

METLURGICAL INDUSTRIES

The metallurgical industries can be broadly divided into primary, secondary, and miscellaneous metal production operations. "Primary metals" refers to the production of metals from ore. "Secondary metals" refers to the manufacturing of alloys by utilizing metals from scrap and salvage, as well as ingots. "Miscellaneous metal" production encompasses industries with operations that produce or use metals for final products. Metallurgical industries include the following:

- Primary Aluminum
- Metallurgical Coke
- Copper Smelting
- Ferroalloy Industry
- Steel Industry
- Primary Lead Smelting
- Zinc Smelting
- Secondary Aluminum
- Secondary Brass and Bronze Melting Processes
- Iron Foundries
- Secondary Lead Smelting
- Steel Foundries
- Secondary Zinc

As a representative industry within the metallurgical classification, iron foundries have been selected for discussion.

Methods to control air pollution produced by iron foundries are selected based on the methods of melting, the handling of sand, the types of molten metals and other materials, and the cleaning of finished castings. Air pollutant characteristics are affected by a number of factors, including the type of melting unit, material-handling and hooding systems, and emission control systems. Air pollution is prevented by capturing the smoke, dust, and fumes at the furnace and other sources, and transporting these contaminants to suitable control devices.

A. PROCESS DESCRIPTION

1. Mold and Core Production

Molds are forms used to shape the exteriors of castings. The green sand mold, the most common type, consists of moist sand mixed with 3-20% clay and 2-5% water, depending on the process. To prevent casting defects, materials such as seacoal (a pulverized high-volatility, low-sulfur bituminous coal), wood or corn flour, oat hulls, or similar organic matter may be added to the sand mixture. Cores are molded sand shapes used to form the internal voids in castings. They are made by mixing sand with various binders, shaping it into a core, and curing the core with a variety of processes.

2. The Melting Process

a. *Electric Furnace (General)*

In the electric furnace, the basic process operations are (1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace; (2) melting, during which the furnace remains closed; (3) back-charging, which involves the addition of more metal and alloys; (4)

refining and treating, during which the chemical composition is adjusted to meet product specifications; (5) slag removal; and (6) tapping molten metal into a ladle or directly into molds.

b. Induction Furnaces

Electric induction furnaces are either horizontal or vertical, cylindrical, refractory-lined vessels. Heating and melting occur when the charge is energized with a low-, medium-, or high-frequency alternating current. Induction furnaces also may be used for holding and superheating. Electric induction furnaces generally have lower emissions per ton of metal melted than the other furnace types. As a result, in spite of a generally lower unit capacity, induction furnaces have supplanted cupolas in many foundries.

c. Electric Arc Furnaces

Electric-arc melting furnaces are large, welded-steel cylindrical vessels equipped with a removable roof through which three carbon electrodes are inserted. The electrodes are energized by three-phase alternating current, creating arcs that melt the metallic charge material. Additional heat is generated by the electrical resistance of the metal to the current between the arc paths. The most common method of charging an arc furnace is by removing the roof and introducing the charge material directly. Alternatives include charging through a roof chute or side charging door. Once the melting cycle is complete, the metal is tapped by tilting the furnace and pouring the metal into a ladle.

d. Cupola

The cupola is a vertical, cylindrical shaft furnace which may use pig iron, scrap iron, scrap steel, and coke as the charge components. Melting is accomplished in the cupola by heat released from the combustion of coke (the reaction between oxygen in the air and carbon in the fuel) that is in direct contact with the metallic portion of the charge and the fluxes.

One of the advantages of using such a furnace is that counterflow preheating of the charge material can occur. In a cupola, upward flowing hot gases come into close contact with the descending burden, allowing direct and efficient heat exchange to take place. The running or charge coke, which replenishes fuel consumed, is also preheated before it reaches the combustion zone, thus enhancing the combustion process. Greater understanding of these features accounts, in part, for the continued popularity of the cupola as a melting unit. However, recent design improvements, such as cokeless, plasma-fired types that alter emission characteristics are now encountered.

3. Casting, Cooling, and Finishing

After melting, molten metal is tapped from the furnace and poured into a ladle or directly into molds. If poured into a ladle, the molten iron may be treated with a variety of alloying agents selected for their desired metallurgical properties. The molten material then is ladled into molds which are allowed to cool in open floor space, or, (in larger, more mechanized foundries) are conveyed automatically through a cooling tunnel before separation of the casting from the mold (shakeout). Molding and core sand are separated from the casting(s) either manually or me-

chanically. In some foundries the cooled molds are placed on a vibrating grid to shake the mold and core sand loose from the casting. Used sand from casting shakeout is usually returned to the sand preparation area and cleaned, screened, and processed to make new molds. Because of process losses and potential contamination, additional makeup sand may be required.

When castings have cooled, any unwanted appendages such as sprues, gates, and risers are removed by an oxygen torch, abrasive saw, friction cutting tool, or hand hammer. The castings then may be subjected to abrasive blast cleaning and/or tumbling to remove any remaining mold sand or scale.

B. SOURCES OF POLLUTION

Exhibit 1 illustrates the operations of a typical iron foundry and emissions they generate. Processes which produce air emissions include melting (furnace or cupola), molding, core-making, pouring, casting shakeout, cooling/cleaning, and finishing. These are described in greater detail in the next section.

C. POLLUTANTS AND THEIR CONTROL

Exhibit 2 summarizes the pollutant emissions from the various processes in a typical iron foundry, and indicates appropriate types of control methods. The nature of emissions from each source is described in this section.

1. Emission Sources

a. Mold and Core Production

The major pollutants emitted in mold and core production operations are particulates from sand preparation, mold core forming, and curing. Volatile organic compounds (VOCs), carbon monoxide, and particulates also may be emitted during core and mold curing or drying.

Exhibit 1: Emission Points in a Typical Iron Foundry **Exhibit 2: Emissions From Iron Foundry Processes**

Emission Point	Pollutants	Control Methods
Mold and Core Production	particulates	
VOCs		
carbon monoxide		Wet Scrubbers
Fabric Dust		
Collectors/Baghouses		
Afterburners		

Charcoal Adsorption

Melting fugitive particulates
fumes

organic compounds

carbon monoxide

VOCs

Induction and Arc Melting particulates (metal oxides)
organics

Cupola Melting dust consisting of:

iron oxide

silicon dioxide

zinc oxide

magnesium oxide

manganese oxide

calcium oxide

lead

cadmium

gases:

carbon monoxide

sulfur oxides

lead

organic emissions

Pouring, Casting, Cooling and Finishing particulates

magnesium oxides

metallic fumes

carbon monoxide

organic compounds

VOCs

b. Melting

The melting process begins with the handling of charge materials going into the melting furnace. Emissions from raw material handling are fugitive particulates generated from the receiving, unloading, storage, and conveying operations. Scrap preparation and preheating may emit one or more of the following: fumes, organic compounds, carbon monoxide, or coarse particulates. Scrap preparation with solvent degreasers may emit VOCs.

c. Induction and Arc Melting

The highest concentrations of furnace emissions occur during charging, back-charging, alloying, slag removal, and tapping operations. These emissions are primarily particulates (metal oxides) and possibly organics, depending on the scrap quality and pretreatment. Typical dust loading from electric arc furnaces can range from 10 - 15 lb/ton melted. Electric induction furnaces, however, may emit particulates at one tenth of that value.

d. Cupola Melting

The quantity and composition of particulate emissions vary among cupolas, and even at intervals in the same cupola. Causes include changes in iron-to-coke ratios, air volumes per ton melted, stack velocity, and the quality of the scrap melted. Where oily scrap is charged, the raw emissions potentially will be greater in quantity and much more visible. Based on a survey, the average emission from an uncontrolled cupola was approximately 13 - 17 pounds of particulate per ton melted. Eighty-five percent of such emissions may be greater than 10 μm in size.

Dust amount and composition vary from cupola to cupola. Each cupola has varying airflows at different phases in the melt process which affect the grains per standard cubic foot in emitted stack gases if all other factors are equal. The source of the raw charge materials also has a significant impact on dust composition and quantity. The dust can include some or all of the following materials:

- Iron oxide
- Magnesium oxide
- Manganese oxide
- Silicon dioxide
- Calcium oxide
- Lead
- Zinc oxide
- Cadmium

In addition, other gases and organic compounds may be emitted as part of the melting process. These include carbon monoxide, sulfur oxides, lead, and organic emissions. Both sulfur and organic emissions are influenced by the amount of oil or grease on the scrap. The quantity of sulfur oxides generated may be large enough to cause corrosion of air pollution control equipment. There are a number of instances where rapid deterioration of dust collectors on cupolas occurred where corrosion protection was not considered. Where fluorspar is used as an additive, the fluorine driven off can cause a corrosion problem with dust collection equipment. Fluorine also has the potential to dissolve glass bags. Carbonic acid, formed when carbon dioxide reacts with water vapor, may cause corrosion problems as well.

e. Pre-pouring, Pouring, Cooling, and Finishing

Particulate emissions can be generated during the treatment and inoculation of molten iron before pouring. For example, the addition of magnesium to molten metal to produce ductile iron causes a very violent reaction accompanied by various emissions of magnesium oxides and metallic fumes, depending on the method of treatment. Some methods, such as the tundish method, result in significantly lower emissions than others. Emissions from pouring consist of metal fumes, carbon monoxide, organic compounds, and particulates evolved when the molten iron contacts the mold and core materials. Emissions continue as the molds cool and during the shake-out operation, although at a much lower rate. Finishing operations, such as the removal of burrs, risers, and gates, and shotblast cleaning, also emit particulates, primarily iron, iron oxide, and abrasive media. The painting of castings also can lead to a variety of VOC emissions.

2. Air Pollution Control Measures

There are two primary collection methods for foundry particulates - wet and dry. Wet scrubbers include low- and high-energy types. Dry collection includes baghouses, mechanical collectors, and electrostatic precipitators. In addition, to control emissions of organic compounds, incineration or afterburners may be required. Air toxics merit special consideration, requiring careful selection of the emission control method.

a. Wet Scrubbers

For particulate collection, the mechanisms used in a wet-type collector are inertial impaction and direct interception. These are used either separately or in combination. In studying wet collector performance, independent investigators developed the contact power theory, which states that, for a well-designed wet-scrubber, collection efficiency is a function of the energy consumed in the air-to-water contact process and is independent of the collector design. On this basis, well-designed collectors operating at or near the same pressure drop can be expected to exhibit comparable performance. All wet collectors have a fractional efficiency characteristic -- that is, their cleaning efficiency varies directly with the size of the particle being collected. In general, collectors operating at a very low pressure loss will remove only medium to coarse particles. High-efficiency collection of fine particles requires increased energy input, which will be reflected in higher collector pressure loss.

In addition to particulates, gas scrubbers may be used to control odors and toxic and sulfur dioxide emissions. In this case, acids, bases, or oxidizing agents may have to be added to the scrubbing liquid. Disposal of this stream is subject to effluent guidelines for metal molding and casting.

b. Dry Collectors

The most frequently encountered equipment for the removal of solid particulate matter from an air stream or gas stream is the fabric dust collector or baghouse. With a mass median size of 0.5 μm , a collection efficiency of 98-99+% can be expected. As the filter medium becomes coated in a fabric collector, the collection efficiency rises. However, as material continues to build on the bag surface, higher pressure drops occur, which result in a significant reduction in airflow. To maintain design flows, the bags must be cleaned periodically by mechanical shaking or with pulsed air.

Filter media are now available for hot corrosive atmospheres, such as furnace emissions. Operating inlet temperatures up to 500°F (260°C) are not uncommon. High humidity can be a problem if no provision is included for the condensation of free moisture. Free moisture and acid dew point are the worst enemies of all fabric collectors. It is important to have the following design information in order to select the proper fabric and the quantity of bags required:

- Gas flow rate
- Temperature and dew point
- Acid dew point
- Particle size and distribution
- Concentration of solids
- Chemical and physical properties of solids

Teflon-coated, woven glass-fiber bags have been used on a large majority of cupola installations because of their high temperature resistance. If fluorspar is used, Nomex bags, which are acid-resistant, but combustible, are generally installed. The temperature of the gases entering the baghouse then must be reduced to a maximum of 400°F (204°C). Use of these lower-temperature bags creates a potential corrosion hazard because of the acid dew point problem. For reverse-air and mechanical shake collectors, air-to-cloth ratios range from 1.5-2.5:1.

Pulse-jet and cartridge collectors also can be used to collect pollutants from sand systems and casting cleaning operations. With either type of unit, care must be taken to select the proper air/cloth ratio (maximum of 25:1 with pulse jet and 1.5:1 with cartridge). In general, these types of collectors will have only marginal results with furnace and inoculation emissions. If considered, they should be employed at a very low air/cloth ratio. In addition, moisture introduced with compressed air may be significant and cause system failure.

c. Incineration

Afterburners may be used in some processes to control emissions, particularly when oily scrap or hydrocarbons in any form are charged into the furnaces or scrap preheat systems. Afterburning is required for below-the-door cupola emission systems. If afterburners are not used, carbon monoxide and oil vapors may be emitted through the discharge stack of the air pollution equipment. In order to achieve the required incineration, sufficient retention time (a minimum of 0.6 second) and ignition temperatures must be maintained.

In general, in the selection of collection devices for all processes, moisture, temperature, and the presence of corrosive materials must be considered. The temptation to operate at higher air/cloth ratios in baghouses must be avoided. Similarly, claims that lower pressure drops in scrubbers create high efficiencies have been proved to be false.

d. Adsorption

Charcoal adsorption has been used in conjunction with other control devices for VOC control.

3. Hazardous Air Pollutants From Other Metallurgical Industries

Hazardous Air Pollutants (HAPs) emitted from other metallurgical industries include both organic and inorganic substances. Exhibits 3 and 4 identify some HAPs from process operations at steel foundries and from aluminum production.

Exhibit 3: Hazardous Air Pollutants from Steel Foundries

HAPs Emission Sources	Potential Emission Sources	Potential Fugitive
Arsenic		
Beryllium		

Chromium		
Copper		
Lead		
Manganese		
Nickel		
Zinc		
Iron	Furnaces	
Foundry mold and core decomposition		Converter/charging
Furnace tapping		
Furnace charging		
Metal casting		

Exhibit 4: Hazardous Air Pollutants from Aluminum Production

HAPs	Potential Emission Sources	Potential Fugitive
Emission Sources		
Fluorides		
Chloride		
Hydrogen chloride	Calciner	
Material handling		
Furnaces		
Material crusher and mills	Storage and handling areas	Reduction cells
Furnace charging		Furnace tapping
Coke quenching		

D. REFERENCES

This report contains excerpts of information taken directly from the following source:

1. Air and Waste Management Association. Air Pollution Engineering Manual. New York: Van Nostrand Reinhold, 1992.

