostatic precipitators seldom are used in foundries in the United States. However, electrostatic precipitators apparently are reasonably popular on recuperative-type hot-blast cupolas in Germany.⁽⁴⁾ Two types of electrostatic precipitator are shown in Figure IV-3.



a. Plate Type (Dry)



b. Pipe Type (Wet)

FIGURE IV-3. HIGH-VOLTAGE ELECTROSTATIC PRECIPITATORS⁽⁵⁾

Cyclone-Type Cleaners

Cyclones have been widely used for industrial dust collection, either alone or followed by a device that captures the fine particles more efficiently. Cyclones operate on the principle of causing the dusty gases to swirl inside a cylindrical vessel, by admitting the dirty gases tangentially at high velocity near the periphery of the vessel, and removing the cleaned gas near the axis of the vessel. Particles are subjected to an outward centrifugal force that carries them to the wall if they have a high enough density to resist the inward viscosity drag of the gas. A typical cyclone collector is shown in Figure IV-4.

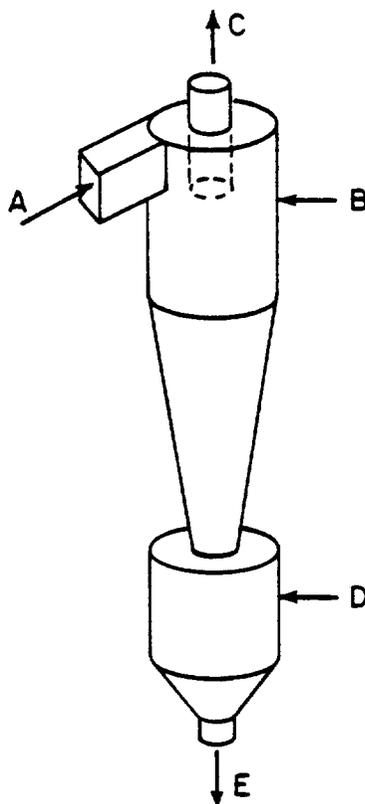


FIGURE IV-4. CYCLONE DUST COLLECTOR (AFTER STAIRMAND⁽¹⁾)

- A - dust-laden gas inlet
- B - centrifuge
- C - cleaned-gas exit
- D - collected dust.
- E - dust discharge

Cyclones are rather inefficient collectors of particles smaller than about 40 micrometers (about 0.0016 inch). Often they are used to collect grinding dusts, where the particles are mostly coarse. Cyclones also are used ahead of other gas cleaners to remove most of the coarse particulate. The efficiency of cyclones can be improved by inserting rotating blades to increase the velocity of the swirling gas, and further improvement is obtained if water sprays are impinged on the blades. However, the best cyclones are not efficient enough to be used as the only gas-cleaning method for most foundry waste gases. A cyclone-type separator frequently is used to remove the water-dust droplets from the effluent from a high-energy venturi scrubber.

Combustion Systems for Controlling Carbon Monoxide and Organic Vapors

The only known effective method of eliminating carbon monoxide (CO) or organic vapors from off gases is to burn the CO and organic vapors with an excess of air, either directly in a flame or with a catalytic-combustion system. The following sections describe some of the various combustion systems commonly employed in foundries for this purpose.

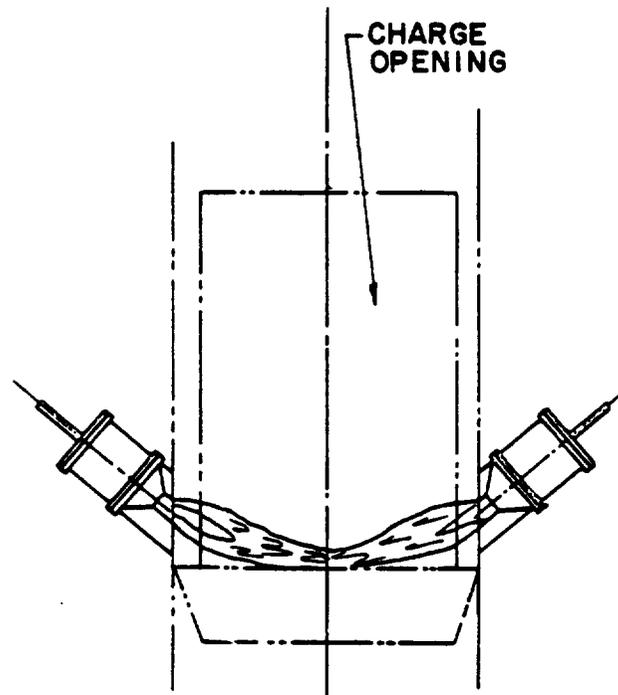
Preheaters for Scrap

Scrap charges for electric furnaces commonly are loaded into metal preheating buckets or conveyors and heated with gas or oil flames to insure a dry charge material and to provide some residual heat in the metal. If the preheating station is properly designed and the burners are properly designed and the burners are properly adjusted, little organic fume or carbon monoxide should be emitted. If the preheaters are poorly designed and the scrap is too oily, afterburners and cyclones also may be used to control emissions. The preheated scrap charge should be added to the furnace while still hot, because moisture could again condense on cold scrap, and less electrical energy is required to melt hot scrap.

Afterburners for Cupola Top Gases
and Other Foundry Waste Gases

To effectively remove carbon monoxide and organic fumes, cupola top gases must be subjected to a direct flame from a gas- or oil-fired burner with some excess air present. There are two reasons for removing these substances from such gases: (1) to comply with emission-control codes and (2) to prevent explosions when the gases are subjected to subsequent gas-cleaning operations.

Many state regulations specify that the gases must be subjected for not less than 0.3 second to a direct flame from a gas or oil burner, or equivalent, operating at a temperature of at least 704 C (1300 F). Under those conditions, properly adjusted afterburners should remove most of the carbon monoxide and organic fumes from cupola top gases. A typical cupola-afterburner system is shown in Figure IV-5.



VERSATILE BURNER-COMBUSTOR
CAN BE ADJUSTED TO DELIVER
BETWEEN 1,000,000 BTU/HR. TO
8,000,000 BTU/HR.

FIGURE IV-5. DIAGRAM OF AFTERBURNER SYSTEM SHOWING THE FLAME INTRODUCED AT THE MOST FAVORABLE LOCATION FOR IGNITING CUPOLA GASES SO AS TO PROVIDE THE MOST ECONOMICAL OPERATION⁽⁶⁾

Carbon monoxide and organic fumes in mold gas or fumes from core-making are more difficult to dispose of than are these constituents in cupola top gases. Since these waste gases generally do not contain enough fuel to support combustion, the afterburner must supply enough heat to raise the temperature of the entire mass of waste gas to above 704 C (1300 F). If this is accomplished, the carbon monoxide and organic fumes will be consumed. However, generally it is more economical to burn these types of waste gases in catalytic-combustion systems.

Catalytic-Combustion Systems for Mold Gases and Coremaking Fumes

Whereas normal afterburner combustion systems must heat the off gases to above about 704 C (1300 F) to insure complete combustion of the carbon monoxide and organic fumes in the gases, catalytic-combustion systems operate effectively at temperatures of about 260 C (500 F). Therefore, much less preheating of the off gases is required when catalytic-combustion systems are employed. A typical catalytic-combustion system is shown in Figure IV-6. In operation, the waste gases that contain the contaminants are heated to about 260 C (500 F) and then are directed through the catalyst elements. Here the oxygen in the exhaust stream combines with the combustible gases to form carbon dioxide and water vapor, with release of thermal energy.

Efficiency increases with increasing catalyst temperature and increasing available catalyst-surface area. Efficiency also is influenced by the type of catalyst used. When needed, systems can be provided for virtually 100 percent oxidation (consumption) of the combustibles in the gas stream. Most foundry waste gases contain enough inorganic particles to cause attrition of the catalyst, so that the catalyst bed must be replaced every 1 to 4 years. Catalytic-combustion systems are fairly expensive to install and maintain. No heavy metals that would poison the catalyst and reduce its efficiency would be expected in mold gas or fumes from coremaking.

Emission-Control Technology Used in Other Industries

Emission-control technology used in other industries may be applicable to the foundry industry when it pertains to the control of

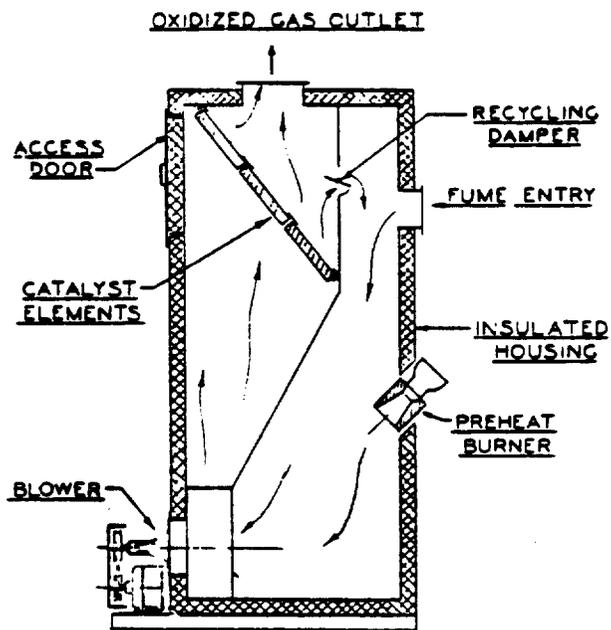


FIGURE IV-6. COMPONENTS OF A RECYCLING-TYPE CATALYTIC-COMBUSTION SYSTEM⁽⁷⁾

particulate in hot gases and to the disposal of carbon monoxide in both hot and warm gases. Both direct-combustion and catalytic-combustion systems for the removal of organic fumes and carbon monoxide are used in most industries, in addition to the foundry industry, when these materials must be controlled.

Control of sulfur emissions (generally present as sulfur oxides or hydrogen sulfide in certain other industries) is not necessary in foundries, because the sulfur content of the charge materials must be selected to give low-sulfur molten metal and, as a result, the effluent gases are very low in sulfur compounds.

Effect of Operating Conditions on Emission-Control-Equipment Requirements

Molding and Coremaking

Considerable dust is generated when dry sands are mullled in the preparation of molding sands. Dry additions of sea coal, clays, cereal, pitch, or other additives will increase the amount of dust generated. The molding-sand additives can be used in the form of slurries so as to reduce the emissions and, thus, reduce the size and cost of emission collection and treatment systems. The use of covered-and-vented mullers permits the collection of dust with relatively inexpensive equipment.

Charge Materials

The unloading, distribution, and preparation of foundry raw materials on the premises of the foundry may produce moderate amounts of particulate emissions. Transfer of coke, limestone, fluorspar, scrap iron and steel, in-plant iron returns, sand, sand binders and additives, and refractories at the foundry site may create some dust (particulates) at every transfer point. Emissions from these sources can be kept to a minimum as follows: sands can be transferred in closed pneumatic tubes; coke, metals, and ferroalloys can be transferred in closed unit boxes and stored under roof; foundry-sand additives can be delivered and used in

a slurry form; and refractories can be used wet or handled in a well-ventilated room. In-plant iron returns can be cleaned better in order to reduce the dust problem, but cleaning processes will require pollution-control devices for either air or water. Particulates created during the transfer of raw materials or during makeup of charges can only be controlled by transferring all dry materials in closed containers or closed conveyor lines that are equipped with an adequate exhaust system connected to an air-pollution-control device. The particulate concentrations generally are not great, even before entering the control devices. However, the design of the enclosed handling systems and the exhaust systems will affect the amount of exhaust gases to be treated and, thus, the size and cost of the pollution-control device required.

Preparation of scrap charges that involves cutting to reduce the size of the pieces in the charge or incineration operations to remove paint, oil, or other contaminants may create excessive amounts of smoke and particulates. The cleanliness of the scrap and the return metal and the design of the incinerator or preheater will determine whether cleaning equipment is needed to reduce the particulate content of the incinerator off-gases and whether an afterburner is needed to burn carbon monoxide and organic fumes.

Melting Operation

The type and conditions of the metallic charge materials greatly affect the amount and composition of the effluent from foundry melting furnaces. All organic materials in or on the scrap must eventually be burned to carbon dioxide and water, either in the preheating process, the melting process, or with afterburners in the melting-furnace off-gas system. Rust, dirt, and mud from the yard, along with nonferrous materials, mixed in with the scrap greatly increase the amount and, at the same time, reduce the average size of the particulates emitted from the melting furnace. Particulates, principally oxides that generally are submicrometer in size and are very difficult to collect, are derived mainly from rust, dirt, zinc, lead, magnesium, and aluminum in the scrap charge. Such fine particulates are more readily removed from the off-gases with fabric filters, once a floc has built up, than with a venturi scrubber.

Cupola Operating Conditions. In cupola melting, the amount of particulate in the emissions per ton of metal melted can be decreased by (1) reducing the amount of coke and limestone and the amount of dirt on return metal and scrap, (2) reducing the blast rate, and (3) using some auxiliary fuel, such as natural gas or fuel oil, in place of part of the coke. However, such variations in melting conditions cannot reduce the amount of particulate in the off-gases to such a level that cleaning will not be necessary, nor do they have a large effect on the volume of off-gases and, hence, the size of the cleaning device required.

If the top gases are removed below the charging door, the gas volume will be reduced appreciably and the size and cost of the gas-cleaning equipment required will be reduced correspondingly.

Arc-Furnace Operating Conditions. Arc furnaces are equipped with various types of hoods to collect the emissions therefrom. These hoods can be classified as full-roof hoods, side-draft hoods, canopy hoods, fourth-hole ventilation, and snorkel ventilation. In general, those hoods that are effective in collecting particulate and at the same time collect the least amount of excess air will result in less gas to be cleaned and, therefore, proportionally cheaper air-pollution equipment and lower cleaning costs. Fourth-hole and snorkel hoods best meet these requirements. Air may be introduced into the furnace, around the electrodes, to assist in burning carbon monoxide to carbon dioxide and, thus, achieve more complete combustion.

Induction-Furnace Melting. No combustion and only a limited amount of metal oxidation occurs in induction-furnace melting. The emissions generally are below the maximum emission rates permitted by state air-pollution codes, and generally no pollution-control equipment is required for these furnaces. A limited number of induction-melting furnaces are equipped with ring hoods. Freedom from excessive emissions has been partially responsible for the very rapid growth in the use of these furnaces as replacements for other types of melting units.

Reverberatory Furnaces. Reverberatory furnaces may be fired with powdered coal, natural gas, or fuel oil. Coal-fired furnaces require air-pollution-control equipment to collect the ash that is generated. Oil- or

gas-fired furnaces, which generally do not require any air-pollution-control equipment, have largely replaced coal-fired units. In any event, operation of reverberatory furnaces to produce iron probably will cease in the near future, because they are inefficient and highly wasteful of fuel.

Metal Treating, Pouring, Mold Cooling,
Shakeout, Cleaning, Sand Preparation,
Mixing and Handling, and Coremaking

Most in-plant foundry operations that create smoke, fume, and particulate must be properly hooded and exhausted to remove the contaminated gases from the foundry work area. Hoods should be constructed so as to permit the collection of the contaminated gases with minimum entrainment of excess air. The smaller the total volume of gases to be cleaned, the lower will be the cleaning-equipment cost and the operating cost.

Some metal oxide fumes normally are evolved when molten iron is tapped from the furnace into a pouring ladle. These fumes can be collected with fairly simple suction hoods. However, when the molten metal is inoculated with magnesium to make ductile iron, dense clouds of magnesium oxide fume often are produced. The process of treating molten iron with magnesium alloys to produce ductile iron is constantly being improved to increase the efficiency of magnesium recovery and thereby reduce the amount of magnesium oxide fumes produced. However, in those cases where a relatively small amount of smoke is produced, some provision still must be made to collect the fumes. These process improvements include:

- (1) The development of the "Inmold" process in which the magnesium alloy is added to a chamber in the mold cavity and the molten metal flows over the alloy during the pouring operation, dissolving the magnesium alloy as it passes through the chamber. This process is said to be smoke free.⁽⁸⁾
- (2) Development by International Nickel Company of an alloy that contains about 95 percent nickel and 5 percent magnesium that is dense enough to sink when added to molten iron. This treatment is said to be smoke free.

- (3) American Cast Iron Pipe Company's method of impregnating coke with magnesium metal. This material reacts very slowly and is said to be smoke free when it is plunged to the bottom of a ladle of the iron to be treated.
- (4) Immersing the magnesium alloy in the molten iron in the ladle by holding the alloy in a metal cup attached to a plunger in a dome-shaped ladle cover. The dome cover seals the top of the ladle, thus preventing almost all of the fumes from escaping during treatment. A small amount of fume may escape during plunging and when the cover is removed.
- (5) Placing the magnesium alloy in the bottom of the ladle, holding it down with scrap-metal punchings or molding sand, and pouring the iron over the alloy and its covering. If properly done, the magnesium reaction is delayed until the ladle is full, the reaction is slow, and no fumes escape.
- (6) Adding magnesium vapor through a porous refractory plug in the bottom of the ladle. This method is smoke free but is complicated.

The fume normally is drawn off with suction hoods, and the particulate is collected with fabric filters. The very fine size of the magnesium oxide particles requires good filtering equipment.

Some foundries must desulfurize the molten iron before it is suitable for conversion to ductile iron or low-sulfur gray irons. This operation creates considerable dust, and some sulfur dioxide is evolved. The desulfurizing operation normally is performed under a suction hood, often the same hood that is used to remove the magnesium oxide fume later.

The smoke produced during the pouring and cooling of sand molds is derived from the organic materials incorporated in the molds and cores. Organic materials distill off from the molds when they are heated by the hot metal poured into the molds, and the hot metal also vaporizes part of the water in the molding sand. The organic fume normally ignites shortly

after the mold is poured and continues to burn until the dilution of the organic fume with air and moisture and the lower temperatures make the gas noncombustible. Organic fumes, carbon monoxide, and some hydrogen, are given off immediately after pouring, before the gases issuing from the vents ignite, and, also, later in the cycle after the flame goes out. These fumes developed during the pouring and the cooling of the molds can be collected and disposed of with a collection-hood system. In the best system the molds are moved past the pouring station on a conveyor system. A suction hood collects the fumes where the molds are filled with molten metal, and the conveyor passes through a closed tunnel connected to a series of suction hoods where the castings cool and the fumes from the molds are drawn off. These fumes can be reacted in afterburners or burned in catalytic incinerators to destroy the carbon monoxide and organic fumes remaining therein; they then can be cleaned with a wet scrubber or a bag filter to remove the particulates. If the moisture is high and the temperature is low, a scrubber must be used, because the water will blind filter bags, or the gases must be heated above the dew point and then filtered. There is no efficient method for collecting the fume and gases emitted when small molds are poured in open areas of the foundry floor or when large castings are poured on the floor or in pits.

Control of these small amounts of carbon monoxide and organic fumes by combustion methods is very expensive, because large volumes of air must be heated to 704 C (1300 F) with afterburners or heated to about 260 C (500 F) to be reacted in catalytic-combustion units.

Most foundry operators have been working towards the reduction of organic-vapor evolution by using low-volatile sea-coal substitutes in the molding sand, rather than trying to remove the carbon monoxide and organic vapors from the air in the cooling tunnels. This system is reported to result in carbon monoxide levels in mold-cooling tunnels that are about the same as urban-street levels of carbon monoxide. (9)

The particulate in the gases from mold pouring and the cooling tunnels can best be collected with wet scrubbers. The very high moisture content of the air makes the use of baghouses difficult unless the gases are heated above the dew point.

The dust and fume from the shakeout of castings from the molds must be collected. The best system consists of suction hoods connected to essentially closed systems. This effluent is best cleaned along with the gases from the mold-cooling tunnel, since these are similar in character. The facilities for casting shakeout and for transportation of the hot, reclaimed sand to the cooling station or sand mixer must all be ventilated with suction hoods. The gases from these areas can be incinerated if excessive carbon monoxide and organic vapors are present, and they can be cleaned with a scrubber or baghouse. There is no economical way to collect the dust and fume from molds shaken out on the foundry floor itself. Inasmuch as the shakeout operation is very noisy, enclosed systems should be insulated so as to reduce the noise level in surrounding areas.

Dusts from casting cleaning and grinding result from dry-blast, grit- or shot-blasting, grinding, and chipping operations. Most of these dusts are normally collected with fabric-filter systems, and most grit-blasting units are connected to individual filtering systems. Coarse grits from some chipping and grinding operations may be collected with cyclone separators.

Dust from sand mixing and handling is best collected in fabric filters or scrubbers. Scrubbers normally are used if the dew point of the collected gases is high. The collection systems and pollution-control devices must be very efficient, because the fine silica dust present is detrimental to health.

Fumes from coremaking or core-baking ovens must be burned to remove the organic constituents and carbon monoxide. The fumes can be burned either with afterburners or catalytic-combustion systems. It is important to collect the fumes with a minimum of air dilution, because the combustion-treatment costs are high.

Performance of Commonly Used Emission-Control Devices

For economic reasons, large cupolas generally use high-energy scrubbers, medium-size cupolas use high-energy scrubbers or baghouses, and small cupolas and arc furnaces use baghouses to control the particulate emissions to acceptable levels. Generally, no pollution control is required for induction furnaces.⁽¹⁰⁾ High-energy scrubbers usually are operated at a

particulate efficiency of 95 percent, and baghouses (fabric filters) operate at an efficiency of 98 percent.⁽¹⁰⁾ With metallurgical cokes presently used for producing iron in the cupola, the sulfur dioxide emitted from the stack when uncontrolled usually is less than the maximum discharge limit permitted by most communities. However, of the approximately 40 percent of the sulfur charged that ends up in the stack gases, about 40 percent can be removed with a water scrubber if that type of equipment is used to control the particulate.⁽¹¹⁾ Electrostatic precipitators also operate at an efficiency of 98 percent⁽¹⁰⁾, but they are seldom used in foundries because of their high initial cost.

The best systems for controlling particulates are presented on page V-1 of Section V. Electric-furnace foundries commonly employ hoods to collect the effluent from the furnaces and other operations. The hoods may vary from completely enclosed furnace hoods, through canopy hoods, to roof hoods, or collection systems. The capture efficiency of these hoods in collecting effluents may vary from about 50 to 90 percent, depending upon the design and specific installation. The effluent gases collected are discharged to the control device where they are cleaned. Efficient equipment must be used if the contents of fine oxide particles and organic fumes in the effluent are to be reduced to a low level. The effluent gases that are not collected are discharged within the plant and are the responsibility of OSHA and not EPA.

Afterburners in the stack above the charging door are used to control carbon monoxide emissions from cupolas⁽¹⁰⁾, and afterburners or catalytic-combustion units are used to control carbon monoxide and organic-vapor fumes from metal-preheating or degreasing operations and from core-making and core baking. Although pollution-control equipment normally is not required for induction-melting furnaces, the fume produced during charging and pouring may be collected with a ventilation system and treated with a small filter system to remove particulate material. An afterburner may be required to incinerate the organic fumes from the scrap preheater. Considerable care is required in ventilating the coremaking and core-curing area in order to collect the organic vapors given off. Removal of the irritants in the fumes requires a direct-combustion or a catalytic-combustion system. The efficiency of these burners generally is taken to be 94 percent.⁽¹⁰⁾

The efficiency of the afterburner combustion will depend on the stack height above the afterburner; a minimum stack height of 25 to 30 feet above the burner is required for optimum results. Carbon monoxide generated in arc furnaces generally is controlled by introducing air into the furnace to burn the carbon monoxide. Afterburners can be used.⁽¹⁰⁾ Carbon monoxide from mold cooling or other foundry operations generally is not controlled.

High energy scrubbers are capable of reducing the particulate in the off gases to about 0.114 g/m^3 (0.05 grain/scf) for cupolas and 0.046 g/m^3 (0.02 grain/scf) for arc furnaces and induction furnaces.⁽¹²⁾ Fabric filters are capable of reducing the particulate in the off gases to about 0.023 g/m^3 (0.01 grain/scf) for cupola, arc, and induction furnaces.⁽¹²⁾ However, fabric-filter manufacturers will guarantee only 0.046 g/m^3 (0.02 grain/scf) in the cleaned gas.⁽¹³⁾ Therefore, this figure is used in computations for fabric filters in subsequent sections, rather than the figure of 0.023 g/m^3 (0.01 grain/scf).

Performance of the Best Systems to Control Emissions from Foundries

The average efficiency of high-energy scrubbers can be increased to about 99 percent by increasing the pressure drop through the system. The average efficiency of baghouses can be increased to about 99 percent by lowering the gas velocity through the bags (increasing the number of bags) and installing a second, backup baghouse filter to collect accidental dust spills while emptying the bags or when bags become torn and leak. However, adding a backup baghouse-filter collection system would be very expensive.

The average efficiency is based on particulate that contains only small amounts of particles less than 5 micrometers (about 197 microinches) in diameter, especially particles less than 1 micrometer (39 microinches), since neither system can efficiently collect small particles. Most foundries probably could install particulate-collection systems that were 99 percent efficient in collecting all particles over 5 micrometers (197 microinches) in size. Table III-4 (page III-33) shows that cupola emissions frequently contain 25 percent or more of particles smaller than

5 micrometers (197 microinches); in those cases, the overall efficiency of either scrubbers or baghouses would be relatively low. No better system is available.

Appreciable improvement in the efficiency of afterburners or catalytic-combustion units would be very difficult. The carbon monoxide in the off gases could be reduced to below 0.1 percent by volume by subjecting them to the direct flame of a suitable afterburner for at least 1.0 second at 816 C (1500 F). The lowest levels of carbon monoxide in the effluent gases could be obtained by placing efficient afterburners, fabric filters, and catalytic-combustion units in series in the gas stream. The afterburner, placed first in the system, would remove most of the carbon monoxide and organic fumes (organic fumes would blind the baghouse and high carbon monoxide concentrations can cause explosions in the baghouse). The baghouse would remove the particulate (particulate damages the catalytic elements by abrasion). The catalytic-combustion unit would reduce the carbon monoxide and oxidizable organic fumes remaining in the gas stream to low levels. Such a system would be very expensive.

Coarse-particulate emissions are the easiest to collect, and very fine particles, less than 5 micrometers (0.00020 inch) in diameter, are more difficult to collect. Unfortunately, these fine particles are most objectionable, because they are visible as dust or smoke and they are most damaging to health.

Some gaseous emissions may be very difficult to control. However, carbon monoxide can be controlled by installing properly designed afterburners in stacks and other gas-take-off systems. Most of the existing regulations that limit carbon monoxide concentration at the point of discharge from the stack are not difficult to meet. On the other hand, ground-level standards are more restrictive.

Particulates and carbon monoxide are the only foundry emissions commonly restricted in the regulations of most states. Other gaseous emissions that should be considered are sulfur compounds, nitrogen compounds, hydrocarbons, and complex chloride or fluoride compounds.

If all cupola and arc-furnace melting units were converted to induction-melting units, almost no carbon monoxide would be emitted, and the particulate emitted would meet most state codes without treatment of

the off gases (excluding any necessary preheating of the scrap, which may emit considerable pollution). If fabric filters were required (required in Los Angeles County), the off gases from an induction furnace (estimated to be 6,000 cubic feet per ton of iron melted) would require one-half the fabric-filter area that an arc furnace would, and one-tenth the fabric-filter area required by a cupola. No afterburners for carbon monoxide would be required with the induction-melting furnace.

References

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- (5) Foundry Air Pollution Control Manual, 2nd Edition, American Foundrymen's Society, Des Plaines, Illinois (1967), p 35.
- (6) Foundry Air Pollution Control Manual, 2nd Edition, American Foundrymen's Society, Des Plaines, Illinois (1967), p 58.
- (7) Foundry Air Pollution Control Manual, 2nd Edition, American Foundrymen's Society, Des Plaines, Illinois (1967), p 50.
- (8) Dunks, C. M., and McCaulay, J. L., "Process for the Manufacture of Ductile Iron", U. S. Patent 3,703,922 (November 28, 1972).
- (9) Private communication on April 10, 1974, with Mr. William B. Huelsen, Editor of Environmental Control, Modern Casting, published by American Foundrymen's Society, Des Plaines, Illinois.
- (10) Battelle, Columbus Laboratories, "The Cost of Clean Air, 1974", Final Report to The United States Environmental Protection Agency, Contract No. 68-01-1538 (Task 1 and Task 2), by Battelle, Columbus Laboratories, Columbus, Ohio (January 15, 1974).
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- (12) "Air Pollution Aspects of the Iron Foundry Industry", by A. T. Kearney and Company, Inc., Chicago, Illinois, Contract CPA 22-69-106, to Division of Air Quality and Emission Data, U. S. Environmental Protection Agency, PB 204-712 (February, 1971).
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SECTION V

ENVIRONMENTAL EFFECTS OF VARIOUS
AIR-POLLUTION-CONTROL SYSTEMS

Air-Pollution Emission When Using the
Best Systems of Control

Iron-Melting Air-Pollution-Control Equipment

Iron-melting equipment commonly used in gray and ductile iron foundries consists of cupola furnaces, arc furnaces, and induction furnaces. The emissions from these furnaces consist almost entirely of particulate and carbon monoxide. Cupola furnaces produce the most particulate and carbon monoxide, arc furnaces produce an intermediate amount of particulate and carbon monoxide, and induction furnaces produce the least particulate and almost no carbon monoxide.

Best Systems for Controlling Particulate Emitted from Cupola, Arc, and Induction Furnaces. The best cleaning devices for removing particulate from furnace off gases are capable of reducing the particulate in the off gases to approximately the following levels:

| <u>Furnace Type</u> | <u>Particulate Level in Cleaned Off Gases, g/m³ (grain/scf*)</u> | |
|-------------------------|---------------------------------------------------------------------------------|---------------------------------------------|
| | <u>High Energy Scrubber⁽¹⁾**</u> | <u>Fabric Filter^(1,2)***</u> |
| Cupola | 0.114 (0.05) | 0.046 (0.02) |
| Arc | 0.046 (0.02) | 0.046 (0.02) |
| Induction | 0.046 (0.02) | 0.046 (0.02) |

* scf = standard cubic feet, that is, the volume of gas measured under standard conditions (70 F and 29.92 inches of mercury) expressed in cubic feet. In this report, gas volumes expressed as cubic meters will imply standard cubic meters, but at 70 F and 29.92 inches of mercury.

** References are listed at the end of the section.

*** Although fabric filters are capable of reducing the particulate in the off gases to about 0.023 g/m³ (0.01 grain/scf) for cupola, arc, and induction furnaces,⁽¹⁾ the manufacturers will guarantee only 0.046 g/m³ (0.02 grain/scf) in the cleaned gas⁽²⁾. Therefore, this latter figure is used in subsequent computations for fabric filters, rather than the figure of 0.023 g/m³ (0.01 grain/scf).

According to Reference 3, the off gases from a cupola might be expected to average 814.5 m³ (28,765 scf) of undiluted top gas per ton of iron melted, and this top gas is diluted with about an equal amount of air (introduced during the combustion of the carbon monoxide as well as from the charging door), so that 1629 m³ (57,530 scf) of furnace off gas would have to be cleaned per ton of iron melted.

The most efficient ventilation system for arc furnaces is the snorkel, or the fourth-hole, fume-collection and ventilation system. This system will collect most of the fumes and particulate with a minimum ventilation rate. Generally, with this system a ventilation rate of 6.243 m³/min for each kkg/hr (200 scfm for each ton/hr) of furnace capacity is adequate. (4) Therefore, 374.6 m³ of ventilation air per kilokilogram of iron processed (12,000 scf per ton of iron) is required. Scrubbers seldom are used on arc furnaces.

Either coreless or channel induction furnaces emit approximately 0.75 kilogram of particulate for each kilokilogram of iron melted (1.5 lb/ton) and are rarely provided with emission-control equipment. A ventilation rate of 3.121 m³/min for each kkg/hr (100 scfm for each ton/hr) of furnace capacity would be expected to be completely adequate. Therefore, 187.3 m³ of air for ventilation for each kkg of iron processed (6000 scf/ton) would be required.

The particulates discharged to the atmosphere after cleaning the furnace off gases, including ventilation air, with the best pollution-control system are summarized in the following tabulation; the particulate contents discharged into the air before and after treatment and the volumes of air treated are based on melting either 1 kilokilogram or 1 short ton of iron:

| Type of Melting Furnace | Volume of Air Discharged, m ³ /kkg of iron (scf/ton of iron) | | Particulate Content of Air Discharged, kg/kkg of iron (lb/short ton of iron) | | | |
|-------------------------|-------------------------------------------------------------------------|----------|------------------------------------------------------------------------------|----------------------|-----------------|---------------|
| | | | Before Treatment (a) | High-Energy Scrubber | | Fabric Filter |
| Cupola, lined | 1795 | (57,530) | 9.5 (19.0) | 0.205 (0.41) | 0.082 (0.164) | |
| Cupola, unlined | 1795 | (57,530) | 20.2 (40.5) | 0.205 (0.41) | 0.082 (0.164) | |
| Arc | 374.6 | (12,000) | 6.9 (13.8) | 0.017 (0.034) | 0.017 (0.034) | |
| Induction | 187.3 | (6,000) | 0.75 (1.5) | 0.0086 (0.0171) | 0.0086 (0.0171) | |

(a) Reference 1.

No other type of melting equipment was considered for the best emission-control system, because all melting units would require good pollution-control equipment to achieve the lowest emission levels, and other types of furnaces with pollution-control equipment would not be economical. Also, other types of pollution-control equipment were not considered, because no other known type of equipment can meet these low emission levels.

Best System for Controlling Carbon Monoxide Emitted from Cupola, Arc, or Induction Furnaces. The raw top gases from a cupola typically contain 10 to 20 percent carbon monoxide before being diluted or processed through an afterburner.⁽¹⁾ The off gases from some special cupola furnaces used in making ductile iron may contain as much as 24 to 28 percent carbon monoxide.⁽¹⁾

Typical afterburner installations would be expected to reduce the carbon monoxide content of the gases emitted from the stack to 2 to 4 percent.⁽⁵⁾ Special multiple burners that burn dirty top gases for recuperative furnaces can reduce the carbon monoxide content to below 1.0 percent.⁽⁶⁾ A special, highly efficient afterburner has been developed to remove carbon monoxide from cupola top gases after they have been cleaned with a high-energy scrubber; it is capable of reducing the carbon monoxide to less than 0.1 percent.⁽⁵⁾

Typical catalytic afterburners will reduce the carbon monoxide content to less than 0.5 percent.⁽⁵⁾ By carefully controlling the gas flow and gas temperature, catalytic afterburners can reduce the carbon monoxide content of gases to less than 0.1 percent. However, waste gases must be cleaned of particulate before they contact the catalyst plates in catalytic burners, because the particulate either will erode the plates rapidly and make it necessary to replace catalyst plates at very frequent intervals or will coat the plates and reduce the catalyst efficiency.

The best emission-control system for controlling carbon monoxide in cupola off gases would use an afterburner of optimum design operated in an optimum manner. Combustion chambers and burners of optimum design operated so as to subject the cupola off gases to the direct flame at 704 C

(1300 F) for at least 1.0 second could reduce the carbon monoxide content in the gases to 0.2 percent. If the operating temperature were increased to 816 C (1500 F) or above and the residence time were a minimum of 1.0 second, then the carbon monoxide content of the gases could be reduced to 0.1 percent. An equally effective alternate system would consist of an afterburner in the stack to reduce the carbon monoxide to 2 to 4 percent in the dirty gas, thus preventing explosions in subsequent cleaning operations, followed by cleaning the dirty gases, either with a high-energy scrubber or a fabric filter, and then further reducing the carbon monoxide content of the cleaned gas to less than 0.1 percent with a special flame afterburner or a catalytic afterburner.

Consumption of the graphite electrodes that deliver the electricity and draw the arc constitutes the source of carbon monoxide emissions from arc-melting furnaces. The consumption of electrodes in arc melting is 4.5 to 5.5 kg/kg (9 to 11 lb/ton⁽¹⁾) of iron melted, which produces about 13.6 kilograms (30 pounds) of carbon monoxide and carbon dioxide. Typical off gases from arc furnaces contain 4 percent carbon monoxide. Normally the carbon monoxide is discharged into the atmosphere without treatment. However, the best control of carbon monoxide emission would be the installation of afterburners in the dirty-gas line, with the burners adjusted to burn the carbon monoxide with an excess of air and set so as to heat the gas to at least 816 C (1500 F) for at least 1.0 second. This procedure should reduce the carbon monoxide in the exhaust gases to less than 0.1 percent. Catalytic-combustion units of similar efficiency could be installed in the exhaust-gas line after the particulate had been filtered out. However, the use of afterburners or catalytic combustors for this application might not be economically feasible. Very little carbon monoxide is emitted from induction-melting furnaces.

Tapping the Furnace and Treating the Iron With Magnesium to Make Ductile Iron

The fumes produced during tapping, desulfurizing, and magnesium treatment normally are collected with suction-type ventilation hoods, and the gases are cleaned with a fabric-filter bag-house system. The bags are normally Orlon or Dacron, because the off gases are hot, up to about 121 C

(250 F). This cleaning system normally is separate from the system used to control emission during the melting operation and is operated only when tapping or treating the metal.

The cleaned gas should contain less than 0.046 g/m^3 (0.02 grain/scf) of particulate, and no carbon monoxide should be present. Some sulfur could be evolved from the high-sulfur slags produced during the desulfurization treatment. However, carbon monoxide and sulfur compounds normally are not considered to be a problem in these off gases.

Pouring and Cooling of Molds and Shakeout of Castings

The particulate-laden gases drawn off in the mold-pouring, mold-cooling, and mold-shakeout operations normally are cleaned with fabric filters. To prevent blinding of the filters, dirty gases from the shakeout operation generally are heated to above the dew point with burners, positioned in the gas-exhaust line, before the gases are filtered.⁽²⁾ Sometimes it is also necessary to heat the gases from the mold-cooling line separately before they are filtered, if the moisture content of the dirty gas is high.⁽²⁾ These gases may be mixed or filtered separately. Fabric filters are capable of reducing the particulate to below 0.046 g/m^3 (0.02 grain/scf).

Attempts have been made to use high-energy scrubbers to clean the off gases from mold-cooling and mold-shakeout operations. The objective has been to avoid the necessity for maintaining the gases above the dew point, which is a requirement when fabric filters are used. However, these gases contain large amounts of oils and organic vapors from the breakdown of molding-sand additives and core binders, and these oils tend to pass through high-energy scrubbers but are effectively trapped with fabric filters.⁽²⁾

The carbon monoxide and organic-vapor content of these gases after cleaning to remove particulates generally is considered to be low enough that controls are unnecessary. If controls were necessary, the organic vapors could be burned to carbon dioxide and water vapor, and the total carbon

monoxide content could be reduced below 0.1 percent by installing after burners in the dirty-gas lines that are capable of heating the gas in a direct flame with an excess of air to at least 816 C (1500 F) for a minimum of 1.0 second. Alternatively, the cleaned gas could be heated to above 260 C (500 F) and treated with suitable catalytic-combustion units to reduce the carbon monoxide below 0.1 percent. Control of these small amounts of carbon monoxide and organic fumes by combustion methods is very expensive, because large volumes of air must be heated to the appropriate reaction temperature.

Sand Transportation and Mixing, and Casting Cleaning and Finishing

Sand transportation and mixing can produce some fine silica dusts that must be controlled to very low levels. The threshold-limit value in the workroom environment is 0.1 milligram of respirable quartz per m^3 , or 0.3 milligram of total quartz dust per m^3 *. Sand mixing also can create considerable dust from dry clays and organic mold additives. These dusts normally are collected in closed transportation tunnels or tubes and closed or hooded sand mixers with suction ventilation. The dirty gases normally are cleaned with fabric filters to at least 0.046 g/m^3 (0.02 grain/scf) before they are discharged.

Dust from the cleaning (grit or shot blasting) and grinding of castings normally is collected with suction hoods provided at the site of each operation. Blasting cabinets are totally enclosed and equipped with clean-air intakes and suction exhausts. The dirty air may be cleaned with high-efficiency cyclone cleaners if most of the particles are of large diameter [greater than 10 micrometers, μm (0.00040 inch)]. The gases should be cleaned to at least 0.046 gram of particulate per m^3 of air (0.02 grain/scf).

*Threshold-limit values adopted by OSHA. "TLV's Threshold Limit Values for Substance in Workroom Air Adopted by ACGIH for 1972", American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (1972), p 30.

Coremaking

All core systems produce some odors and organic vapors during the mixing and coremaking operations and considerably more organic vapor and odor if they are cured with heat. However, only minor amounts of particulate are emitted during the coremaking and core-curing processes. The organic vapors from coremaking and core baking should be collected with suitable ventilation systems and burned with an afterburner operating at at least 816 C (1500 F) for at least 1.0 second, or burned in a suitable catalytic-combustion unit. These control systems are capable of reducing the organic vapor and carbon monoxide content to less than 0.1 percent.

The organic materials that remain after the cores are cured are mostly evolved during the pouring, mold-cooling, and mold-shakeout operations. Much of the combustible gas is burned at the mold vents shortly after the castings are poured.

Estimate of the Reduction in the Emission When Using the Above Best Systems Over the Average State Emission Requirements

A list of the 1473 gray and ductile iron foundries in the United States contained in the Penton foundry tabulation is given in Subtask F. The combined melting capacity of these foundries is as follows:

| <u>Type of Melting Furnace</u> | <u>Capacity, kg/hr (short tons/hr)</u> | | <u>Percent of Total Capacity</u> |
|----------------------------------------|--------------------------------------------|-----------------|--------------------------------------|
| Cupola | 13,174 | (14,522) | 78.3 |
| Arc | 1,381 | (1,522) | 8.2 |
| Induction | <u>2,278</u> | <u>(2,511)</u> | <u>13.5</u> |
| Total | 16,833 | (18,555) | 100.0 . |

The total production of gray, ductile, and malleable iron castings for 1973 was 16.43 million kilokilograms (18.12 million short tons). It is estimated that the yield of good castings was 60 percent. Therefore, 27.40 million kilokilograms ($18.12/0.60 = 30.20$ million short tons) of iron was melted in the various kinds of melting equipment used by the industry, broken down approximately as follows:

| Type of Melting Furnace | Percent Melted | Quantity of Iron Melted Per Year, million kkg (million short tons) | |
|-------------------------|----------------|--------------------------------------------------------------------|----------------|
| | | | |
| Cupola | 78.3 | 21.45 | (23.65) |
| Arc | 8.2 | 2.25 | (2.48) |
| Induction | <u>13.5</u> | <u>3.70</u> | <u>(4.07)</u> |
| Total | 100.0 | 27.40 | (30.20) . |

Total Particulate Emission from Melting Operations With Best and Average Systems

With no emission controls on foundry melting furnaces operating in 1973, the emission of particulate for the year would have been 172.5 million kilograms (190.2 thousand short tons) and the emission of carbon monoxide would have been 1454 million kilograms (1603 thousand short tons). Assuming that all melting units are equipped with pollution-control equipment that is 95 percent effective in controlling both particulate and carbon monoxide, then the particulate emitted is reduced to 8.63 million kilograms (9.51 thousand short tons), and the carbon monoxide emitted is reduced to 72.7 million kilograms (80.2 thousand short tons) per year.

The best emission-control system for particulate is capable of reducing the particulate in the gases emitted to 0.046 g/m³ (0.02 grain/scf). (See the previous part of this section entitled "Best System for Controlling Particulate Emitted from Cupola, Arc, and Induction Furnaces".) Based on the above production figures for 1973, the amount of particulate that would be emitted in the melting-furnace off gases of the United States iron-foundry industry, if all foundry melting units were equipped with the best particulate-control system, was calculated to be as follows:

| Type of Melting Unit | Quantity of Iron Melted Per Year, million kkg (million short tons) | | Unit Amount of Particulate Emitted, kg/kkg (lb/ton) | Total Amount of Particulate Emitted Per Year, kkg (short tons) |
|----------------------|--------------------------------------------------------------------|----------------|-----------------------------------------------------|----------------------------------------------------------------|
| | | | | |
| Cupola | 21.45 | (23.65) | 0.082 (0.164) | 1759 (1939) |
| Arc | 2.25 | (2.48) | 0.017 (0.034) | 38 (42) . |
| Induction | <u>3.70</u> | <u>(4.07)</u> | 0.0086 (0.0171) | <u>32 (35)</u> |
| Total | 27.40 | (30.20) | | 1829 (2016) . |

The amount of particulate that would be emitted by the melting furnaces of the United States iron-foundry industry if all of the foundries met a typical state code was calculated as follows:

The 1496 gray, ductile, and malleable iron foundries in the United States have an average melting capacity of 11.8 kilokilograms (13 short tons) per hour. The average state emission code will permit the emission of 8.71 kilograms (19.2 pounds) of particulate per hour at a melting rate or process rate of 9.07 kilokilograms (10 short tons) per hour, or 0.96 kilogram of particulate per kilokilogram of iron (1.92 lb/ton) melted at that melting rate. Therefore, the 27.40 million kilokilograms (30.20 million short tons) of iron melted in 1973 would have resulted in the emission of 26,304 kilokilograms (28,992 short tons) of particulate if they had all just met the average state code. (These results were obtained as follows: 30.20 million short tons x 1.92 pounds of particulate per ton equals 57,984,000 pounds of particulate, or 28,992 tons.)

Therefore, the calculated total particulate that would be emitted in the cleaned furnace off gases if all foundries were equipped with the best air-pollution-control equipment or if they were equipped with pollution controls that would just meet an average state code is as follows:

| | Total Particulate Emitted in the United States per Year, kkg (tons) |
|--------------------|---------------------------------------------------------------------------|
| | ----- |
| Best system | 1,829 (2,016) |
| Average state code | 26,304 (28,992) . |

Total Carbon Monoxide Emission from Melting Operations
with Best System and Average State Emission Code

The best system for removing carbon monoxide from melting-furnace off gases will reduce the carbon monoxide to 0.1 percent by volume, or less. This treatment consists of burning the off gases in the direct flame of an after-burner for at least 1.0 second at a temperature of at least 816 C (1500 F).

Typical state codes specify that the off gases be burned in the direct flame of an afterburner for at least 0.3 second at 704 C (1300 F). This procedure will reduce the carbon monoxide in the off gases to 0.5 percent by volume, or less. The amounts of carbon monoxide that would be emitted per kilogram (or short ton) of iron melted, after treatment, were calculated to be as follows:

| Type of Melting Furnace | Volume of Clean Air Discharged, m ³ /kg of iron (scf/ton of iron) | Carbon Monoxide Discharged After Treatment | |
|-------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| | | Best Treatment (0.1 Percent), m ³ /kg of iron (scf/ton of iron) | Typical State Code (0.5 Percent), m ³ /kg of iron (scf/ton of iron) |
| Cupola | 1795 (57,530) | 1.79 (57.5) | 8.95 (287.5) |
| Arc | 374.6(12,000) | 0.37 (12) | 1.85 (60) |
| Induction | 187.3(6,000) | 0.19 (6) | 0.95 (30) . |

The total amount of carbon monoxide that would be discharged into the atmosphere per year if all foundry melting units were equipped with the best control system or were equipped to meet the average state code, was calculated as follows:

| Type of Melting Unit | Quantity of Iron Melted Per Year, million kkg (million short tons) | Amount of Carbon Monoxide Emitted Per Year With Treatment | |
|----------------------|--------------------------------------------------------------------|-----------------------------------------------------------|----------------------------------------------------------|
| | | Best System, million m ³ (million scf) | Average State Code, million m ³ (million scf) |
| Cupola | 21.45 (23.65) | 38.4 (1360) | 192.0 (6799) |
| Arc | 2.25 (2.48) | 0.8 (30) | 4.2 (149) |
| Induction | <u>3.70</u> (<u>4.07</u>) | <u>0.7</u> (<u>24</u>) | <u>3.5</u> (<u>122</u>) |
| Total | 27.40 (30.20) | 39.9 (1414) | 199.7 (7070) . |

Therefore, the calculated maximum total amount of carbon monoxide that would be emitted if all existing U. S. foundry melting equipment were equipped with the best air-pollution-control equipment or were equipped with pollution controls that would just meet an average state code is as follows:

| <u>Treatment Method</u> | <u>Total Carbon Monoxide Emitted in the United States Per Year, million m³ (million scf)</u> |
|-------------------------|---------------------------------------------------------------------------------------------------------|
| Best system | 39.9 (1414) |
| Average state code | 199.7 (7070) . |

Possible Benefits to Health and Welfare Due to the
Decrease in Emission from the Controlled Plants

The undiluted off gases as emitted from the stack could be expected to have the following particulate and carbon monoxide contents after treatment:

| <u>Treatment Method</u> | <u>Content, mg/m³</u> | |
|-------------------------|----------------------------------|------------------------|
| | <u>Particulate</u> | <u>Carbon Monoxide</u> |
| Best system | 46 | 1250 |
| Average state code | 538 | 6250 . |

The threshold-limit values (TLV) set by the American Conference of Government Industrial Hygienists (ACGIH) for workroom air are 10 mg/m³ for particulate and 55 mg/m³ for carbon monoxide. These values are far lower than the concentrations in the off gases from even the best cleaning system.

If the undiluted off gases from the baghouse of the best system were discharged into an enclosed work area, the carbon monoxide concentration could far exceed the threshold-limit value for workroom air of 55 mg/m³, and the concentration of nuisance particulates could exceed the threshold-limit value of 10 mg/m³ considerably. The cleaned off gases (best system) would need to be diluted about 1 to 5 to meet the TLV for particulate in workroom atmospheres and 1 to 23 to meet the TLV for carbon monoxide. The average state code permits about 12 times as much particulate to be discharged as is discharged by the best system and about 5 times more carbon monoxide. Therefore, off gases that just meet the average state code would need to be diluted 1 to 75 for the particulate content to be reduced to the limit suitable for workroom atmospheres. Therefore, the cleaned off gases should be discharged through tall stacks above the population level. If the off gases are exhausted through suitable, tall stacks, dilution of 1 to 100 would be expected before the off gases and the contained pollutants reach street level.⁽⁷⁾ At this dilution, the ambient concentration of the pollutants would be as follows (with EPA primary and secondary air-quality standards given for comparison):

| | Content, mg/m ³ | | | |
|-----------------------------------|----------------------------|------------------------|-----------------------|-----------------------|
| | <u>Particulate</u> | <u>Carbon Monoxide</u> | | |
| Best control system | 0.46 | 12.5 | | |
| Average state code ^(a) | 5.4 | 62.5 | | |
| | <u>Annual Mean</u> | <u>24-Hour Average</u> | <u>8-Hour Average</u> | <u>1-Hour Average</u> |
| EPA Air-Quality Standards | | | | |
| Primary standard | 0.075 _{mg} | 0.260 | 10 | 40 |
| Secondary standard | 0.060 | 0.150 | 10 | 40 |

(a) Undiluted off gases that just meet the average state code would have the indicated composition after being diluted 1 to 100.

Even after dilution of 1 to 100 by means of a tall stack, the emission from the best control system does not meet the EPA primary air-quality standards for either particulate or carbon monoxide, based on the annual mean allowable concentration or the 8-hour average, respectively. Thus, the reduction of particulate or carbon monoxide in the cleaned off gases from the level necessary to meet the average state code to the lowest level possible by known technology would be expected to have considerable additional benefit to health or welfare, provided that the cleaned gases are exhausted from suitable stacks.

Impact on Potential Water Pollution and
Solid-Waste Disposal When Employing
the Best Control System

The best system for reducing the particulate content of the off gases to minimum levels for foundry melting operations is a baghouse, that is, an enclosed facility comprising a group of fabric filters in the shape of vertically positioned, cylindrical bags, along with the necessary controls and dust-removal equipment.

The best system for controlling carbon monoxide in the off gases is to burn the carbon monoxide with an excess of air, using afterburners operating at a minimum temperature of 816 C (1500 F), the residence time being at least 1.0 second.

No water is used with the afterburners. However, water may be used to cool the stack gases and extinguish sparks before the gases enter the baghouse. If the cooling water is injected directly into the gas stream, the amount of water used must be controlled so that it vaporizes entirely (see page IV-7); if it is applied externally to the take-off ducts, it would not be polluted because it would be equipment-cooling water. Thus, with either method of cooling, water pollution is not a problem.

High-energy scrubbers are not capable of meeting the particulate concentration that can be achieved with the best system of emission control, that is 0.046 g/m^3 (0.02 grain/scf), for the off gases of cupolas, and they seldom are used for arc furnaces. Thus, usually there is no problem of water pollution from this source. If scrubbers are used, the water is recirculated with a settling pond, and no water is discharged.

The particulates removed from the off gases from foundry melting furnaces must be disposed of in some manner. Dry dusts from baghouse filters may be collected in paper bags and sealed or collected in other sealed containers and disposed of in land-fills or at similar sites. The containers must be covered with fill dirt before leaks occur so as to prevent polluting the atmosphere in the dump area with dust. The dry particulates may be mixed with water to suppress dusting, and then they can be disposed of in land-fills. Again, the resulting muds must be covered with fill dirt before they start to dry and emit dust at the disposal site. Sometimes the damp dusts are pelletized before being disposed of in land-fills.

Particulates removed with high-energy scrubbers generally are contained in a settling pond, and the scrubbing water is recirculated. The sludge in the ponds must be kept damp to prevent dust pollution in the area until the pond is about full of sludge. Abandoned settling ponds must be covered with fill dirt to prevent pollution in the area. Also, settling ponds may be cleaned and the wet sludge disposed of in land-fills where it can be covered with fill dirt.

Disposal of the extra dry waste that results from the best air-pollution-control system, in contrast with systems that just meet average state codes, is not expected to be a problem. The additional dry waste would represent about 4 to 5 percent of the total dry waste collected with the best air-pollution-control system.

Increase in Pollutant Emissions from the Power
Sources that Provide the Energy for the
Best Emission-Control System

The best system for reducing particulate in foundry-melting-equipment off gases to the lowest possible level entails fabric filters used with the proper ratio of the area of the filters to the flow of the gases to be cleaned. The ratio should be at least 0.093 m^2 (1.0 ft^2) of fabric filter to $0.057 \text{ m}^3/\text{min}$ (2.0 cfm) of raw gas to be cleaned at the temperature that it enters the filters. This ratio insures that the filtering system can reduce the particulate load to no more than $0.046 \text{ g}/\text{m}^3$ ($0.02 \text{ grain}/\text{scf}$)⁽²⁾ in the cleaned gases. Of course, to do this consistently requires that the system always be properly maintained. Most present fabric-filter systems that were installed to treat foundry-melting-equipment off gases and that were designed to meet average-state-code levels of particulate emission also will meet the best-emission-control levels if they were installed properly and are maintained properly. Therefore, no increase in electrical power would be needed for reducing particulate to the lowest possible level with such existing systems. Also, increasing the area of the bags above that indicated by the above ratio, if necessary to obtain higher efficiency, would not increase the power required to force the raw gases through the bags. Therefore, no increase in electrical power requirements are anticipated if the ratio of filter area to raw-gas volume is increased above the ratio given above. However, typical high-energy scrubbers will not provide the best control of particulate emission. Baghouses use less electrical power than do scrubbers for treating a given off-gas flow rate, so switching from scrubbers to baghouses will not increase pollution associated with power generation.

Reducing the carbon monoxide in cupola off gases to the minimum level, as compared with the average-state-code level, requires an increase in the afterburner-combustion-temperature level of the off gases from 704 C (1300 F) to 816 C (1500 F). This increased temperature will increase the demand for burner fuel but will not entail an increase in electrical power. Under the most adverse conditions, an afterburner would require an input of 116 million joules per hour per kilokilogram of iron melted ($100,000 \text{ Btu}$ per hour per ton of metal melted) to heat the off gases to 816 C (1500 F) for 1.0 second.⁽¹¹⁾ If natural gas at a cost of $\$0.80$ per million Btu were

used as a fuel, the total fuel cost of the afterburner under the most adverse conditions would be about \$0.80 per ton of iron melted, or \$0.088 per kilokilogram. The fuel required to heat the off gases from 704 C (1300 F) for at least 0.3 second to 816 C (1500 F) for 1.0 second would be appreciably less. Thus, the difference between the cost of fuel for meeting most state codes and the cost of meeting a specified maximum carbon monoxide content in the exit gases of 0.1 percent by volume would be low.

Reducing the Emission from Iron-Foundry Melting
Units by Changing the Melting Equipment

The main pollutants from iron-foundry melting units are particulates and carbon monoxide. Cupolas emit the most air pollutants, and induction-melting units emit the least. Typical emissions from various foundry melting units are as follows:

| Melting Furnace | Capacity, thousand kkg/hr (thousand tons/hr) | Pollutants Emitted Per Ton of Iron Melted (Raw Off Gases Before Cleaning) | |
|--------------------|----------------------------------------------------|------------------------------------------------------------------------------|-------------------------------------------------------|
| | | Particulate, kg/kkg (lb/ton) | Carbon Monoxide, m ³ (ft ³) |
| Cupola | 13.17 (14.52) | 15 (30) ^(a) | 130 (4,600) ^(b) |
| Arc | 1.38 (1.52) | 6.9 (13.8) | 13.6 (480) ^(c) |
| Induction | 2.28 (2.51) | 0.8 (1.5) | 0 (0) |

- (a) Average of 19 lb/ton for lined cupolas and 40.5 lb/ton for unlined cupolas.
- (b) Cupolas average 57,530 scf of undiluted top gas per ton of iron melted. The top gas contains an average of 16 percent CO, but half of the CO will be burned in the stack (8 percent of 57,530 = 4,600 ft³).
- (c) Arc furnaces average about 12,000 ft³ of off gas per ton of iron melted, and the off gas averages 4 percent CO (4% of 12,000 = 480 ft³).

If all cupola and arc-furnace melting units were converted to induction-melting units, almost no carbon monoxide would be emitted, and the particulate emitted would meet most state codes without treatment of the off gases (excluding any necessary preheating of the scrap, which may emit considerable pollution). If fabric filters were required (required in Los Angeles County), the off gases from an induction furnace (estimated

to be 6,000 cubic feet per ton of iron melted) would require one-half the fabric-filter area that an arc furnace would, and one-tenth the fabric-filter area required by a cupola. No afterburners would be required with the induction-melting furnace.

An induction furnace requires about 2,381 megajoules of electrical energy per kilokilogram of iron melted (about 600 kWh/ton⁽⁸⁾). Of this total energy requirement, about 1984 MJ/kg (500 kWh/ton) is for melting and 397 MJ/kg (100 kWh/ton) is for holding. The 21.45 million kilokilograms (23.65 million short tons) of cupola iron melted per year would require 5.11×10^{10} megajoules (600 kWh/ton \times 23.65 million tons, or 1.42×10^7 megawatt-hours) of electrical energy per year. The iron now melted in arc furnaces could be melted in induction furnaces with about the same amount of electrical energy that is required with arc furnaces. The amount of pollutants that would be emitted in the generation of 5.11×10^{10} megajoules (1.42×10^7 megawatt-hours) of electrical energy was calculated as follows:

Assumptions

kg coal/MJ
(1b coal/kWh)

Average coal consumption = 0.144 kg/MJ
(1.14 lb/kWh⁽⁹⁾)

Average with transmission losses = 0.155 kilograms of coal per megajoule delivered (1.23 pounds of coal per kilowatt-hour delivered⁽⁹⁾)

Coal contains 1.0 to 3.0 percent sulfur; average = 2.0 percent

1 kilokilogram of coal would produce 20 kilograms of sulfur or 40 kilograms of SO₂ (1 ton of coal would produce 2,000 \times 0.020 = 40 pounds of sulfur, or $40 \times \frac{32+32}{32} = 80$ pounds of SO₂)

Particulate/MJ (kWh)

Coal contains 12 percent ash
The ash consists of 80 percent flyash
90 percent of the flyash is collected by electrostatic precipitation

The amount of ash emitted is 9.6 kilograms per kilokilogram of coal (2,000 \times 0.12 \times 0.80 \times 0.10 = 19.2 lb/ton).

The 5.11×10^{10} megajoules (1.42×10^7 MWh) would require 7.92×10^6 kilokilograms (1.42×10^{10} kWh \times 1.23 lb coal/kWh \div 2000 = 8.75×10^6 short

tons) of coal per year. This amount of coal burned in industrial power plants would produce the following amount of air pollution per unit weight of coal burned:

| Units | Unit Weight of Pollutants | | | | |
|----------------|----------------------------|-------------------------------|--------------------|--------------------|-------------------|
| | Particulate ^(a) | Sulfur Dioxide ^(b) | Carbon Monoxide | Hydrocarbons | Nitrogen Oxide |
| kg/kkg of coal | 9.6 | 40 | 0.5 | 0.15 | 9 |
| lb/ton of coal | 19.2 | 80 ^(b) | 1.0 ^(c) | 0.3 ^(c) | 18 ^(c) |

- (a) The amount of particulate emitted with a 90 percent-efficient electrostatic precipitator.
 (b) No controls; 2 percent average sulfur content in the coal.
 (c) Reference 10.

The annual average pollution resulting from the generation of electricity to melt all of the iron presently being melted in cupolas in induction furnaces would be as follows:

| Units | Total Weight of Pollutants Per Year | | | | |
|---------------------------------------|-------------------------------------|-------------------------------|--------------------------------|-----------------------------|-------------------------------|
| | Particulate ^(a) | Sulfur Dioxide ^(b) | Carbon Monoxide ^(c) | Hydrocarbons ^(c) | Nitrogen Oxide ^(c) |
| Thousand kilokilograms ^(d) | 76.0 | 317 | 3.96 | 1.19 | 71.3 |
| Million pounds | 168 | 700 | 8.75 | 2.62 | 157.5 |
| Thousand short tons | 84.0 | 350 | 4.38 | 1.31 | 78.8 |

- (a) The amount of particulate emitted with a 90 percent-efficient electrostatic precipitator.
 (b) No controls; 2 percent average sulfur content in the coal.
 (c) Reference 10.
 (d) Thousand kilokilograms equals thousand metric tons.

References

- (1) "Air Pollution Aspects of the Iron Foundry Industry", by A. T. Kearney and Company, Inc., Chicago, Illinois, Contract CPA 22-69-106, to Division of Air Quality and Emissions Data, U. S. Environmental Protection Agency, PB 204-712 (February, 1971).
- (2) Private communication from Tom Harsell, Jr., Harsell Engineering Company, Palos Verdes Peninsula, California.

- (3) Cowen, P. S., "Various Approaches to Air Pollution Control for Cupola Melting Units", Gray and Ductile Iron News, pages 5-11 (June, 1967).
- (4) Foundry Air Pollution Control Manual, Second Edition, American Foundrymen's Society, Des Plaines, Illinois (1967), page 12.
- (5) Private communication from A. J. Stone, United McGill, Inc., Columbus, Ohio.
- (6) Private communication from Harry Watson, Jr., Swindel-Dressler Company, Pittsburgh, Pennsylvania.
- (7) "New Process Regulation APC-13", Air Pollution Control Board of the State of Indiana.
- (8) Warren, J. W., "Induction Furnaces", Modern Castings, 46 (6), 760-762 (December, 1964).
- (9) Data from Columbus and Southern Ohio Electric Company, 1973.
- (10) "Compilation of Air Pollution Emission Factors", Second Edition, U.S. Environmental Protection Agency, AP-42 (April, 1973).
- (11) Economic Impact of Air Pollution Controls on Gray Iron Foundry Industry, NAPCA Publication AP-74, U.S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, National Air Pollution Control Administration, Raleigh, North Carolina (November, 1970), Appendix E.

SECTION XII

MODIFICATIONS

Standards of Performance For New Stationary Sources

One portion of the Clean Air Amendments of 1970* discusses standards of performance for emission of air pollutants from new stationary sources. The document states that the term "new source" should be taken to mean any stationary source, the construction or modification of which is commenced after the publication of the regulations. Following is a quotation from Section 111(a). "(4) The term 'modification' means any physical change in, or change in method of operation of, a stationary source which increases the amount of any air pollutant emitted by such source or which results in the emission of any air pollution not previously emitted".

Therefore, in developing standards of performance regarding emission of air pollutants from foundry melting furnaces, it is mandatory that the effects of modifications in equipment or operating procedures that may increase air pollution be considered.

Changes in Melting Equipment That Could Increase the Amount of Air Pollution

The pollutants normally controlled in the operation of foundry melting equipment are particulates and carbon monoxide. Cupola furnaces normally emit the most particulates and carbon monoxide, arc furnaces emit an intermediate amount, and induction furnaces emit the least. Any change in melting equipment from induction furnace to arc furnace to cupola furnace will increase the amount of pollutants emitted in the raw off gases and, also, in the off gases after treatment with similar air-cleaning equipment. The minimum amount of off gases from a cupola is about five times the minimum amount from an arc furnace and about 10 times the minimum amount

* Enacted by Public Law 91-604, 91st Congress, H. R. 17255, December 31, 1970.

from an induction furnace. If the off gases are all cleaned to equivalent purity, the cupola furnace will emit the most pollutants because of the greater volume of gases emitted, the arc furnace about two-tenths as much, and the induction furnace about one-tenth as much, all based on the pollutants emitted per ton of iron melted.

Changes in Melting Procedures That
Could Increase the Amount of Pollution

Changes in operating procedures can have an appreciable effect on the pollutants in the raw off gases from cupola furnaces. For example, a change from a lined to an unlined cupola or a change from a cold air blast to a hot blast will increase the amounts of particulate and carbon monoxide in the raw off gases. However, if the off gases are cleaned with equipment that has been designed to meet some specific code, then the cleaned gases will contain about the same amount of particulate and carbon monoxide regardless of the type of furnace operation. In other words, changes in the melting operation that produce an increase in uncontrolled emissions will not cause the emissions from the control device to exceed the specified limit, provided that the volume of gases to be treated does not exceed the value. According to Reference 1*, a fabric filter might well operate with the same outlet concentration of particulate when the inlet loading changes tenfold. Differences in the type of lining used in arc and induction furnaces have little effect on the amount of pollutants emitted.

The metallic-charge materials for iron foundries are mostly of secondary origin and may contain variable amounts of extraneous material that contribute to the air pollutants emitted. Scrap borings and turnings, machine parts, engine blocks, and similar materials often contain large amounts of oil and grease or other organic compounds. In addition, scrap may contain paints, coatings of zinc, aluminum, or cadmium, or solders that contain lead, tin, and zinc. Various nonferrous metals may be incorporated

* Reference is listed on page XII-4.

in the scrap as a result of incomplete sorting or as bimetallic parts. For example, machinery scrap may contain bronze or babbitt bearings, and automotive scrap may contain copper electrical wiring. The organic materials will burn or vaporize as the charge is heated to melting temperature, producing smoke and carbon monoxide. The metallic impurities, if volatile at the operating temperature, will vaporize and generally will oxidize, and, thus, they normally are emitted in the raw gases as particles of condensed metal vapor or fine oxides. Again, provided that the off gases are cleaned with equipment designed to meet a specific code, the cleaned gases emitted should be similarly low in pollutants, regardless of the quality and cleanliness of the charge materials.

If the applicable code is based on a prescribed weight of pollutants per unit volume of off gases emitted, the allowable amount of pollutants emitted per unit weight of iron melted can be increased by diluting the off gases, either before or after cleaning, and cleaning so that the diluted gases meet the prescribed code. However, most state codes prohibit foundry operators from meeting air-pollution-emission restrictions by diluting the off gases.

Changes in Plant Operations Other Than Melting
That Could Increase the Amount of Pollution

The Occupational Safety and Health Administration (OSHA) has set limits on the amount of pollutants that can be tolerated in the workroom environment. Foundries must install ventilation systems to exhaust the polluted air at the source of the contamination and replace the air exhausted with clean air. The air that is exhausted thus becomes a part of the total foundry air-pollution emission and must be cleaned before it is discharged into the atmosphere. Foundry operations other than melting that produce some air pollutants are as follows:

| <u>Operation</u> | <u>Type of Pollutants</u> |
|--------------------------------------------|---------------------------------------------------------------------|
| Scrap preparation and handling | Dust, dirt, and smoke from cutting torches |
| Sand handling and mixing | Fine silica dust and dust from clays, sea coal, and other additives |
| Coremaking and core curing | Volatile organic compounds, smoke, and some dust |
| Metal pouring and ductile iron inoculation | Oxides of iron, manganese, and magnesium |
| Mold cooling | Smoke, dust, carbon monoxide, and organic vapors |
| Shakeout | Smoke, dust, fine silica, carbon monoxide, and organic vapors |
| Cleaning and grinding of castings | Dust, fine silica, metal oxides, and grinding-wheel grit. |

Most foundries collect the polluted off gases from these non-melting operations and filter them so as to remove particulates before they are discharged. However, very few foundries treat the off gases from mold cooling, shakeout, or from the making or curing of cores to remove carbon monoxide or organic vapors, because the large volumes of ventilation air to be handled make such treatment very expensive. Very few data are available on the composition of these ventilation off gases and how changes in the operations influence the amount of pollution. Changes in the foundry operation toward more modern and efficient production would, in most cases, also result in a cleaner operation with less in-plant air pollution. However, the development of new organic core binders or new organic molding-sand additives could result in greatly increased air pollution in the coremaking, core-curing, mold-cooling, and casting-shakeout areas. However, in general, the trend appears to be in the direction of decreased pollution. After changes in these operations, the off gases should be monitored to determine their effect on human health.

Reference

- (1) Beach, G. H., "The Stack Test -- Final Proof of Non-Pollution", paper in Proceedings of the Specialty Conference on: The User and Fabric Filtration Equipment, Sponsored by the Air Pollution Control Association (October 14-16, 1973), page 35.

SECTION XIII

UNRESOLVED ISSUES

Emissions From Foundry Melting Furnaces That Are Not Controlled in the Recommended Best Emission-Reduction System

The best system of particulate-emission reduction for foundry melting furnaces (cupola, arc, and induction furnaces) consists of a fabric-filter baghouse arrangement capable of reducing the particulate to below 0.046 g/m^3 (0.02 grain/scf) in the cleaned gas. To achieve this level of cleanliness, the loadings are based on the volume of off gases necessary to insure adequate ventilation and removal of carbon monoxide with afterburners, but without the addition of excess air for dilution.

The best system of carbon monoxide-emission reduction in the off gases from foundry melting furnaces is the use of afterburners capable of reducing the carbon monoxide content to below 0.1 percent by volume.

Most state emission controls limit sulfur dioxide emissions. At present, the sulfur content of metallurgical coke suitable for foundry use is under 1.0 percent, and the resultant sulfur emissions do not need to be controlled. However, if the sulfur content of available coke should increase significantly, some control of sulfur dioxide emissions must be considered. Sulfur in coke generally is partitioned about as follows: 50 percent or more is dissolved in the metal melted, 10 percent goes into the slag, and the remaining 40 percent or less is emitted to the atmosphere.* A part of the sulfur (about 40 percent of the sulfur emitted), may be removed by means of a high-energy scrubber, if such equipment is used to control the particulate instead of fabric filters. The large proportion of the sulfur from the coke that ends up in the molten metal makes it necessary to use low-sulfur cokes to prevent excessive buildup of sulfur in the iron.

It is conceivable that the concentration of certain toxic metal oxides, such as those of mercury, lead, and cadmium, in the off gases

* Shaw, F. M., "Iron Foundry Air Pollution in the United Kingdom", The British Foundryman, 65, 90-105 (March, 1972).

could increase to the point where it exceeded the human tolerance levels, even though the total particulates in the off gas did not exceed the maximum permitted. However, such concentrations of toxic metal oxides in particulates are not expected to occur if the total particulates are controlled so as to meet the more stringent state limits.

The Level to Which Pollutants Should Be Controlled

Almost all foundry emissions could be controlled to very low levels by installing elaborate collection systems and cleaning the air with the very best cleaning systems technically available. However, such systems would be too expensive for most small and medium-size foundries to install and maintain, and the small and medium-size foundries comprise about 90 percent of the industry. Therefore, adoption of very restrictive standards would destroy our small-foundry industry and force the consumers of castings to rely increasingly on foreign foundries. On the other hand, somewhat less restrictive emission requirements would permit most small foundries to survive without unduly jeopardizing the air quality of the surrounding community.

Particulate emissions from foundry melting furnaces can be controlled to a maximum emission of 0.046 g/m^3 (0.02 grain/scf) with fabric filters. Particulate emissions also could be controlled to 0.046 g/m^3 (0.02 grain/scf) with high-energy scrubbers operating under ideal conditions. However, most equipment manufacturers probably would not guarantee that high-energy scrubbers would meet these levels for all operating conditions. However, most manufacturers of high-energy scrubbers will guarantee that particulate emission will be controlled to 0.114 g/m^3 (0.05 grain/scf) for cupolas, and 0.046 g/m^3 (0.02 grain/scf) is usually achieved with arc furnaces and induction furnaces. Thus, the fabric filters constitute the best system for controlling particulate emissions from furnaces. No other equipment is capable of matching the best system (fabric filters in a baghouse) with respect to control of particulate emissions.

Carbon monoxide can be controlled in the off gases from foundry melting furnaces to less than 0.1 percent CO by volume with afterburners where all of the off gases are subjected to the direct flame at a temperature of at least 816 C (1500 F) for no less than 1.0 second. Similar

results can be obtained if the cleaned gas (particulates removed) is subjected to a catalytic-combustion unit where all of the off gases are passed over the catalytic material and reacted with oxygen at a temperature of at least 260 C (500 F). No other method is known for reducing the carbon monoxide content of off gases below 0.1 percent. The unresolved issue is whether it is necessary to reduce the carbon monoxide content of furnace off gases to 0.1 percent.

The Problem of Disposal of Particulates from Air-Cleaning Systems

The particulates removed from the off gases from foundry melting furnaces must be disposed of in some manner. An unresolved issue is whether a proposed standard for control of foundry-melting-furnace emissions should regulate the disposal of the collected wastes so as to prevent pollution of the ambient air at the disposal sites. Dry dusts from baghouse filters must be properly handled during disposal so as to prevent pollution of the air. They may be collected in paper bags and sealed or collected in other sealed containers and disposed of in land-fills or similar sites. If the containers are not covered with fill dirt before leaks occur, the atmosphere in the dump area may be polluted with dust. The dry particulates may be mixed with water to suppress dusting, and then they can be disposed of in land-fills. Again, the resulting muds must be covered with fill dirt before they start to dry and emit dust at the disposal site. Sometimes the damp dusts are pelletized before being used in land-fills.

Particulates removed with high-energy scrubbers generally are contained in a settling pond, and the scrubbing water is recirculated. If the sludge in the ponds is not kept damp, dust pollution can occur in the area before the pond is full of sludge. Abandoned settling ponds must be covered with fill dirt to prevent pollution in the area. Also, settling ponds may be cleaned and the wet sludge disposed of in land-fills where it can be covered with fill dirt.

Effect of the Emission-Control System for Carbon
Monoxide on the Consumption of Fuel

Most state codes specify that melting-furnace gases that contain carbon monoxide be subjected to the direct flame of an afterburner for at least 0.3 second at 704 C (1300 F). This treatment will reduce the carbon monoxide concentration to about 2 to 4 percent. If the temperature is increased to 816 C (1500 F) and the time of contact is increased to 1.0 second, the carbon monoxide will be reduced to less than 0.1 percent by volume. Afterburners consume large quantities of fuel, either oil or natural gas. The alternative control method, catalytic-combustion systems, consume less fuel because the off gases must be heated only to 260 C (500 F), but the catalytic materials are not readily available and, thus, are expensive. The unresolved issue is whether a standard should be set that would result in large increases in the use of oil or natural gas, inasmuch as both are in short supply.

The carbon monoxide in the off gases from a cupola generally can be burned to harmless carbon dioxide with an afterburner with only a modest amount of fuel, because the cupola off gases are already hot and they contain enough carbon monoxide to be combustible in air. In contrast to cupola off gases, the ventilation gases collected from arc-furnace melting or from the mold-cooling, mold-shakeout, coremaking, or core-baking operations generally are much cooler and do not contain enough fuel (carbon monoxide) to be combustible in air at those temperatures. The amount of fuel that would be necessary to heat these ventilation gases above about 816 C (1500 F) and maintain them at temperature for at least 1.0 second in the direct flame of an afterburner will depend on the amount of excess air collected by the ventilation system. (This treatment would insure that the carbon monoxide content of the off gases is reduced to below 0.1 percent.) In any case, the cost of fuel to remove the carbon monoxide and organic fumes in ventilation off gases would be considerably more than the cost of fuel for similar afterburners when treating a similar volume of cupola off gases.

Restriction of Air Flow

Another unresolved issue is whether standards for ambient-air quality that restrict air flow should be adopted.

Air-pollution control systems must not only comply with applicable air-pollution-control regulations, but they must do so without preventing attainment of or maintenance of a healthful and acceptable work environment for the foundry's employees. Particularly with electric-arc-melting furnaces that use collection hoods to capture the dust and fume, the control of furnace-generated pollution is closely related to, and affected by, the ventilation system, and vice-versa. A pollution-control system that minimizes pollution of the ambient air might result in increased concentrations of particulates and carbon monoxide in the workroom air. Such increases in particulate concentration would be detrimental in that they might endanger the respiratory systems of the employees and they might decrease visibility, a condition that could increase the likelihood of serious accidents; carbon monoxide is toxic. Also, a pollution-control system that restricts ventilation air would increase the possibility of serious injury through heat stress. Therefore, in an electric-furnace foundry, the air flow must be quite high to assure adequate ventilation and an acceptable workroom environment.

Mass emissions from pollution-control devices are the product of the concentration of pollutants in the cleaned discharge and the air-flow rate; thus, the total mass of emissions is directly proportional to the volume of gas that must be cleaned. Therefore, minimizing the air flow will minimize the total mass of emissions. Consequently, a regulation expressed in mass units will automatically limit the air flow. However, a regulation expressed in terms of concentration limits will not place any restrictions on air flow; as much air can be used as is needed to ventilate the building satisfactorily. Restricting the air flow has an important economic advantage, because the size, capital cost, and operating cost of pollution control equipment is directly proportional to the volume of gases that must be cleaned. On the other hand, with hoods, the air flow must be high enough to insure adequate capture of emissions. Also, if a proposed standard of performance limits air flow, consideration must be given to the

effects of reduced ventilation on deterioration of the workers' environment. The volume of ventilation air must be adequate to comply with OSHA standards for iron oxide dust, nuisance dust, and carbon monoxide in the workroom air. Also, OSHA is developing a standard for workers in hot environments. Although higher air ventilation rates can lower the temperature in the melting area, they do not reduce the effects of radiant energy. So other means must be adopted to adequately protect the workers from heat stress.

Foundry Emissions From Sources Other Than Melting
That Are Not Included in This Document

This document deals primarily with standards of performance for new sources in gray iron foundries resulting from the operations of cupola and electric furnaces. Other sources of air pollution from foundries were intentionally omitted.

The Occupational Safety and Health Administration has set limits (Threshold Limit Values) on the amount of pollutants that can be tolerated in the workroom environment. Foundries must install ventilation systems to exhaust polluted air at the source of the contamination and replace the air exhausted with clean air. Also, the air that is exhausted should be cleaned before it is emitted to the atmosphere. Operations, in addition to melting, that produce some air pollutants are as follows:

| <u>Operation</u> | <u>Type of Pollutants</u> |
|--------------------------------------------|---------------------------------------------------------------------|
| Scrap preparation and handling | Dust, dirt, and smoke from cutting torches |
| Sand handling and mixing | Fine silica dust and dust from clays, sea coal, and other additives |
| Coremaking and curing of cores | Volatile organic compounds, smoke, and some dust |
| Metal pouring and ductile iron inoculation | Iron oxides, magnesium oxides, and manganese oxides |
| Mold cooling | Smoke, dust, carbon monoxide, and organic vapors |
| Shakeout | Smoke, dust, fine silica, carbon monoxide |
| Cleaning and grinding | Dust, fine silica, metal oxides, and grinding-wheel grit. |

The methods of collecting the off gases and the methods commonly used to remove the pollutants from the off gases are discussed in Sections III and IV of this document. Most foundries filter some of the off gases from the dirtiest operations to remove particulate matter. However, very few foundries treat the off gases from mold cooling, shakeout, or core-making and curing of cores to remove carbon monoxide or organic vapors. The unresolved issue is whether it is necessary to reduce the carbon monoxide content of these off gases and, if so, to what level. Very few data are available on the composition of these ventilation off gases. Off gases from mold cooling, shakeout, and coremaking and curing of cores would be suspected of containing carbon monoxide, carcinogens, and other organic pollutants. EPA or OSHA monitoring of these gases is recommended. In-plant silica-dust levels from sand-handling operations are presently being monitored by OSHA.

Reverberatory Furnaces

Reverberatory furnaces include all types of fuel-fired furnaces in which the heat from a flame is radiated from the refractory roof onto the iron to be melted. This broad class of furnaces includes reverberatory, air, and open-hearth furnaces. Interest in this type of furnace has developed recently because the emissions from the operation when fuel-oil or natural-gas fuel is used are low and air-pollution-control equipment normally is not required. (Air furnaces formerly were fired with powdered coal which produced considerable flyash particulate, but these furnaces have been almost completely converted over to petroleum fuel.) The unresolved issue is whether a melting process that uses fuels that are in short supply should be used to melt iron because use of pollution-control equipment to provide clean air can be avoided.

Reverberatory furnaces are very inefficient in converting the potential energy of the petroleum into heat in the metal. New installations of these furnaces in particular and, also, continued use of existing reverberatory furnaces to avoid the installation of air-pollution equipment in small foundries should be discouraged, because the petroleum is badly needed elsewhere.

SECTION XIV

ANTICIPATED REACTION OF THE PUBLIC AND INDUSTRY TO THE STANDARDS SUPPORT DOCUMENT

Introduction

The present state air-pollution codes that apply specifically to iron foundries generally limit the particulate that can be emitted and sometimes specify that the off gases from cupola furnaces must be subjected to the direct flame of an afterburner. Except for Illinois, these codes do not specify emission limits for carbon monoxide, hydrocarbons, sulfur dioxide, fluorides, or other potentially objectionable materials. Most state codes indicate that emissions from any industrial process must not exceed the air-quality index at ground level, but the relationship between foundry emissions and the concentrations of pollutants at some ground-level monitoring station are not clear. Pollutants in the emissions from iron foundries cannot be controlled properly unless limits for various potential pollutants in the off gases are clearly indicated.

The best system of emission reduction with present technology would be capable of limiting the potential pollutants in the off gases in new or modified iron-foundry sources to the following levels:

| | |
|--------------------------------------|---------------------------------------------|
| Particulate matter | 0.046 g/m ³ (0.02 grain/scf) |
| Carbon monoxide | 0.1 percent (1000 ppm by volume) |
| Hydrocarbons and organic fumes | To be included as potential carbon monoxide |
| Nitrogen oxides, as NO ₂ | 325 ppm (by volume) ^{(1)*} |
| Sulfur, expressed as SO ₂ | 500 ppm (by volume) ⁽¹⁾ . |

The allowable pollutants in the off gases from iron-foundry melting units should be based on a gas volume no greater than 1093 m³/kkg of iron melted (35,000 scf/short ton), the average undiluted gas volume emitted from a cupola furnace.

* References are listed at the end of the section.

The pollutants from in-plant ventilation gases should meet the same standards adopted for effluent from melting furnaces before they are discharged into the atmosphere. The total pollutants in the ventilation air should be based on an air volume of 1093 m³/kkg of iron melted (35,000 scf/short ton). (The volume of the ventilation air could vary over a large range; a value equal to the emission from a cupola melting furnace was arbitrarily selected for a maximum ventilation rate. A maximum ventilation rate must be specified so as to prevent circumventing cleaning of the in-plant gases through excessive dilution.)

The maximum amount of all iron-foundry pollutants that will be permitted to be emitted per unit weight of iron melted (based on the best system with current technology) can be calculated from the allowable concentration of the pollutants in the off gases and the base-level amount of off gases and ventilation air discharged per unit weight of iron melted, that is, a total gas emission of 2,186 m³/kkg of iron melted (70,000 scf/short ton). If this volume of off gases contained the maximum allowable amount of pollutants (as based on the capabilities of the best pollution-control system), the total emission of pollutants per unit weight of iron melted would be as follows:

| <u>Pollutant</u> | <u>Emission Per Unit Weight of Iron Melted</u> | | |
|------------------------------------|------------------------------------------------|---------------------|---------------------|
| | <u>m³/kkg</u> | <u>kg/kkg</u> | <u>lb/short ton</u> |
| Particulate | -- | 0.10 | 0.20 |
| Carbon monoxide | 2.19 | 2.73 ^(a) | 5.46 |
| Nitrogen oxide, as NO ₂ | 0.71 | 1.39 | 2.79 |
| Sulfur, as SO ₂ | 1.09 | 3.12 | 6.24 |

$$(a) \left(\frac{2.186 \text{ m}^3/\text{kkg} \times 1000 \text{ dm}^3/\text{m}^3}{22.414 \text{ dm}^3/\text{mole}} \right) \times 28 \text{ g CO/mole} = 2731 \text{ g/kkg} \\ = 2.73 \text{ kg/kkg.}$$

Anticipated Public Reaction to the Proposed Emission Standards

It is anticipated that the general public will be pleased with the above standards for emission of pollutants from iron foundries, because new foundries meeting those suggested standards will be good neighbors. The only possible objection that is foreseen is the increased cost of items made

with iron castings as iron foundries pass on to their customers the increased operating costs resulting from more stringent pollution-control requirements.

Anticipated Reaction of the Iron-Foundry Industry to the Revised Emission Standards

Some reaction from the iron-foundry industry is anticipated. The technical problems and the cost of meeting the emission standards are discussed in the following sections for each pollutant.

Particulates

The limit on particulate emission of 0.046 g/m^3 (0.02 grain/scf) is presently being met by many foundries that use fabric filters. The filtering units must be maintained in top working order, and they must be properly controlled. No additional costs for fabric-filter baghouse installations are anticipated for those foundries that already use such systems.

A high-energy venturi scrubber normally operates with a pressure drop of about 12,442 pascals (50 inches of water). The cleaning efficiency of such a unit operated with that pressure differential is about 0.11 g/m^3 (0.05 grain/scf). The efficiency of this type of unit can be improved to meet a controlled level of 0.046 g/m^3 (0.02 grain/scf) by increasing the operating differential pressure across the orifice to about 19,907 pascals (80 inches of water). Such an increase in pressure drop would increase the total operating cost of the unit about 14 percent when it is operated 4,000 hours per year.⁽²⁾ Some opposition to this 14 percent increase in the cost of operating a high-energy scrubber is anticipated.

Cleaning of in-plant ventilation air to meet a controlled level of particulate emission will require the installation of suitable cleaning equipment on almost all exhaust sources. Many existing plants do not clean all of the ventilation air before it is exhausted to the atmosphere. Foundry operators are expected to resist cleaning ventilation air because of the cost.

Carbon Monoxide, Hydrocarbons, and Organic Fumes

A much greater weight of carbon monoxide than particulate is emitted from foundry cupola melting units. Much more attention has been paid to

particulate, because the smoke and dust are visible evidence of pollution. The carbon monoxide probably is more of a health hazard than is the particulate emission.

Some of the present state codes specify that the cupola off gases be subjected to the direct flame of an afterburner for at least 0.3 second at 704 C (1300 F), a practice which will reduce the carbon monoxide content of the effluent gas to about 2 to 4 percent. The proposed system would require the off gases to be subjected to the direct flame of an afterburner for at least 1.0 second at 816 C (1500 F). This procedure would reduce the carbon monoxide content to less than 0.1 percent.

The use of afterburners is a relatively inexpensive control technique for the reduction of unburned volatile materials and black smoke from cupolas. The cost of operating an afterburner would depend upon the amount of air dilution brought in through the charge door and the amount of combustible material in the off gases. The efficiency of the afterburner combustion will depend on the stack height above the afterburner, a minimum stack height of 25 to 30 feet above the burner being required for optimum results. Under the most adverse conditions, an afterburner would require an input of 116 million joules per hour per kilokilogram of iron melted (100,000 Btu per hour per ton of metal melted) to heat the off gases to 816 C (1500 F) for 1.0 second.⁽³⁾ If natural gas at a cost of \$0.80 per million Btu were used as a fuel, the total fuel cost of the afterburner under the most adverse conditions would be about \$0.080 per ton of iron melted, or \$0.088 per kilokilogram. The fuel required to heat the off gases from 704 C (1300 F) for at least 0.3 second to 816 C (1500 F) for 1.0 second would be appreciably less. Thus, the difference between the cost of fuel for meeting most state codes and the cost of meeting a specified maximum carbon monoxide content in the exit gases of 0.1 percent by volume would be low.

Organic fumes or carbon monoxide emissions from in-plant operations (coremaking, core baking, mold cooling, or mold shakeout) should be controlled when the organic fumes and/or the carbon monoxide exceeds 0.1 percent equivalent carbon monoxide. The installed cost of afterburners to control these emissions is \$105.93 to \$176.55 per actual cubic meter per minute (\$3.00 to \$5.00 per actual cubic foot per minute⁽¹⁾) that is, the

gas volume at the temperature at which it is treated, and the cost of catalytic-type burners is \$176.55 to \$247.18 per actual cubic meter per minute (\$5.00 to \$7.00 per actual cubic foot per minute) of gas to be treated⁽¹⁾. Operating costs would be more per hour than would the cost of using afterburners for cupolas. However, the carbon monoxide and/or the organic fumes from in-plant ventilation would not be expected to exceed 0.1 percent most of the time, and operation of the afterburner or catalytic-combustion unit would not be required to treat pollution from in-plant operations except when excessive fumes are being produced. It would be necessary to monitor the exhaust gases with suitable instruments at all times that the exhaust system is in operation to determine when the control system is needed. Iron foundries can be expected to object to monitoring and controlling in-plant gases.

Nitrogen Oxides

Foundries are not expected to require pollution-control equipment to meet the nitrogen oxide limits for combustion processes. However, the nitrogen oxide content of the gases emitted from melting furnaces and scrap preheaters should be monitored periodically to insure that proper burner adjustment is maintained.

The emission of small amounts of nitrogen oxides would be expected for a brief interval when the arc is first started during meltdown in an arc furnace. At all other times, the nitrogen oxides level in the emissions from the best system for controlling particulates and carbon monoxide in furnace and scrap-preheater off gases probably will be acceptable. Inasmuch as additional control devices probably will not be needed for nitrogen oxides, objections by foundrymen probably will be minor.

Sulfur Expressed as Sulfur Dioxide

Foundries are not expected to require control equipment to meet the sulfur-emission limits. Sulfur compounds are generated from (1) the sulfur in the coke fuel used in cupolas, (2) during water quenching or granulation of high-sulfur slags, or (3) during desulfurization of iron.

With present practice, low-sulfur coke is required to meet the limit on the sulfur content of the iron produced. Therefore, the sulfur emissions are not expected to exceed the specified limits unless changes are made in the sulfur content of the coke fuel, or other process changes are made that generate more sulfur-bearing gases. Inasmuch as additional controls probably will not be required to control sulfur dioxide, little objection should be encountered.

References

- (1) "Background Information for Establishment of National Standards of Performance for New Sources: Gray Iron Foundries", Report on Contract No. CPA 70-142, Task Order No. 2, to Division of Abatement, Air Pollution Control Office, Environmental Protection Agency, Durham, North Carolina, by Environmental Engineering, Inc., and PEDCo Environmental Specialists, Inc., Gainesville, Florida (March 15, 1971).
- (2) "Systems Analysis of Emissions and Emissions Control in the Iron Foundry Industry. Volume II. Exhibits", Report to Division of Process Control Engineering, Air Pollution Control Office, Environmental Protection Agency, Contract No. CPA 22-69-106, from A. T. Kearney & Company, Inc., Chicago, Illinois (February, 1971), PB 198-349.
- (3) Economic Impact of Air Pollution Controls on Gray Iron Foundry Industry, NAPCA Publication AP-74, U. S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, National Air Pollution Control Administration, Raleigh, North Carolina (November, 1970), Appendix E.

SUBTASK A

INDIVIDUALS AND FIRMS THAT HAVE EXPERTISE ABOUT
THE IRON-FOUNDRY INDUSTRY AND HAVE BEEN
HELPFUL IN THE BATTELLE PROGRAM

1. American Air Filter Company
Louisville, Kentucky
(502) 637-0011
James Onnen, Manager
Equipment Manufacture
(High-Energy Scrubbers)
2. American Foundrymen's Society
Golf and Wolf Roads
Des Plaines, Illinois 60016
(312) 824-0181
William B. Huelsen
Environmental Control
(Foundry Equipment and Environment)
3. Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
(614) 299-3151
Earl Schulz
Salo (Sy) Miller
James Howes
(Sampling and Analysis)
4. Gray and Ductile Iron Founder's Society, Incorporated
Cast Metals Federation Building
20611 Center Ridge Road
Rocky River, Ohio 44116
(218) 333-9600
William O. Ferguson
(Foundry)
5. Gray Iron Research Institute
870 West Third Avenue
Columbus, Ohio 43212
(614) 299-3336
Daniel Krause
(Foundry)

6. Harsell Engineering Company
28425 Cyuse Lane
Palos Verdes Peninsula, California 90274
(213) 377-7054
Tom L. Harsell, Jr.
(Equipment Engineering)
7. The Penton Publishing Company
Penton Plaza
Cleveland, Ohio 44114
(216) 696-7000
David Shanks
(Foundry Market Analysis)
8. Kenneth Robinson
(General Motors, Retired)
112-B Silver Lake
Mears, Michigan 49436
(616) 873-5332
(In-Plant Ventilation)
9. Swindell-Dressler Company
Division of Pullman, Inc.
441 Smithfield Road
Pittsburgh, Pennsylvania 15222
(412) 562-7145
Harry Watson
(Equipment)
10. George Tubich and Associates
251 Emerald Avenue, NE
Grand Rapids, Michigan 49505
(616) 363-2302
(Equipment Engineering and Comprehensive Practice of Industrial Hygiene)
11. United McGill Corporation
2400 Fairwood Avenue
Columbus, Ohio 43207
(614) 443-0192
A. J. Stone
(Equipment)
12. Ford Motor Company
Engine and Foundry Division
Michigan Casting Center
22000 Gibraltar Road
Flat Rock, Michigan 48134
M. C. Krill, Plant Manager
(Foundry)

SUBTASK B

ESTIMATE OF THE NATIONWIDE AIR-CONTAMINANT
EMISSIONS FROM GRAY IRON FOUNDRIES

Iron foundries in the United States produced 16.44 million kilokilograms (18.12 million short tons) of gray, ductile, and malleable iron castings in 1973.* If the yield of good castings was 60 percent, then 27.40 million kilokilograms (30.20 million short tons) of iron was melted. The proportion of the total iron production that was melted in cupola, induction, arc, or reverberatory-type furnaces, is not known, nor is the number of furnaces equipped with air-emission-control equipment known. However, the capacity of the melting equipment of most of the foundries is available in the Penton Publishing Company list of foundries^{(1)**} (see Subtask E, Table F-1 of the Standards Support Document). This list was used to determine the total capacity of melting equipment in United States foundries, broken down as to furnace type (see page III-10). The capacity of the melting furnaces was further divided into "large foundries" (over 250 employees), "medium foundries" (249 to 50 employees), and "small foundries" (49 or less employees) as is shown in Table B-1. The average production per day was assumed to be proportional to the total capacity of each size category of foundry when they melted for the following period of time each working day:

| <u>Foundry Size</u> | <u>Daily Melting Period</u> |
|---------------------|-----------------------------|
| Large | 16 hours |
| Medium | 8 hours |
| Small | 4 hours. |

On this basis, the estimated capacity per typical working day that is presented in Table B-1 was calculated from the hourly capacity and the melting time. Based on these assumptions, 65.7 percent of the iron is produced in large foundries, 28.5 percent in medium-size foundries, and 5.8 percent in small foundries. Based on experience, this proportion appears to be about right.

* See Section III.

** References are listed at the end of this writeup.

The annual production from each type of melting furnace in each size of foundry was assumed to be proportional to the estimated daily capacity for the assumed typical working day. That is, 48.0 percent of the total annual production of 30.2 million short tons of iron melted was produced in cupolas in large foundries, as is shown in Table B-2. The production of all four types of melting furnaces in the various size foundries was estimated based on these proportions.

The proportion of melting furnaces in each size category of iron foundry that had emission-control equipment has been estimated previously for cupolas and arc furnaces.⁽²⁾ The proportion is shown in Table B-3, and the type of control equipment is indicated. That source did not include data on emission-control equipment for induction or air furnaces. Therefore, the number of these furnaces that have emission-control equipment was estimated arbitrarily to be as is shown in Table B-3.

The number of tons of iron melted per year in each type of melting furnace, shown in Table B-2, either with or without emission-control equipment, as shown in Table B-3, was used to calculate the total emission from all iron-foundry melting furnaces, with the emission factors and results shown in Table B-4. For example, in large foundries, an estimated 14,496 thousand short tons of iron per year is melted in cupolas. About 95 percent of these foundries are equipped with scrubber-type emission-control equipment that will remove all but 0.8 pound of particulate for each ton melted. Therefore, 95 percent of 14,496 thousand tons of iron (or 13,771 thousand tons) times the emission factor of 0.8 pound per ton results in an emission of 11,017 thousand pounds of particulate per year from all the cupola furnaces equipped with scrubbers, in large foundries. The remaining 5 percent of the cupolas in large foundries that did not have emission-control equipment emitted 12,325 thousand pounds of particulate per year.

The carbon monoxide emission was calculated in a similar way. Cupola furnaces equipped with emission controls for particulates were assumed also to be equipped with afterburners to control the carbon monoxide. The emission factor for carbon monoxide emission from cupolas was obtained from Reference 3. The emission factor for carbon monoxide from arc furnaces was calculated to be 37 pounds of carbon monoxide per ton of iron melted. The calculation of the carbon monoxide factor for arc furnaces

TABLE B-1. HOURLY CAPACITY AND ESTIMATED CAPACITY PER TYPICAL WORKING DAY FOR CAST IRON FOUNDRIES IN THE UNITED STATES

| Type of Melting Furnace | Large Foundries (More than 250 Employees) | | Medium-Size Foundries (50 to 249 Employees) | | Small Foundries (Less than 50 Employees) | |
|-------------------------|-------------------------------------------|--------------------------------------------------------------|---------------------------------------------|--------------------------------------------------------------|------------------------------------------|--------------------------------------------------------------|
| | Capacity, tons/hour | Estimated Capacity per Working Day ^(b) , tons/day | Capacity, tons/hour | Estimated Capacity per Working Day ^(c) , tons/day | Capacity, tons/hour | Estimated Capacity per Working Day ^(d) , tons/day |
| Cupola | 6,239 | 99,824 | 5,638 | 45,104 | 2,645 | 10,580 |
| Induction | 323 | 5,168 | 986 | 7,888 | 213 | 852 |
| Arc | 1,940 | 31,040 | 408 | 3,264 | 163 | 652 |
| Air ^(a) | <u>512</u> | <u>512</u> | <u>2,993</u> | <u>2,993</u> | <u>54</u> | <u>54</u> |
| Total | 9,014 | 136,544 | 10,025 | 59,249 | 3,075 | 12,138 |
| Percent of Total | -- | 65.7 | -- | 28.5 | -- | 5.8 |

- (a) For air furnaces, the capacity is given in tons per charge, which is assumed to be equivalent to tons per day for this type of furnace.
- (b) Based on average melting period of 16 hours per day.
- (c) Based on average melting period of 8 hours per day.
- (d) Based on average melting period of 4 hours per day.

TABLE B-2. ESTIMATED AMOUNT OF IRON MELTED IN THE VARIOUS TYPES OF FOUNDRY MELTING FURNACES PER YEAR

| Type of Melting Furnace | Estimated Production of Castings in Various Furnace Types and Different Sizes of Foundries | | | | | | |
|-------------------------|--------------------------------------------------------------------------------------------|------------------------------------|-----------------------|------------------------------------|-----------------|-------------------------|---------------------|
| | Large Foundries | | Medium-Size Foundries | | Small Foundries | | All Foundries |
| | Percent (a) | Thousand Short Tons ^(b) | Percent (a) | Thousand Short Tons ^(b) | Percent (a) | Thousand Short Tons (b) | Thousand Short Tons |
| Cupola | 48.0 | 14,496 | 21.7 | 6,553 | 5.1 | 1,540 | 22,589 |
| Induction | 2.5 | 755.00 | 3.8 | 1,148 | 0.4 | 121 | 2,024 |
| Arc | 14.9 | 4,500 | 1.6 | 483 | 0.3 | 91 | 5,074 |
| Air | <u>0.3</u> | <u>90</u> | <u>1.4</u> | <u>423</u> | -- | -- | <u>513</u> |
| Total | 65.7 | 19,841 | 28.5 | 8,607 | 5.8 | 1,752 | 30,200 |

- (a) Estimated percentage of total production, based on capacity and assumed daily melting period.
- (b) Estimated annual tonnage melted, based on 1973 production of 18.12 million short tons of castings. At an estimated yield of good castings of 60 percent, then the total weight of iron melted was $18.12/0.60 = 30.20$ million short tons.

TABLE B-3. ESTIMATED PROPORTION OF IRON-FOUNDRY MELTING FURNACES
EQUIPPED WITH VARIOUS TYPES OF AIR-POLLUTION-CONTROL
EQUIPMENT

| Type of Melting Furnace | Type of Control Equipment | Proportion of Melting Furnaces Equipped With Pollution-Control Equipment, percent | | |
|-------------------------------|---------------------------------|--------------------------------------------------------------------------------------|---------------------|---------------|
| | | Large Foundry | Medium-Size Foundry | Small Foundry |
| Cupola (a) | Scrubber | 95 | 40 | 0 |
| | Filter | 0 | 40 | 20 |
| | None | 5 | 20 | 80 |
| Induction (b) | Filter | 50 | 15 | 0 |
| | None | 50 | 85 | 100 |
| Arc (a) | Filter | 95 | 85 | 50 |
| | None | 5 | 15 | 50 |
| Air furnace (b) | Filter | 50 | 15 | 0 |
| | None | 50 | 85 | 100 |

(a) From Reference 2.

(b) Estimated.

TABLE B-4. ESTIMATED TOTAL IRON-FOUNDRI EMISSIONS IN 1973

| Type of Melting Furnace | Type of Air-Emission-Control Equipment | Foundry Size Category | Estimated Proportion of Furnaces Equipped(a), percent | Estimated Quantity of Iron Melted in 1973(b), thousand short tons | Particulate Emission(c), pounds per ton | Total Particulate Emitted, thousand pounds | Carbon Monoxide Emission(c), pounds per ton | Total Carbon Monoxide Emission, thousand pounds |
|-------------------------|----------------------------------------|-----------------------|-------------------------------------------------------|-------------------------------------------------------------------|-----------------------------------------|--------------------------------------------|---------------------------------------------|-------------------------------------------------|
| Cupola | Scrubber | Large(d) | 95 | 13,771 | 0.8 | 11,017 | 9(g) | 123,939 |
| | Scrubber | Medium(e) | 40 | 2,621 | 0.8 | 2,097 | 9(g) | 23,589 |
| | Filter | Medium | 40 | 2,621 | 0.2 | 524 | 9(g) | 23,589 |
| | Filter | Small(f) | 20 | 308 | 0.2 | 62 | 9(g) | 2,772 |
| | None | Large | 5 | 725 | 17 | 12,325 | 145 | 105,125 |
| | None | Medium | 20 | 1,311 | 17 | 22,287 | 145 | 190,095 |
| None | Small | 80 | 1,232 | 17 | 20,944 | 145 | 178,640 | |
| Induction | Filter | Large | 50 | 378 | 0.2 | 76 | 0 | 0 |
| | Filter | Medium | 15 | 172 | 0.2 | 34 | 0 | 0 |
| | None | Large | 50 | 378 | 1.5 | 567 | 0 | 0 |
| | None | Medium | 85 | 976 | 1.5 | 1,464 | 0 | 0 |
| | None | Small | 100 | 121 | 1.5 | 182 | 0 | 0 |
| Arc | Filter | Large | 95 | 4,275 | 0.2 | 855 | 37(j) | 158,175 |
| | Filter | Medium | 85 | 411 | 0.2 | 82 | 37(j) | 15,207 |
| | Filter | Small | 50 | 46 | 0.2 | 9 | 37(j) | 1,702 |
| | None | Large | 5 | 225 | 10(h) | 2,250 | 37(j) | 8,325 |
| | None | Medium | 15 | 72 | 10(h) | 720 | 37(j) | 2,664 |
| None | Small | 50 | 46 | 10(h) | 460 | 37(j) | 1,702 | |
| Air(k) | Filter | Large | 50 | 45 | 0.2(i) | 9 | 0 | 0 |
| | Filter | Medium | 15 | 63 | 0.2(i) | 13 | 0 | 0 |
| | None | Large | 50 | 45 | 1.5(i) | 68 | 0 | 0 |
| | None | Medium | 85 | 360 | 1.5(i) | 540 | 0 | 0 |
| Total | | | | | | 76,585 | | 835,524 |

Footnotes for Table B-4 appear on next page.

Footnotes for Table B-4.

- (a) From Table B-3.
- (b) The quantity of iron melted (from Table B-2) times the proportion of units equipped with controls.
- (c) From Reference 3, except as noted.
- (d) Foundries with over 250 employees.
- (e) Foundries with less than 250 but more than 49 employees.
- (f) Foundries with 49 or less employees.
- (g) Assume that all cupolas equipped with particulate controls have after-burners.
- (h) From Reference 3.
- (i) Estimated.
- (j) Calculated from
$$\frac{\text{scf off gas/ton} \times (\% \text{ CO}/100) \times \text{lb CO/mole}}{\text{scf/mole}} =$$
$$\frac{12,000 \times 0.04 \times 28}{359} = 37 \text{ lb/ton.}$$
- (k) Includes air, reverberatory, and open-hearth furnaces.

was based on the assumption that 12,000 scf of ventilation air would be required per ton of iron melted and that the ventilation air would contain 4 percent carbon monoxide by volume.

It was assumed that the emissions from induction or air furnaces contained no carbon monoxide. The carbon monoxide emitted from induction furnaces is known to be insignificant. However, gas- or oil-fired air furnaces could have emitted some carbon monoxide if the burners were not properly adjusted. Air furnaces include reverberatory and open-hearth furnaces.

Summarizing, the total emissions from foundry melting furnaces per year, based on the production and the operating conditions that prevailed in 1973, were estimated to be as follows:

| | <u>Particulate</u> | <u>Carbon Monoxide</u> |
|-----------------------------|--------------------|------------------------|
| Kilokilograms (metric tons) | 34,739 | 378,988 |
| (Short tons) | (38,293) | (417,762) . |

The estimated average emissions per unit weight of iron melted* were:

| | <u>Particulate</u> | <u>Carbon Monoxide</u> |
|----------------------------|--------------------|------------------------|
| Kilograms per kilokilogram | 1.25 | 13.9 |
| (Pounds per short ton) | (2.50) | (27.7) . |

Emissions from in-plant ventilation systems are not included in this estimate.

References

- (1) Penton Computer Print-out of Gray Iron Foundries in the United States, The Penton Publishing Company, Cleveland, Ohio (March, 1974).
- (2) Battelle, Columbus Laboratories, "The Cost of Clean Air, 1974", Final Report to The United States Environmental Protection Agency, Contract No. 68-01-1538 (Task 1 and Task 2), from Battelle, Columbus Laboratories, Columbus, Ohio (January 15, 1974).
- (3) "Compilation of Air Pollution Emission Factors", Second Edition, U. S. Environmental Protection Agency, AP-42 (April, 1973).

* Total estimated emissions for 1973 divided by the total weight of iron melted in 1973, 27.40 million kilokilograms (30.20 million short tons).

SUBTASK C

LIST OF PLANTS THAT HAVE EXEMPLARY
AIR-POLLUTION-CONTROL SYSTEMS

Plants with exemplary air-pollution-control systems were selected by consulting specialists in the field who are knowledgeable concerning air-pollution-control requirements. Both large and small plants and plants that employ high-energy scrubbers and others that use baghouse-filter systems were selected. Several foundries with good air-pollution-control systems requested that their companies not be listed.

1. American Cast Iron Pipe Company (ACIPCO)
Birmingham, Alabama
(205) 325-7701
Carl P. Farlow, Jr.
Vice President in Charge of Engineering

One cupola with a capacity of 100 tons per hour is equipped with a high-energy scrubber capable of cleaning 560,600 cfm of air to less than 0.03 grain/scf.

2. Auto Specialties Manufacturing Company
St. Joseph, Michigan
(616) 983-2521
Richard Lee

One cupola with a capacity of 42 to 45 tons per hour is equipped with a baghouse capable of cleaning 98,600 cfm of off gases at 400 F.

3. J. I. Case
Division of Teneco
Clausen Works
Racine, Wisconsin
(414) 636-7450
Mr. L. D. McDowell, Chief Facilities Engineer

One cupola with a capacity of 300 to 350 tons per day is equipped with a high-energy scrubber.

4. Clow Corporation
Bensenville Plant
Bensenville, Illinois
(312) 625-9060
Mr. Charles Savage, Plant Manager

One cupola with a capacity of 200 tons per day is equipped with a high-energy scrubber.

5. The Dotson Company, Inc.
Mankato, Minnesota 56001
(507) 345-5018
Mr. Gerald Dotson, President

Two cupolas with a combined capacity of 60 to 70 tons per day are both equipped with high-energy scrubbers.

6. Ductile Iron Company of America
Havana, Georgia
(912) 234-4423
Howard Hughes, Plant Engineer

One cupola with a capacity of 8.3 tons per hour is equipped with a baghouse.

7. Lynchburg Foundry
A Mead Company
Drawer 411
Lynchburg, Virginia 24505
(804) 847-1873
Mr. Tom T. Norwood, Chief Engineer

The following cupolas are all equipped with baghouse air-cleaning equipment:

Two cupolas - 20 tons per hour each - operate 24 hours per day

One cupola - 16 tons per hour - operates 16 hours per day

One cupola - 38 tons per hour - operates 12 hours per day

One cupola - 35 tons per hour - operates 16 hours per day.

8. Neenah Foundry Company
Neenah, Wisconsin
(414) 725-3041
Mr. James Keating, Vice President

Cupolas in three plants with a total capacity of 700 tons per day are all equipped with high-energy scrubbers.

9. Tioga Foundry Corporation
Owego, New York
(607) 687-1830
Mr. John Sweet, President and General Manager

One cupola is equipped with a baghouse capable of treating 27,000 cfm of off gases at 500 F. The cupola has a capacity of 5 to 6 tons per hour and operates 8 hours per day.

10. Waupaca Foundries
Plant No. 2
(A wholly-owned subsidiary of Budd and Company)
Waupaca, Wisconsin 54981
(715) 258-5571
Mr. Fred Laswell, Manager of Engineering

One cupola with a capacity of 30 tons per hour is equipped with a high-energy scrubber.

SUBTASK D

ALTERNATIVES FOR THE BEST SYSTEM OF EMISSION CONTROL IN IRON FOUNDRIES

Iron foundries generate emissions principally from the melting processes that they use. Secondary sources of emissions include material handling, molten-metal treatment to desulfurize the iron or to convert it to ductile iron, metal pouring, mold cooling, casting shakeout, casting cleaning, casting finishing, coremaking, and molding-sand preparation. The emissions consist of particulates, visible smoke or fume, and invisible emissions, such as carbon monoxide. Particulate in the emissions can be removed with either fabric filters or high-energy scrubbers. Electrostatic precipitators and mechanical cyclones are seldom used by iron foundries, because their efficiency is not high enough and, in addition, electrostatic precipitators are expensive to install and operate^{(1)*}. The carbon monoxide and combustible smoke and fume in the emissions can be rendered harmless with direct-fired afterburners or catalytic combustors. The various possible control systems are discussed in the order of their importance in the sections that follow.

Control of Particulate

Fabric Filters

Fabric filters generally are considered to be capable of reducing the particulate content of foundry off gases to about 0.023 g/m^3 (0.01 grain/scf). Most equipment manufacturers will guarantee a particulate loading of less than 0.046 g/m^3 (0.02 grain/scf) in the emissions from properly installed and maintained fabric-filter units. However, filtering efficiencies this high can only be obtained when the equipment is kept in excellent order, recommended flow rates through the bags are not exceeded, no breaks occur in the bags, and no dust is permitted to escape when the bags are emptied and the dust is disposed of.

* References are listed at the end of the writeup on this subtask.

Fabric filters have several disadvantages. Most filters will not effectively capture particles less than about 0.2 micrometer, or micron (about 8 microinches) in size.⁽²⁾ (However, fabric filters appear to be the most effective means of removing small particles from industrial off gases.) In addition, the fabrics have temperature limitations that vary from about 82 C (180 F) for cotton, 93 to 204 C (200 to 400 F) for various synthetic fabrics, and up to 288 C (550 F) for glass fiber. These temperatures must not be exceeded or the bags will either burn or melt. All burning embers and sparks carried along in the gas stream from the melting equipment must be extinguished before they reach the filter bags so as to prevent ignition of the filters.

Fabric filters will become plugged and cease to operate when the incoming gases contain appreciable amounts of water vapor and the temperature is below the dew point or when they contain oil, grease, or organic fumes that condense on the filter surface. Filter bags that become plugged by one or more of these processes are said to be blinded.

A baghouse-pollution-control system that contains a multiplicity of filter bags generally contains more controls and more valves and requires more maintenance than do other pollution-control systems.

Glass-fabric bags cannot be used if the effluent contains appreciable amounts of fluorides, because they react with the glass fabric.

Fabric filters have the advantages of being the most efficient pollution-control system. They normally operate with a low pressure drop through the filters, for example, a differential pressure of 747 to 1244 Pa* (3 to 5 inches of water) and, therefore, have low power requirements. The fabric-filter baghouse system normally is not subject to corrosion or water-pollution control, because no water is involved.

High-Energy Scrubbers

High-energy venturi scrubbers are capable of collecting particles down to 0.1 to 0.2 micrometer (4 to 8 microinches) in size; however, to remove such very small particles requires a pressure drop in the equipment

* 1 pascal (Pa) = 1 newton/meter² (N/m²).

somewhat greater than 24,884 pascals (100 inches of water), and the power required to achieve such a differential is very high. To operate in that manner is not considered to be economically feasible. Most equipment manufacturers will guarantee particulate control to 0.11 g/m^3 (0.05 grain/scf) with a high-energy venturi scrubber. As normally operated to achieve that level of particulate control, the smallest particles that can be collected effectively are about 0.5 micrometer (20 microinches) in diameter.⁽²⁾ This level of cleaning generally will result in no visible plume of emission except for the plume of steam that eventually dissipates.

High-energy scrubbers have several advantages, as follows:

(1) reasonably low maintenance cost, (2) very little control is necessary (the operators turn them on and forget them), (3) the temperature of the furnace off gases to be cleaned is not a problem, (4) combustible gases in the off gases can be tolerated, (5) moisture, oils, grease, or organic vapors in the gases do not plug up the equipment, and (6) sparks or embers are extinguished.

The major disadvantages of high-energy scrubbers are (1) high operating costs (they require large electric motors to drive the fans to pull the gases through the venturi scrubber), (2) the noise emitted by the fans, (3) considerable corrosion of the equipment caused by the water used, and (4) the need for settling and recycling or cleaning the water used before it can be discharged.⁽²⁾

Some gaseous impurities from the off gases being treated are dissolved in the water and, thus, are removed from the gas effluent. This condition may be an advantage or a disadvantage, depending upon the problems encountered in removing the impurities from the water.

The total cost of installing and operating baghouses generally is about the same as the cost of high-energy venturi scrubbers of the same capacity, provided that the cost of land and water treatment for the high-energy scrubber is included in its cost. High-energy venturi scrubbers have higher operating-energy requirements but lower maintenance costs than do fabric-filter baghouses, so that the annual costs, including amortization of installation costs, operation, and maintenance, are about the same. Each situation must be evaluated individually to determine which pollution-control system is the most economical to use.

The high-energy venturi scrubbers made by most manufacturers are guaranteed to provide a maximum particulate loading of only 0.11 g/m^3 (0.05 grain/scf) in the effluent gases, whereas most makers of baghouses guarantee that a maximum loading of 0.046 g/m^3 (0.02 grain/scf) can be achieved. Thus, the baghouse removes more particulate than does the high-energy scrubber. At those loadings, the baghouse also is capable of removing smaller particles from the off gases than is the high-energy scrubber with normally used pressure differentials, that is, with differentials considered economically feasible.

Although the baghouse, when properly designed, installed, and maintained, is more effective at reducing particulate pollution in the off gases from iron-foundry melting furnaces than is the high-energy scrubber, it appears that regulations should not preclude use of the latter equipment. Plants that already have well-designed high-energy scrubbers should be doing a good job of removing particulate pollutants. When expanding melting facilities, for such a plant to be required to install a completely different system, namely fabric filters, for control of particulate emission from the new facilities would constitute an appreciable economic penalty. For example, such a plant already has an appreciable investment in water-treatment facilities for use with the high-energy scrubbers; an expanded water-treatment facility could be operated at relatively little additional cost. Also, operating two vastly different systems for control of particulate emission would increase operating costs considerably as compared with the cost of operating a single enlarged system.

Hoods

Hoods are required in conjunction with arc furnaces and selected in-plant operations. The capture efficiency depends on the design and installation and varies between about 50 and 90 percent.

Control of Carbon Monoxide and Other Combustible Gases

The carbon monoxide and other combustible gases in the effluent from foundry operations can be controlled by burning the gases with an excess of air in the direct flame of an afterburner or with a catalytic-combustion system.

Afterburners

Afterburners generally are installed in cupola stacks to reignite the gases that have been extinguished during charging and to insure combustion of the carbon monoxide and other combustible gases before they enter the baghouse or high-energy scrubbers. The efficiency of an afterburner depends on a number of factors, including (1) presence of an excess of air, (2) thorough mixing of the off gas and the dilution air, (3) suitable contact of the diluted gas with the afterburner flame, (4) the temperature of the off gases during the combustion, and (5) the time that the off gases are subjected to the direct flame of the afterburner. Most state codes specify that cupola off gases must be subjected to the direct flame of an afterburner operating at 704 C (1300 F) for at least 0.3 second. These conditions should reduce the carbon monoxide content to 2 to 4 percent by volume with the usual degree of mixing. The carbon monoxide can be further reduced to below 0.5 percent by good mixing and a combustion time of at least 1.0 second at 704 C (1300 F). The carbon monoxide content can be reduced to less than 0.1 percent by increasing the time of contact to 1.0 second and raising the temperature to 816 C (1500 F).⁽³⁾ Afterburners are commonly used in cupola stacks or scrap preheaters, but they are seldom used to treat the off gases from arc furnaces, induction furnaces, coremaking, or mold-cooling operations.

The effluent from the cupola in the stack just above the charging door generally is fairly hot, so that not much fuel is required for the afterburner to heat the gas up to the ignition temperature. On the other hand, effluent from arc furnaces, coremaking, or mold cooling is at a lower temperature, and considerable fuel would be required to heat the effluent gases up to the ignition temperature.

Catalytic Combustors

Combustible fumes and carbon monoxide can be burned at 260 to 530 C (500 to 1000 F)⁽²⁾ provided that they are in contact with suitable catalytic agents and an excess of air is present. A properly designed catalytic-combustion unit should be capable of reducing the carbon monoxide content of the gases being treated to below 0.1 percent with the expenditure of much less fuel to heat the gases than would be required with direct-flame afterburners.

The catalytic agents will be slowly eroded from the catalytic plates by the solid particles in the uncleaned gas, thus making it necessary to replace the units once or twice per year. The high cost of replacing the catalytic units makes it desirable to remove the particulate from the polluted effluent before passing it over the catalytic plates to burn the combustible gases.⁽²⁾ However, the presence of organic material in the uncleaned off gases may make it difficult to filter out the particulate.

Catalytic-combustion units have not been used extensively in the control of combustible materials in the effluent from foundry operations.

Control of Emissions by Changing Melting Equipment

Most of the emissions from iron foundries originate in the melting operation, and most of the particulate and carbon monoxide emissions originate in the cupola melting operation. Arc furnaces produce enough particulate emissions that they are readily visible and must be controlled, but the carbon monoxide in the emissions rarely is controlled. Induction furnaces produce the least amount of particulate emissions and almost no carbon monoxide emissions.

Changing the melting furnaces from cupola to induction furnaces will, in most cases, reduce the amount of particulate and carbon monoxide effluent enough to reduce the need for pollution-control equipment for the melting operation. It is necessary to preheat the scrap before it is charged into the induction furnace. If the scrap contains large amounts of oil or grease or volatile metals (such as lead or zinc), some cleaning of the effluent from the preheater is desirable. In most small foundries, the emissions from scrap preheating and induction-furnace melting are not controlled and are discharged through stacks or inside the plant. If the effluent is discharged within the plant building, it adds to the pollution within the plant from other foundry operations. Recent restrictions by OSHA (Occupational Safety and Health Act) will make it necessary to clean the atmosphere inside iron foundries.

Changing the melting furnaces from cupola to arc furnaces will, in most cases, reduce the amount of particulate and carbon monoxide effluent, but pollution controls will still be required.

Effect of Emission-Control Systems on In-Plant
Occupational Safety and Health Act Requirements

When cupola or arc furnaces are equipped with fabric filters in a baghouse, the carbon monoxide in the effluent gases often can exceed the threshold-limit value of 50 ppm established by OSHA for workroom air. Most of the effluent from the baghouse would be discharged outside of the plant. However, fumes in the baghouse and in the dust-disposal areas could exceed the safe limits for workroom air, and suitable precautions must be taken before maintenance men or operators enter those areas. Carbon monoxide detectors equipped with alarms should be installed in suspected locations.

Carbon monoxide often exceeds the threshold limit value of 55 ppm⁽⁴⁾ established by OSHA for workroom air in mold-cooling tunnels. Effluent from cooling tunnels generally is discharged outside of the plant, either raw or after filtering. However, most foundries make no attempt to remove carbon monoxide and organic fumes from the cooling-tunnel discharge with afterburners. Maintenance men should monitor these cooling tunnels for carbon monoxide before entering.

Part of the organic materials in the molding sand would vaporize and form fumes when molds are cooled in the cooling tunnels. The fumes result when molding-sand or core-sand additives, such as sea coal, pitch, tar, oil, wood flour, or core binders are vaporized by the hot castings. Part of these organic fumes would be expected to condense on the mold-cooling-tunnel walls, ventilation ducts, and air filters. Human contact with polluted air or the condensed fumes should be avoided, because these materials are suspected of being carcinogenic.⁽⁴⁾

Fine silica dust is a hazard in workroom air. Fine silica dust in the workroom air can originate from dust or dry sand on the floors, the transport of dry sand or molding sand within the plant, sand-mixing operations, molding or coremaking, filing or cutting dry-sand molds or cores, casting shakeout, or finishing castings that are coated with sand. The airborne silica can be reduced to a level below the OSHA threshold-limit value by employing good housecleaning and proper ventilation. Contaminated ventilation air should be filtered before it is discharged. The respirable quartz (silica) threshold-limit value established by OSHA is 0.10 mg/m³.⁽⁴⁾

Noise is considered to be an occupational hazard by OSHA. High-energy venturi scrubbers are noisy and must be provided with suitable sound

insulation to protect the workroom environment. Other ventilation fans and blowers could be noisy if not properly installed and maintained. The medical profession has defined the noise level above which hearing is impaired as an average threshold level of 25 decibels (ANSI 53.6-1969) at frequencies of 500, 1000, and 2000 Hz. ⁽⁴⁾ OSHA ⁽⁴⁾ has set a permissible noise exposure of 90 decibels (dBA) for 8 hours' exposure, with progressively shorter exposures with increasing noise level, to 1/4 hour at 115 dBA, and no exposure above 115 dBA. (The sound level, in dBA, is to be measured with a standard-level meter operating on the A-weighting network with a slow meter response. ⁽⁴⁾)

References

- (1) "Air Pollution Aspects of the Iron Foundry Industry", by A. T. Kearney and Company, Inc., Chicago, Illinois, Contract CPA22-69-106, to Division of Air Quality and Emissions Data, U.S. Environmental Protection Agency, PB204-712 (February, 1971), page IV-33.
- (2) "Systems Analysis of Emissions and Emissions Control in the Iron Foundry Industry. Volume 1. Text", Report to Division of Process Control Engineering, Air Pollution Control Office, Environmental Protection Agency, Contract No. CPA 22-69-106, from A. T. Kearney & Company, Inc., Chicago, Illinois (February, 1971), PB 198-348.
- (3) Private communication from Tom L. Harsell, Jr., Harsell Engineering Company, Palos Verdes Peninsula, California.
- (4) "TLVs Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1972", American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (1972).

SUBTASK E

TESTING AND ANALYSIS METHODS FOR

