AIR POLLUTION ASPECTS OF BRASS AND BRONZE SMELTING AND REFINING INDUSTRY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service

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Brass and Bronze Ingot Institute

and

National Air Pollution Control Administration

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National Air Pollution Control Administration
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PREFACE

To provide reliable information on the air pollution aspects of the brass and bronze ingot industry, the Brass and Bronze Ingot Institute (BBII) and the National Air Pollution Control Administration, Public Health Service, U. S. Department of Health, Education, and Welfare entered into an agreement on May 29, 1967. A cooperative program was established to study atmospheric emissions from the various industry processes and publish information about them in a form helpful to air pollution control and planning agencies and to brass and bronze industry management. Direction of this study was vested in a BBII-NAPCA Steering Committee composed as follows

Representing NAPCA	Representing BBII
Stanley T. Cuffe*	Earl S. Schwartz*
John L. McGinnity	George E. Heizman, Jr.
Guntis Ozolins	Irving Tanenberg

Information in the report describes the nature and range of atmospheric emissions during normal operating conditions and the performance of established devices and methods employed to limit and control these emissions.

*Principal representatives.

ACKNOWLEDGMENTS

Many companies and individuals in the brass and bronze ingot industry have been helpful in providing plant visits and questionnaire data for the study.

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The sponsors also wish to acknowledge the contributions of the principal author, Mr. Robert A. Herrick of Resources Research, Inc. and of the source testing personnel of the Division of Abatement, National Air Pollution Control Administration.

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AIR POLLUTION ASPECTS OF BRASS AND BRONZE SMELTING AND REFINING INDUSTRY

SUMMARY

This state-of-the-art survey covers information made available through members of the Brass and Bronze Ingot Institute (BBII) and from field studies conducted by the National Air Pollution Control Administration (NAPCA). Brass and bronze are generally considered to be copper-base alloys with zinc and tin, respectively, as the largest secondary components. Members of the Brass and Bronze Ingot Institute produce 31 standard copper-base alloys.

There are approximately 60 producers of brass and bronze ingots in the United States. In the years since World War II, the production of brass and bronze ingots has been fairly constant, averaging slightly more than 300,000 tons annually. The 12 BBII member plants represent some 40 percent of this total production. A questionnaire survey of the BBII members revealed that substantive data were sparse, and so an emission test program was instituted by the National Air Pollution Control Administration. The resultant test data are the basis for most of the conclusions drawn in this report.

The "ingot" manufacturers are naturally tied closely to the overall secondary copper industry. As of 1961, in addition to ingot makers, the industry consisted of several thousand dealers and collectors, several thousand foundries, about a dozen primary smelters using scrap and mineral concentrates, and several secondary smelters using scrap only. These plants are located mostly in the Northeastern States, the Pacific Coast States, and the East North Central States. A few plants are located in the Southern and West Central States.

MANUFACTURING PROCESSES

Obsolete domestic and industrial copper-bearing scrap is the basic raw material of the brass and bronze ingot industry. Scrap as received is frequently not clean and may contain any number of metallic and non-metallic impurities. These impurities can be removed by mechanical methods such as hand sorting or magnetizing, heat methods such as sweating or burning, or gravity separation in a water medium.

Brass and bronze ingots are produced from a number of types of furnaces through a combination of melting, smelting, refining, and alloying of the processed scrap material. Reverberatory, rotary, or crucible furnaces are used, depending on the size of the melt and the desired alloy. Stationary reverberatory furnaces refine batches, or heats, of up to 100 tons in 24- to 48-hour periods. When such large amounts of a single alloy are not required, the cylindrical "rotary" furnace is more often used. Whereas the reverberatory furnaces are usually built for 50 tons or more, capacities of the rotary furnaces range from only a few tons up to perhaps 30 or 40 tons. Both of these furnaces are normally heated by direct firing, in which process the flame and gases come into direct contact with the melt. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller, whether electric or non-electric, and are used principally for small quantities of special-purpose alloys.

EMISSIONS FROM BRASS AND BRONZE PRODUCTION

The principal source of atmospheric emissions in the brass and bronze ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, soot, and smoke. The use of low-sulfur fuel results in trace amounts of sulfur oxide emissions. Because zinc is a major low-boiling-point alloying constituent, appreciable amounts of zinc oxide are normally present in the exit gases also.

Analysis of dust collector catch indicates that from 56 to 96 percent of the collected dust is zinc oxide. About 6 to 8 percent is lead oxide along with lesser amounts of other metallic oxides. These small particles are in the submicron range, wherein they have the greatest opacity to light; therefore, the uncontrolled emissions form dense plumes.

Limited data indicate that concentrations of dust from "brass furnaces" may range from 0.05 to 4.1 grains per standard cubic foot (scf). Concentrations as large as 20 grains per cubic foot may be expected during the use of compressed air beneath the molten metal.

The average daily discharge of particulate emissions from a typical 50-ton reverberatory brass ingot furnace, covering a variety of alloy formulations, is 3,000 to 4,000 pounds, based upon an industry average-emission factor of 60 to 80 pounds of particulate per ton of ingots produced. On any individual heat the amount may vary widely. The results of recent NAPCA tests on reverberatory, rotary, and cupola furnaces show emissions ranging from 20 to 157 pounds per ton. From an annual production of 300,000 tons of ingots, the emission potential is about 10,000 tons of particulate. Other sources of particulate emissions include the preparation of raw materials and the pouring of ingots.

CONTROL OF EMISSIONS

The only air pollution control equipment to receive general acceptance in the brass and bronze ingot industry is the baghouse filter collector. The emissions from a baghouse in satisfactory condition are usually invisible. The concentration of dust being emitted from one Los Angeles installation was only 0.004 grain per cubic foot. Recent NAPCA data indicate particulate concentrations between 0.006 and 0.036 grain per standard cubic foot. These NAPCA tests were at operating baghouse installations under typical conditions.

Cost for installation of a baghouse depends to a large extent upon the auxiliary equipment required for proper ductwork, hooding, gas cooling equipment, and so forth. The baghouse itself is only a part of the total cost. Reports indicate installed costs for dust collection systems of up to $5.00 or more per cubic foot per minute capacity.

Information from a few installations that use wet scrubbers and electrostatic precipitators indicates that significant maintenance problems and low efficiency have been encountered. Recent development work on these dust collector systems may make them more applicable in the future.

Most of the material preparation processes involving mechanical or wet treatment do not produce air pollutants. Some heat treatment operations produce emissions that are combustible. These fumes may be satisfactorily controlled by an afterburner or by secondary combustion techniques.

EMISSION GUIDELINES

In spite of wide variations in types of furnaces, charge materials, and operating conditions, the major component of the emissions in nearly every case is zinc oxide. Typically, from 60 to 95 percent of the total material collected from brass and bronze smelting emissions is zinc oxide.

The generally accepted air pollution control device for this industry is the baghouse. Filter ratios of 2.0 to 2.7 cfm/ft^2 and pressure drops of 2 to 6 inches are usually encountered. The cooling of gases prior to filtration is a major engineering design consideration because the filter materials burn or melt at excessive temperatures. Too low a temperature, on the other hand, causes water condensation and consequently clogging of the filter. Typical operating temperatures for some filter materials are as follows:

Filter fabric	Peak temperature, °F	Operating temp., °F
Cotton	180	160
Dacron, heat-set	300	275
Glass fiber	600	500
Orlon, heat-set	300	270
Wool, treated	240	220

The source testing studies show that it is possible to reduce exit particulate emissions to between 0.01 and 0.03 grain per scf with no visible emissions.

The major air pollution control problem is the capture and ducting of fume emissions from the furnaces to the baghouses. Capturing the dust-laden gases generated during charging and pouring operations is particularly difficult. Ultimate control of air pollution and occasional in-plant contamination may require changes in furnace design, new metallurgical processes, or new technology for the capture of fumes at the point of generation.

GROWTH OF THE BRASS AND BRONZE REFINING INDUSTRY

Copper alloys have served the needs of mankind in many useful and decorative ways throughout recorded history. The terms "brass" and "bronze," today, are inaccurate descriptions of metallic content that have been passed down through historical usage. Brass has been generally considered to be an alloy of copper in which zinc is the principal alloying material. Bronze has been considered to be an alloy in which tin is the largest secondary component. In actuality this is no longer necessarily true.

The variety of copper alloys that can be made is virtually infinite, especially when secondary metals are recovered from a complete variety of scrap materials. Over the years it has been found advantageous to classify many of the standard scrap materials as well as the finished ingots being produced. The recovery of these alloys constitutes a major contribution to our economy because the domestic production of virgin metals would not meet the demand for copper-base alloys in this country. U. S. Bureau of Mines statistics indicate that secondary copper (recovered from scrap) was produced in quantity approximately equal to new production of copper from domestic ores during the 1950's.

The secondary copper industry is composed of many groups, including dealers, collectors, foundries, ingot makers, and smelters. "Secondary" refers only to origin and not to quality. The shortages existing after World Wars I and II led to an acceptance and rapid growth of the recovery industry.

Brass and bronze ingot manufacturing covers only a portion of the overall "secondary copper industry," though there appears to be some overlapping of the recovery processes. This usually depends upon the economic situation and the condition in which copper scrap is available.

Following surveys in 1939, 1947, and 1960, the Brass and Bronze Ingot Institute has adopted a list of 31 standard alloys that are now produced by the members of that organization. The BBII list of basic alloys and their nominal compositions[1] is presented in Table 1. This list parallels other lists of ingot and product specifications such as those of the American Society for Testing and Materials (ASTM), the Federal Stock Catalog, and the U.S. Department of Defense. Many other alloys are produced when needed.

Table 1. NOMINAL CHEMICAL SPECIFICATIONS FOR BBII STANDARD ALLOYS

Alloy No.	Classification	Cu, %	Sn, %	Pb, %	Zn, %	Fe, %	Al, %	Ni, %	Si, %	Mn, %
1A	Tin bronze	88.0	10.0		2.0					
1B	Tin bronze	88.0	8.0		4.0					
2A	Leaded tin bronze	88.0	6.0	1.5	4.0					
2B	Leaded tin bronze	87.0	8.0	1.0	4.0					
2C	Leaded tin bronze	87.0	10.0	1.0	2.0					
3A	High-lead tin bronze	80.0	10.0	10.0						
3B	High-lead tin bronze	83.0	7.0	7.0	3.0					
3C	High-lead tin bronze	85.0	5.0	9.0	1.0					
3D	High-lead tin bronze	78.0	7.0	15.0						
3E	High-lead tin bronze	71.0	5.0	24.0						
4A	Leaded red brass	85.0	5.0	5.0	5.0					
4B	Leaded red brass	83.0	4.0	6.0	7.0					
5A	Leaded semi-red brass	81.0	3.0	7.0	9.0					
5B	Leaded semi-red brass	76.0	2.5	6.5	15.0					
6A	Leaded yellow brass	72.0	1.0	3.0	24.0					
6B	Leaded yellow brass	67.0	1.0	3.0	29.0					
6C	Leaded yellow brass	61.0	1.0	1.0	37.0					
7A	Manganese bronze	59.0	1.0	1.0	37.0	1.0	0.6			0.5
8A	Hi-strength mang. bronze	57.5			39.0	1.0	1.0			1.5
8B	Hi-strength mang. bronze	64.0			24.0	3.0	5.0			3.5
8C	Hi-strength mang. bronze	64.0			24.0	3.0	5.0			3.5
9A	Aluminum bronze	88.0				3.0	9.0			
9B	Aluminum bronze	89.0				1.0	10.0			
9C	Aluminum bronze	85.0				4.0	11.0	2.0		0.5
9D	Aluminum bronze	81.0				4.0	11.0	4.0		3.0
10A	Leaded nickel brass	57.0	2.0	9.0	20.0			12.0		
10B	Leaded nickel brass	60.0	3.0	5.0	16.0			16.0		
11A	Leaded nickel bronze	64.0	4.0	4.0	8.0			20.0		
11B	Leaded nickel bronze	66.5	5.0	1.5	2.0			25.0		
12A	Silicon bronze	88.0			5.0	1.5			4.0	1.5
12B	Silicon brass	82.0			14.0				4.0	

Each of the classes of copper-base alloys has characteristics making it particularly suitable for products that may be subjected to different stresses, corrosion, or machining operations.[1] Tin bronze and leaded tin bronze are very corrosion-resistant and have good casting characteristics. High-leaded tin bronzes are malleable and are readily machined. Red and semi-red brasses are especially useful in products for water systems, such as valves, meters, and fittings because they are inexpensive, corrosion-resistant, and have good casting and machining characteristics.

Yellow brasses are moderately strong and have excellent machining and polishing characteristics. Manganese bronze has especially good tensile strength and corrosion resistance to sea water. Aluminum bronzes also have high tensile strength and hardness and are resistant to fatigue and to high temperature. The aluminum bronzes containing nickel are particularly suitable for marine pumps and propellors because of their resistance to corrosion and cavitation.

Leaded nickel brass and bronze are silvery in color, have excellent mechanical properties, and are tarnish and corrosion resistant. Silicon bronze and brass have expecially good casting characteristics. Dross formation is minor, leaving clean casting surfaces.

Since World War II, the production of brass and bronze ingots has been fairly constant and has averaged slightly more than 300,000 tons per year for the past 20 years (from a low of 203,000 tons in 1949 to a high of 360,000 tons in 1966). Table 2 shows the annual production of brass and bronze ingots as reported to the Bureau of Mines, U. S. Department of the Interior.[2]

Table 2. U. S. PRODUCTION OF BRASS AND BRONZE INGOTS DURING THE PERIOD 1947 THROUGH 1966

Year	Ingot production, tons
1947	284,800
1948	300,300
1949	203,400
1950	346,900
1951	366,600
1952	319,700
1953	305,400
1954	291,800
1955	335,900
1956	316,800
1957	284,100
1958	261,200
1959	293,100
1960	266,000
1961	270,000
1962	272,300
1963	291,200
1964	308,500
1965	333,500
1966	360,600

INGOT-MANUFACTURING PROCESSES

RAW MATERIALS

The basic raw material of the brass and bronze ingot industry is not ore or virgin metals but rather copper and copper-base alloy scrap. About two-thirds of the amount of secondary copper recovered is in the form of the brasses and bronzes, while one-third is in the form of copper alone.

Both the ingot industry and the American Society for Testing and Materials have made a continuing effort over the past 30 years or so to reduce the number of varieties of copper-base alloys. The classification of scrap metal is an important step in the production of brass and bronze ingots. Of the many hundreds of copper-base alloys that become available for reuse through scrap recovery channels, 54 primary types of copper-bearing scrap are now included in the standards published by the National Association of Secondary Material Industries.[3] These are listed in Table 3.

The ingot manufacturer is faced not only with many classes of scrap metal to refine and blend but also with a great deal of nonmetallic material that contributes nothing to the composition of the ingot and that increases the problems in producing a high-quality product. Among these undesirable materials are oil, grease, paint, insulation, rubber, antifreeze, chemicals, and many others. As more uses are found for copper-base alloys, the variety of undesirable and contaminating materials arriving in scrap recovery channels increases correspondingly.

Scrap dealers often provide the ingot manufacturer with an approximate classification of each lot of scrap sold, based principally on a quick visual check and experience. Larger scrap dealers are able to sort and segregate scrap into more precise classifications by using procedures such as examining metal color and structure, filing and drilling, chemical spot tests, and quick chemical analysis. Ingot manufacturers must classify, segregate, and analyze scrap shipments by additional methods, which may include sampling and melting for spectrographic analysis of alloys not readily identifiable.

RAW MATERIAL PREPARATION

Before the scrap metal is blended in a furnace to produce the desired ingots, removal of some of the nonmetallic contaminants or, in some instances, preprocessing the raw material to yield

Table 3. TYPES OF COPPER-BEARING SCRAP

No.	Designation
1.	No. 1 copper wire
2.	No. 2 copper wire
3.	No. 1 heavy copper
4.	Mixed heavy copper
5.	Light copper
6.	Composition or red brass
7.	Red brass composition turnings
8.	Genuine babbitt-lined brass bushings
9.	High-grade, low-lead bronze solids
10.	Bronze papermill wire cloth
11.	High-lead bronze solids and borings
12.	Machinery or hard red brass solids
13.	Unlined standard red car boxes (clean journals)
14.	Lined standard red car boxes (lined journals)
15.	Cocks and faucets
16.	Mixed brass screens
17.	Yellow brass scrap
18.	Yellow brass castings
19.	Old rolled brass
20.	New brass clippings
21.	Brass shell cases without primers
22.	Brass shell cases with primers
23.	Brass small arms and rifle shells, clean fired
24.	Brass small arms and rifle shells, clean muffled (popped)
25.	Yellow brass primer
26.	Brass pipe
27.	Yellow brass rod turnings
28.	Yellow brass rod ends
29.	Yellow brass turnings
30.	Mixed unsweated auto radiators
31.	Admiralty brass condenser tubes
32.	Aluminum brass condenser tubes
33.	Muntz metal tubes
34.	Plated rolled brass
35.	Manganese bronze solids
36.	New cupro-nickel clippings and solids
37.	Old cupro-nickel solids
38.	Soldered cupro-nickel solids
39.	Cupro-nickel turnings and borings
40.	Miscellaneous nickel copper and nickel-copper-iron scrap
41.	New monel clippings and solids
42.	Monel rods and forgings
43.	Old monel sheet and solids
44.	Soldered monel sheet and solids
45.	Soldered monel wire, screen, and cloth
46.	New monel wire, screen, and cloth
47.	Monel castings
48.	Monel turnings and borings
49.	Mixed nickel silver clippings
50.	New nickel silver clippings and solids
51.	New segregated nickel silver clippings
52.	Old nickel silver
53.	Nickel silver castings
54.	Nickel silver turnings

more efficient and economical utilization of the scrap may be desirable. These processes may be either mechanical or pyrometallurgical or hydrometallurgical.

Mechanical Methods

1. Hand Sorting is usually done as scrap is unloaded and placed into storage. This can be done by the types of objects (faucets versus industrial valves), their color (red versus yellow brass), and other visual clues that come with years of experience.

2. Stripping is a method used to remove the insulation or other coverings, particularly from copper cables. This can be done by hand or with machines.

3. Shredding is a recently developed process whereby material such as insulated copper wire is introduced to a hammermill, which achieves the separation of metal from other materials. Insulation is removed by air sweeping, and cyclones are necessary to prevent atmospheric contamination. Capital cost is high, and hence, this operation will probably not be found in small plants.

4. Magnetizing simply employs conveyors and magnetized pulleys to remove gross or tramp iron particles from brass borings and small items of brass scrap.

5. Briquetting forms small bales from bulky scrap. It is accomplished by powerful hydraulic presses. Compression of this type of scrap permits more compact storage plus easier handling and loading into furnaces. Rapid melting of compressed scrap involves minimum oxidation of the metal.

Pyrometallurgical Methods (Heat)

1. Sweating is the removal of low-melting-point metals such as lead, solder, and babbitt metal. This may be done by heating in a furnace, which is commonly designed with an open hearth and sloping bed so that the charge is placed on the high side. This placement permits the low-melting components to flow toward the lower end and be collected. Sweating is becoming less economical as improvements are made in radiator construction because less tin and solder are available for separation into valuable lower-melting-point fractions. A sweating furnace is shown in Figure 1.

2. Burning is the removal of insulation that is not mechanically stripped from wire or cable and that requires carefully controlled burning for removal.[4] This may more properly be considered part of the scrap preparation problem, but this type of scrap material often reaches storage areas and becomes a problem in the manufacture of ingots. Many different types of materials are used for insulation. The burning of some of these materials may create an air pollution problem. Burning polyethylene and polypropylene insulation does not require high temperatures, and the combustion products are not harmful, being largely carbon dioxide and water. Polyvinyl chloride insulation has, however, much higher resistance to flame and thereby requires much more heat input for combustion. Its combustion products include carbon dioxide, water, phthalic anhydride, and hydrogen chloride. Fluorocarbon insulation may

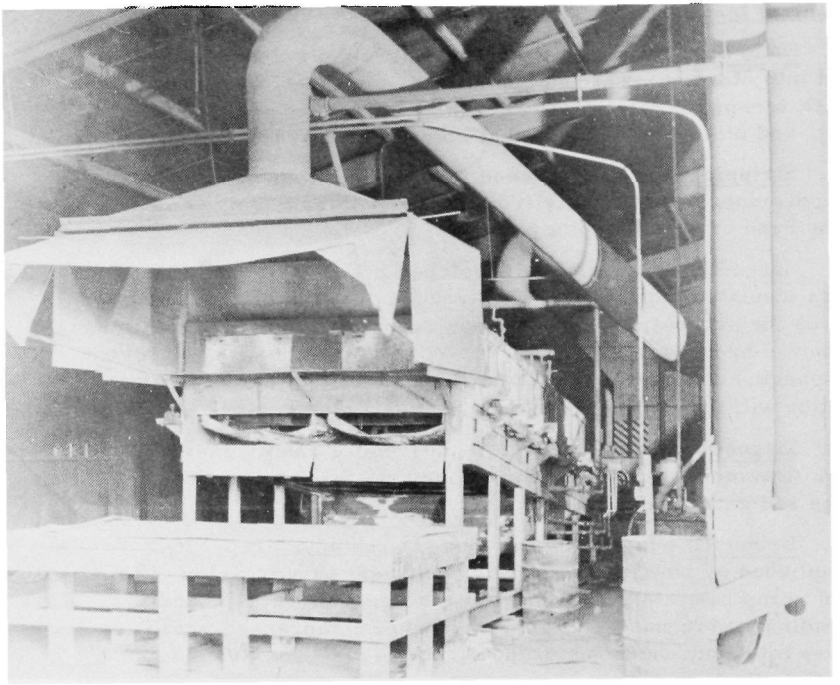

Figure 1. Tunnel-type sweating furnace.
(Courtesy H. Kramer and Company)

release hydrogen fluoride when burned. Some of these chemicals are highly toxic and corrosive.

3. Drying involves the use of a heated rotary kiln to vaporize excess cutting fluids from machine shop chips or borings. This must be done carefully to prevent high temperatures that would warp the steel kiln and begin to cause oxidation on the large surface area exposed on the metal chips.

4. Blast Furnace or Cupola. Although the names are sometimes used interchangeably, the cupola can be used simply to melt down metal or reduce oxides, whereas the blast furnace reduces an ore or metal oxide to the molten metal. A blast furnace is shown in Figure 2. The industry furnaces recover metal from skimmings, slags, and so forth, and the reducing atmosphere allows direct reduction of metallic oxides. Coke is employed both as fuel and reducing agent through the production of carbon monoxide. The dense molten metal settles from the nonmetallic glass-like slags. The resulting metals (black copper or cupola melt) must be further refined in the ordinary furnaces to produce a finished ingot alloy.

Hydrometallurgical Methods (Water)

1. Concentrating is the process by which the metallics in fine

materials are recovered through differences in density. Although the total loss of metal is greater than in the blast furnace, this method is well adapted to fines that might be blown out of the furnace. It involves grinding, screening, and gravity separation in a water medium. There is no air pollution, but water pollution must be carefully avoided.

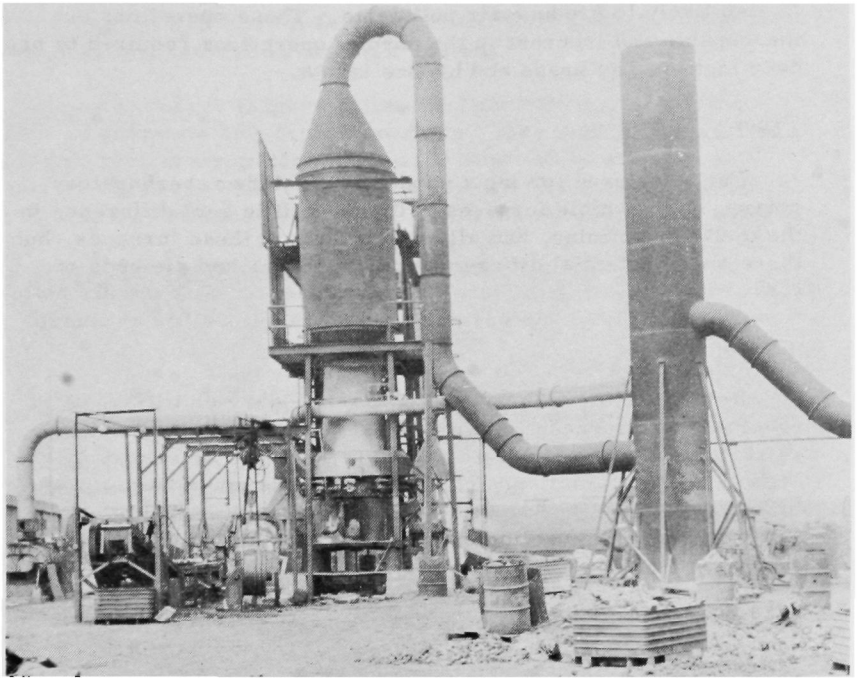

Figure 2. Blast furnace for smelting copper-base scrap slag and residues.
(Courtesy H. Kramer and Company)

INGOT PRODUCTION

Brass and bronze ingots are produced from a number of types of furnaces through a combination of melting, smelting, refining, and alloying of the processed scrap material. Virgin metals are used at times as additional raw material to obtain the specifications desired. They may be used in diluting certain elements that cannot be refined out of the metal and in increasing the percentage of a desired constituent that may be deficient in the initial scrap charge.

Basic to the processes is the fact that air pollutants are generated. The scrap raw materials contain both metallic and nonmetallic impurities that must be removed in order to produce ingots of desired specifications. Smelting and refining are the processes by which these impurities are removed. If these materials cannot be removed as part

of a slag or flux covering, then they will usually be emitted as part of the hot gas stream and become part of the air pollution problem.

One of the most common methods of removing metallic impurities is to introduce compressed air beneath the surface of the molten metal. This violent agitation is almost sure to produce large quantities of finely dispersed air pollutants in the exhaust gas stream. The introduction of combustible ingredients with the scrap metals is also likely to produce air pollutants. These operations are inescapable and inherent in the normal operations required to produce high-quality brass and bronze ingots.

Types of Furnaces

Furnaces used for ingot production include reverberatory, rotary, and crucible furnaces. There is little real difference in the melting, refining, and alloying actions in these furnaces, but there are substantial differences in capacities and methods of charging and heating. There are also differences in the air pollution potential of the various units and the applicability of control procedures.

Reverberatory Furnaces may be stationary or tilting. A reverberatory furnace is a large rectangular box-like structure, refractory lined, that uses direct firing to heat the charge by conduction and radiation. The lining depends upon the manufacturer's experience, the types of alloys and fluxes, and other factors. Charging may be either by side door or by an overhead door, as in Figure 3.

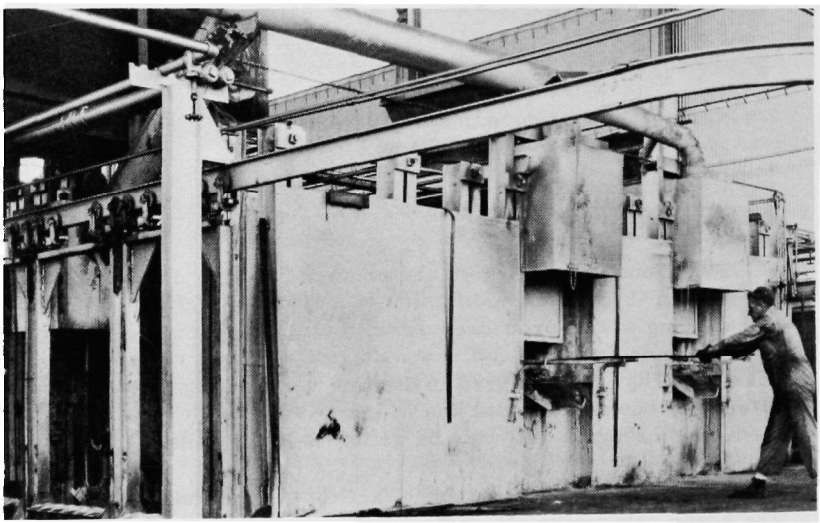

Figure 3. Reverberatory furnace for melting and refining copper and brass scrap. Designed for charging through roof doors.
(Courtesy H. Kramer and Company)

The capacity of a stationary reverberatory furnace may be as much as 100 tons or more per heat or charge. Reverberatories are the basic production unit for large runs of the more common copper-base alloys. A charge of scrap metal is made at the beginning of the heat and at intervals during the melt-down period. Melting is done as rapidly as possible and may be done in oxidizing or reducing atmospheres, depending upon the types of scrap, alloy, and other factors. Burner fuels are often enriched with oxygen to increase the rate of melting. The fuel is normally gas or low-sulphur-content fuel oil. A fairly light and fluid slag cover helps in reducing volatilization and oxidation losses.

Rotary Furnaces (Figure 4) can be either tilting, nontilting, or capable of complete 360-degree rotation. They are cylindrical and lined with refractory material. Heat is supplied by movable gas or fuel oil burners. The charging, alloying, fluxing, and sampling procedures are similar to those used with the reverberatory furnace.

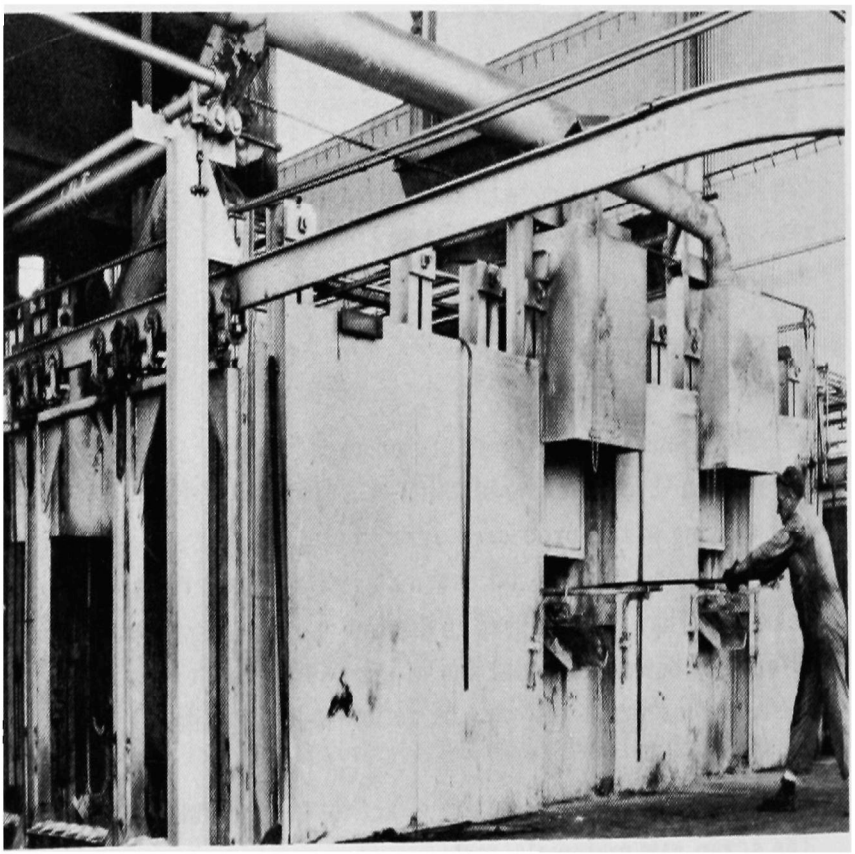

Figure 4. Gas-fired rotary brass melting furnace.
(Courtesy H. Kramer and Company)

They are usually somewhat smaller than reverberatories, frequently having capacities of 15 to 20 tons per heat, though they may be as large as 50 tons per heat. The rotary or rocking action promotes rapid heat transfer and lengthens refractory life by spreading the slag line over charging areas. Charging ports may be located on the side, top, or end of the cylinder.

Crucible Furnaces are most useful for melting small quantities of clean scrap and for refining specialized alloys, but they can be used for common alloys as well. The gas- or oil-fired crucible has a steel cylindrical furnace shell lined with refractory material, inside of which the crucible is mounted. These furnaces use indirect firing; that is, the flame is aimed tangentially into the annular combustion space between the crucible and the refractory lining, heating the crucible's contents without contacting the charge.

Electric crucible furnaces use either high- or low-frequency induction heating. They are especially well adapted to rapid melting of small batches. Heating is due to the resistance to the flow of electrical currents induced in the charge by high-frequency electric currents in an induction coil surrounding the crucible, or, with low-frequency heating, by currents induced by an insulated, water-cooled iron core transformer under the crucible. A certain amount of mechanical turbulence is caused in the low-frequency type by reaction of primary and secondary magnetic fields. The relatively higher cost of electrical equipment and energy is offset to some degree by high speed of melt and excellent temperature control, especially for relatively small heats of special alloys.

The direct-heating furnaces such as rotaries and reverberatories have greater fuel efficiency than the indirect-heating furnaces such as the gas- or oil-fired crucibles and the electric induction furnaces. Direct-fired furnaces are, however, invariably more difficult to control with regard to dust, smoke, and fume losses. Since they are also much larger, they are usually the primary sources of air pollution from the plant.

INGOT POURING AND MISCELLANEOUS

Samples of the furnace melt are taken as the refining operation progresses. As soon as analysis indicates that the correct grade has been achieved and that the melt is at proper temperature, pouring of ingots is begun. In most instances the metal molds are handled by a semiautomatic system. Metal from the furnace is tapped into some sort of holding ladle, and this is tilted by an operator to fill one or several molds as they pass by. This arrangement can be varied in a number of ways, the method being adapted to the quantity of alloy being prepared.

The line of molds may be movable or stationary. When a large reverberatory furnace is tapped, an automated line of molds is commonly used. Several are filled at once by operator control;

the next section is moved into position; time is allowed for cooling; water sprays are used for final cooling; the ingots are removed and conveyed to temporary container boxes; the mold cavities are cleaned and, if necessary, lined; pretreatment material such as charcoal is added; then the molds are taken back to the pouring station.

In the process of melting, smelting, refining, pouring, and so on, several miscellaneous operations may occur. Coverings of molten slags and fluxes are sometimes formed. A flux is not necessarily a slag but is a chemical added to accomplish a metallurgical purpose, though at times they may both act as liquid covers. Figure 5 illustrates the reduction in zinc loss accomplished by a cover. These covers, which are eventually removed along with drosses and skimmings, contain metal and are reprocessed for the ultimate recovery of the metal.

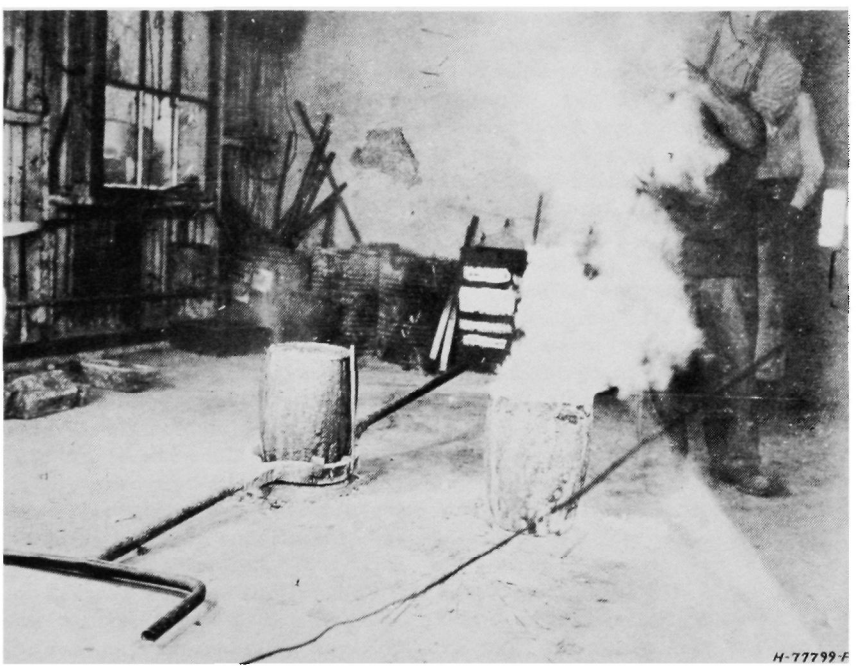

Figure 5. Transfer crucibles, with cover and without.[5]

More detailed descriptions of these processes are included in numerous references containing additional information on brass and bronze production. [5-8]

AIR POLLUTANTS GENERATED — CAUSE AND CONTROL

GENERAL CHARACTER OF EMISSIONS

The various types of ingot furnaces and intermediate processes such as blast furnaces have individual operating problems with regard to the generation and control of air pollutants within the plant. Direct-fired furnaces create greater problems in this respect than indirect-fired furnaces because of the open flames impinging on the scrap metals. The large reverberatory and rotary furnaces produce the greatest quantity of pollutants because of their large capacity per heat and the volume and high velocity of their combustion gases. Large or small, rotary or reverberatory, the amount of particulate emission from any kind of brass furnace is roughly proportional to the amount of zinc contained in the furnace and the amount of charging and refining that must be done to bring the alloy into the required chemical specification.

Emissions that may contribute to atmospheric pollution are released from various operations in a brass or bronze ingot plant. Included are the handling and concentrating of raw materials; the burning of oil, grease, and insulating materials; the refining and concentrating of low-grade scrap and metallurgical wastes in a blast furnace; plus the firing up, charging, alloying, and pouring operations connected with the ingot furnaces themselves. Solid and liquid particulates such as fly ash, carbon particles, mechanically produced dust, unburned fuel oil mist, and particularly, metallic fumes produced from the oxidation of some of the more volatile alloying constituents are among the types of emissions that need to be controlled. The types and ranges of emissions depend on factors such as fuel, composition and melting temperature of the alloys, types of furnace, and various operating factors such as methods of charging, melting, refining, removing slag, adding alloy metals, and pouring the ingots. A typical analysis of fumes[9] emitted and caught in baghouse filters is shown in Table 4.

Particulates other than metallic fumes are not generally considered too troublesome to control, but the particle size of zinc and other oxide fumes requires the use of extremely efficient air pollution control equipment. The particle size is in the range of 0.03 to 0.5 micron.[3] The individual particles tend to form lace-like agglomerate structures, as shown in Figure 6. The dense white plume so characteristic of zinc oxide is due in large measure

Table 4. RANGE OF CHEMICAL ANALYSIS OF DUST COLLECTED BY A BRASS AND BRONZE SMELTER BAGHOUSE[5]

Element	Composition range, %
Zinc	45.0 to 77.0
Lead	1.0 to 12.0
Tin	0.3 to 2.0
Copper	0.05 to 1.0
Chlorine	0.5 to 1.5
Sulfur	0.1 to 0.7

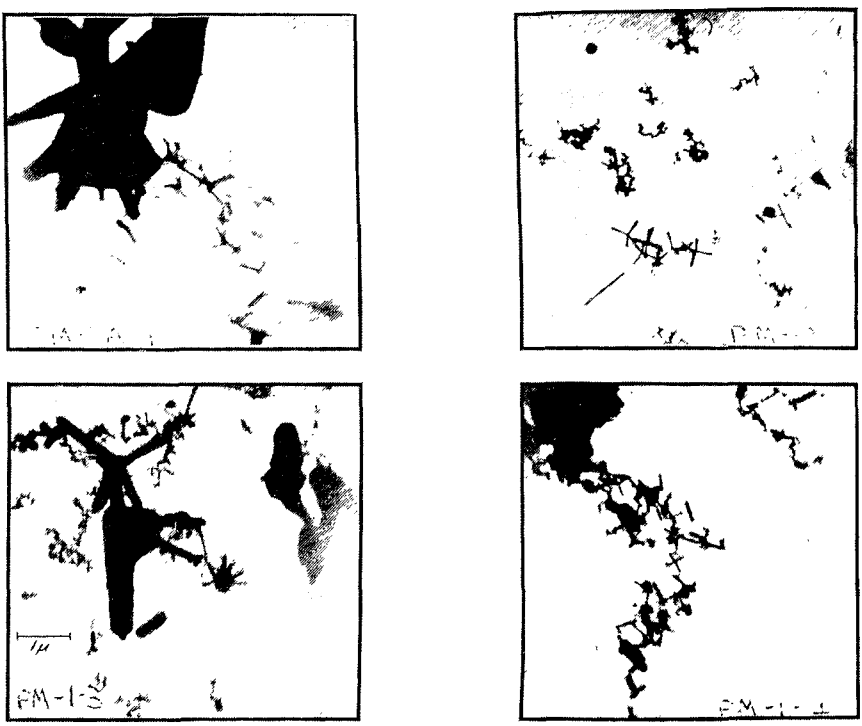

Figure 6. Electron photomicrographs of fume from zinc smelter.[6]

to the fact that maximum scattering of light is caused by particles from 0.2 to 0.5 micron in diameter.[8]

Gaseous emissions from ingot plants include the oxides of carbon (principally carbon dioxide but including some monoxide), nitrogen, and sulfur (if the fuel contains sulfur). The sulfur content of natural gas is too small to cause sulfur oxides to be emitted in objectionable quantities, but fuel oil can have an appreciable sulfur content. Limited source testing data[10] indicate that trace amounts of NO_2, H_2S, and halogens are present in concentrations of below 1 ppm.

RAW MATERIALS

Although the nature of the scrap metal has much to do with the ultimate emissions, most of it arrives in solid forms not likely to cause pollution. Pipe, chunks, casting, and so forth, cause no problem. Borings, chips, and grindings become progressively smaller, but they are usually associated with cutting oils and are not likely to produce dust. A very few scrap items might cause dust in handling. When slags and other similar materials are handled, there can be fugitive dust, but this is not much different from handling a pile of sand or other minerals. Emissions should be negligible except during periods of very dry, windy weather. Fuel, such as gas or oil, arrives by pipeline. Coke for the blast furnace contains a minimum of dust.

RAW MATERIAL PREPARATION

The mechanical methods of processing scrap, as described under manufacturing processes, should cause little or no pollutant problems. The hydrometallurgical process of concentrating must be carefully controlled to prevent water pollution. Pyrometallurgical processes all create air pollutants to some degree.

Sweating

Sweating is carried out at medium temperatures because only the solders and low-melting-point constituents are to be melted, not the entire radiator. Metal fume losses are very low, but fumes and combustion products of antifreeze residues, soldering salts, and hose connections will be drawn into the collection system.[7] Sweating furnaces are infrequently provided with wet scrubbers using a slightly alkaline spray or with afterburners.

Burning

When a separate operation is set up for burning off the insulation from wire it should properly be considered as preparation of scrap rather than as the manufacture of ingots. Little information is available concerning these emissions. An effective scrubber must be used when insulations containing halogens are burned so that dangerous fumes will be prevented from reaching the atmosphere.[4] Source tests in Los Angeles indicate that uncontrolled emissions can be dense black smoke containing particulate matter in concentrations as large as 29 grains per scf at 12 percent CO_2. Control of these emissions, largely combustible matter, by the use of secondary combustion at 2,000° F resulted in emissions with concentrations of particulate matter as small as 0.16 grain per scf at 12 percent CO_2 and with smoke opacities of 0 to 10 percent white.[8] The addition of these materials to the ingot furnace will be considered under "charging."

Drying

The removal of cutting oils from chips and borings creates considerable amounts of hydrocarbons. The nature of the combustion process that eliminates these hydrocarbons will determine whether fumes and soot escape or whether emissions are clean and fully oxidized. The vaporized fumes must be burned in afterburners to oxidize the hydrocarbons and prevent air pollution. Afterburners placed on this type of emission source have been observed, and no emissions were visible.[9]

Blast Furnaces

The blast furnace (or cupola) produces a concentrated product called "black copper" or "cupola melt" from low-grade materials such as slag and skimmings. The product actually has variable proportions of copper, tin, lead, zinc, nickel, and other metals. This is a cheaper process than the ingot furnaces in which to recover the metallic values in the low-grade feed materials. The blast furnace is not common in the smaller ingot-producing companies. Operation on a 24-hour basis is normally advantageous with relatively large quantities of material.

The charge is introduced at the top of a vertical furnace, along with coke for fuel and a reducing agent, plus limestone or other materials for fluxing. Slag and concentrated alloy are tapped near the bottom of the furnace. Slag is often tapped continuously while metal is obtained at intervals. A large volume of air is introduced through tuyeres spaced around the periphery of the furnace. Temperatures in the smelting zone are sufficient to reduce oxides to molten metal. These temperatures drop rapidly as the gas rises through the charge material to the top of the furnace.

Fumes and dust from the blast furnace or cupola are similar to those from the ingot furnaces. The particulate matter and gases emitted from the blast furnace are likely to be rather variable because of the large variety of scrap, slag, skimmings, and spills that are processed. Limited data from three samples indicated that particulate matter reaching the baghouse ranged from 35 (following a sand catcher) to 220 pounds per hour.[10] A common practice is to direct these fumes to the same collection devices used for ingot furnace emissions. A dry inertial collector, such as a cyclone or a sand catcher, frequently precedes a baghouse in order to remove the large abrasive particles, but high-efficiency particulate collection equipment is necessary to remove the finer (submicron) particulate.

SMELTING AND REFINING

Direct-fired (or open-flame) furnaces such as reverberatory and rotary types will produce larger concentrations of zinc oxide fume than indirect-fired furnaces such as crucibles and electric

induction furnaces will, other conditions being comparable. Since the very hot and high-velocity combustion gases come in direct contact with the metals in the charge, metal losses are high when there is an appreciable proportion of zinc in the alloy. The direct-fired type of furnace is often more difficult to hood effectively. Except for the physical arrangements, however, the actual smelting and refining that produce high-quality ingots are similar in both direct-fired and indirect-fired furnaces.

A number of factors in furnace operation can affect the type and quantity of emissions. Among these are the type of fuel used, control of air-fuel ratios, control of temperatures, the order of adding metals to the furnace, provision of proper slag cover, and good housekeeping in the furnace area. These items will be discussed in typical chronological order.

Heating

Fuel used in the various furnaces can have important effects on the types of emissions from the plants. Electric furnaces do not add any objectionable emissions, and what is more important, they do not have the sweeping effect of hot gases across the surface of the melt. Indirectly heated furnaces also avoid this sweeping effect.

The choice of oil or gas as a fuel is usually made on the basis of lowest cost for a given heat content, but gas is often more trouble-free, both in minimizing pollution and in maintaining proper combustion conditions. Plants are often equipped to burn either type of fuel so as to take advantage of price fluctuations and seasonal availability. When oil is used, very careful control of the air-fuel ratio is necessary to reduce pollutants such as soot, smoke, and unburned fuel particles to a minimum.

Furnaces are often preheated and maintained hot before scrap is added. The exhaust gases at this time are usually very clean and are exhausted directly to the atmosphere. A common technique is to alternate two furnaces, running only one at a time into a single dust collection device.

Charging

The type and condition of the scrap raw material are factors that may affect the content of emissions. Scrap that is oily, greasy, or dirty may have these contaminants removed by preliminary treatment, or the operations may be done directly in the main ingot furnaces. In either case considerable smoke emissions are apt to occur. With combustion there will be emissions of the normal products of combustion plus unburned hydrocarbons, fly ash, and dust in the stack gases. When the scrap material being used has relatively large proportions of low-volatility constituents such as zinc, metallic oxide fume will be in the stack gases of the furnaces.

During the charging cycle, emissions are also dependent upon factors such as location of the charging doors, the percentage of volatile alloy constituents (principally zinc), and upon whether the entire charge is made at the beginning of the heat or at intervals during the melting stage. Overhead charging doors in reverberatory furnaces will permit large losses of hot gases, fly ash, and fume into the plant when charges are loaded at intervals during the heat. Effective hooding of overhead charge doors poses difficult problems because of the necessity of providing access for loading equipment into the space between the charge door and the hood. End and side doors are not as vulnerable to the loss of furnace gases, especially end doors that load the charge in the direction of the induced flow of the furnace gases.

Some of the greatest air pollution problems occur during charging. It is physically difficult to place the entire charge into the furnace at one time. Later charges are, therefore, added to molten metal, and the combustible materials (and plain dirt) are emitted in tremendous bursts that are almost impossible to burn completely or even to contain within the capacity of the collection system.

During the charging of extremely oily scrap metal it is considered good practice to turn off the burners. This reduces the total volume of gases that must be collected during this short period of time. Escape of pollutants during this period, however, still poses a challenging problem for the industry. The volume and equipment necessary to capture this escaping effluent would be extremely large and expensive. One reverberatory furnace installation, using top charging, is covered by a 12- by 24-foot hood with an air intake capacity of nearly 40,000 cubic feet per minute.[9] This is still sometimes insufficient to capture all the emissions.

Melting

After material is charged, all doors and openings of the furnace are closed. Burners are set to maximum efficiency for fastest melt down and superheating of the molten metal. Supplemental oxygen may be used at this time. A great amount of fumes may occur whenever zinc is present or combustible contaminants are present in the charge. The latter may include items such as grease, oils, and rubber. Much of the combustible emissions may be controlled by proper draft regulation and burner setting. A few materials contain nearly as much oil as is normally fed to the burners, so that theoretically no additional fuel should be required. The lack of uniformity in scrap, however, makes this control a difficult art.

Refining

The terms "refining" and "smelting" are somewhat analogous and interchangeable in that the raw materials are purified and impurities are removed. Scrap normally contains 5 to 10 percent of wood,

dirt, and other nonmetallic contaminants that must be removed. In a majority of the copper-based alloys certain elements such as iron, manganese, silicon, and aluminum are normally considered contaminants and must be removed by refining.

Refining is that cycle of the heat in which impurities and other constituents of the charge, present in excess of specifications, are reduced or removed. Many different processes are employed to bring the composition of the melted scrap within permissible limits. Refining methods vary with the type of furnace, the type of alloy being produced, the condition or availability of different types of scrap in the charge, and the experience and opinions of the personnel involved.

Refining is a chemical process of purification. These chemicals, commonly termed fluxes, may be gaseous, liquid, or solid. By far the most extensively used gas for refining is compressed air (oxygen). Blowing air into the molten bath of metal causes a selective oxidation of metals in accordance with their position in the electromotive series. Iron, manganese, silicon, and aluminum are high in the series and are, therefore, oxidized in preference to copper, tin, and other metals. Part of the zinc is oxidized, but this is an unavoidable loss, and below certain concentrations, the undesirable metals are oxidized simultaneously.

The metal oxides, which are lighter than the molten metal, are removed from the melt by entrapment in the slag covering and as entrainment in the gases leaving the furnaces. The fumes and dust in this hot airstream must be removed as an air pollutant. When oxidation is purposely avoided, an inert gas such as nitrogen may be used to remove entrained gases of solid impurities such as occluded oxides. Bubbling of these inert gases in the molten metal can sometimes loosen foreign materials and bouyantly lift them to the surface, where they are removed.

A slag is usually formed on the surface of the melt. Part of this is formed from nonmetallic material in the scrap, part is deliberately added as a cover, and sometimes the slag also forms part of the flux. Solid and liquid fluxes for refining can be either nonmetallic, pure metals, or alloys. They may degasify, densify, fluidize, and homogenize the alloy; deoxidize; act as hardener; or become part of the alloy.

Fluxes as a whole do not contribute to air pollution, except in releasing impurities that must be removed from the alloy in one way or another. Flux covers, which are eventually skimmed off, have a generally beneficial effect on the quality of stack emissions by preventing excessive volatilization losses. Some of the more common fluxes are broken glass, charcoal, borax, sand, limestone, iron scale, soda ash, and caustic soda.

The use of slag covers on the melt is generally desirable in all types of furnaces. A thick layer is not desirable, since it will reduce heat transfer to the melt in direct-fired furnaces. Maintaining the cover between 1/4 and 1/2 inch, depending on the type of alloy and the furnace being used, is normally satisfactory. The composition of the cover will vary with the type of furnace, the scrap in the charge, and the alloy being made. A heavy, inert, and tenacious slag cover is, however, required in all cases.

It is the nature of refining to remove impurities from the molten bath of metal. When these can be removed by the slag or flux covering, there will be no air pollutants. When compressed air or gas is blown beneath the molten bath of metal, impurities are entrained in the effluent airstream. Most of these metal oxides are formed as a condensed fume and are submicron in size.

Alloying

Modification of the alloy during the heat by addition of virgin metal or specialized scrap may lead to an increase in fume emission. Having very nearly the required quantity of these alloy constituents in the initial charge is preferable in order that the flux cover will be formed early in the heat, protecting against excessive oxidation and volatilization of the zinc. The problem of excessive formation of fume naturally becomes greater as the percentage of volatile constituents increases. Owing to its very low boiling point, zinc is the most serious problem.[5]

Pouring of Ingots

Physical methods of pouring the molten alloy into ingot molds vary. The furnaces may be tapped directly to a moving, automatically controlled mold line, the alloy sometimes filling one or more molds at once and then being shut off while a new set of molds moves into position on the endless conveyor. In other variations, the metal is tapped from the furnace into a ladle which should have a slag cover, especially for high-zinc alloys. The molten alloy is then moved to a mold line, which may be movable or stationary.

Metal oxide fumes are produced as the hot molten metal is poured through the air, even over these short distances. Other dusts and the like may be produced, depending upon the type of linings or coverings associated with the mold as it is filled with hot molten metal. Covering of the metal surface with ground charcoal is one of the methods used to make "smooth-top" ingots. This charcoal creates a shower of sparks, as in Figure 7. These emissions are released into the plant environment at the vicinity of the tap and the molds being filled. If there is no local exhaust system, fumes may spread over a wide area of the plant. Hooding this movable equipment can become exceedingly complex. The design of hoods, air velocities, and associated ductwork has been treated at length in various papers and books.[11-13]

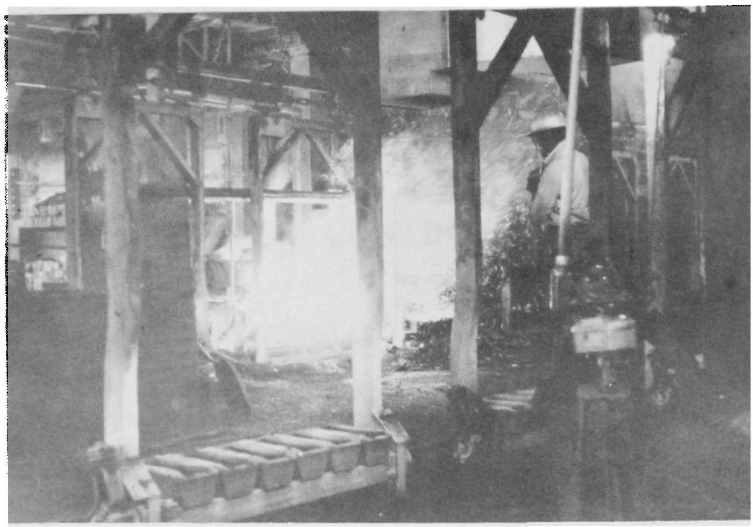

Figure 7. Pouring of ingots.[9]

The control of pouring and melting temperatures is important. The quality of the alloy will be affected by losses of the volatile constituents. Too high a temperature during the melting and refining cycle may result in having to add additional zinc because of excessive fume loss. The "proper" pouring and melting temperature will depend upon the alloy in question. There are disadvantages if the pouring temperature is either too high (zinc losses) or too low (freezeup). Exact control of temperature is not always an easy task over the period of time required to empty the furnace, but control within ±90° F is important.

Figure 8 indicates the melting, boiling, and pouring points of some common copper-base alloys and their constituent metals.[6] The boiling points of alloys containing zinc are approximately proportionate to the zinc content. Alloys with 20 to 40 percent zinc have boiling points around 2,100° F and melting points of from 1,700° F to 1,900° F.

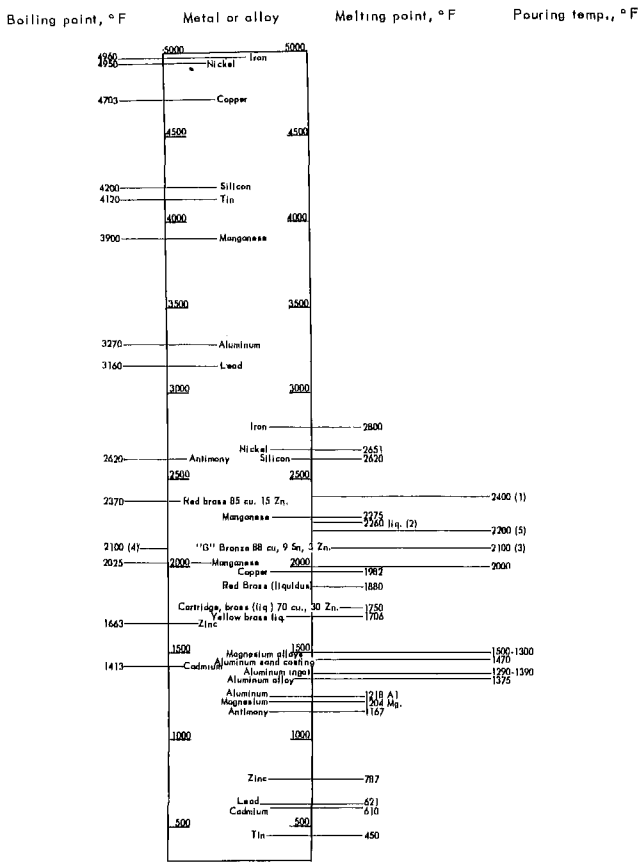

Figure 8. Boiling, pouring, and melting points of metals and alloys.[5]

PRESENT CONTROL SYSTEMS

AVAILABILITY AND GENERAL USE

A number of basic types of control equipment are available for removing particulates suspended in airstreams. They may be classified into five general groups: settling chambers, cyclones or centrifugal collectors, scrubbers, electrostatic precipitators, and baghouses. The first two types of equipment are not satisfactory for submicron-sized particles. Wet scrubbers and precipitators have not been particularly successful in the collection of zinc oxide fumes.[4] The use of baghouse collectors has been the prime method to receive general acceptance to this date by the brass and bronze ingot industry. This does not imply that they are completely satisfactory or that other devices are not occasionally employed.

Baghouses are filter devices with multiple tubular cloth bags contained within roughly cubical airtight compartments. Figure 9 shows the configuration of a typical baghouse compartment. Fabrics include cotton, glass fiber, wool, or synthetic fibers such as Orlon* and Dacron.* Baghouses are among the most efficient devices for submicron particles. Manufacturers claim efficiencies up to 99.9 percent. Recent tests of operating units[10] showed efficiencies generally between 95 and 99.6 percent. Temperature limitations of the filter fabrics may require cooling or dilution of the incoming particle-laden airstream.

DESIGN OF CONTROL SYSTEMS

The typical dust collection system in the brass and bronze ingot industry is not constructed with the overall operation but has been added to existing furnaces. Often there are space limitations or other problems in the physical layout.[7, 9, 14, 15]

A common practice is to operate furnaces as pairs, wherein one furnace is heating in preparation for the charge while the second furnace is concluding the previous refining operation and pouring ingots. Rarely would both furnaces be in operation simultaneously. This is because facilities for pouring and charging are shared between the two furnaces. The air pollution control system is designed around this type of operation to make the best use of the capacity available for effectively cleaning the stack gases at optimum cost.

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*Mention of company or product does not constitute endorsement by the U.S. Department of Health, Education, and Welfare.

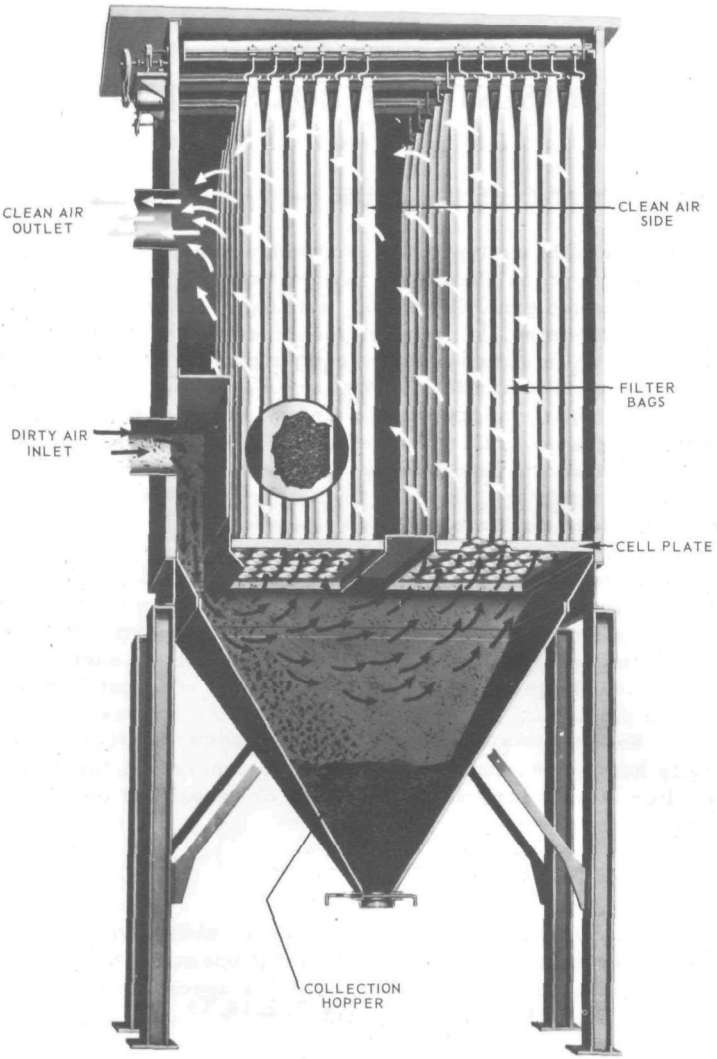


Figure 9. Typical simple fabric filter baghouse design.

Because the furnaces are already in existence, with associated exhaust stacks, the existing ductwork and refractory-lined flues are often used in the new construction. These flues first offer some degree of cooling and, at least in some instances, offer a collection of coarse dust. The operation of fabric filters requires that all oxidizable or combustible material be provided with sufficient air

to oxidize the furnace effluent and eliminate the possibility of burning within the baghouse. These hot, refractory-lined flues are ideal for the introduction of sufficient air to complete all combustion.

When the temperature of the exhaust gases is reduced to a certain point, they may be contained in metal ductwork to take advantage of radiation cooling. The initial cooling is often accomplished by means of water sprays. This reduces the temperature and volume of the gases to be filtered but adds moisture that must be carefully controlled to avoid reaching the dew point at any time before final emission of these gases. Figure 10 shows an all-dry system that uses a water-jacketed flue.

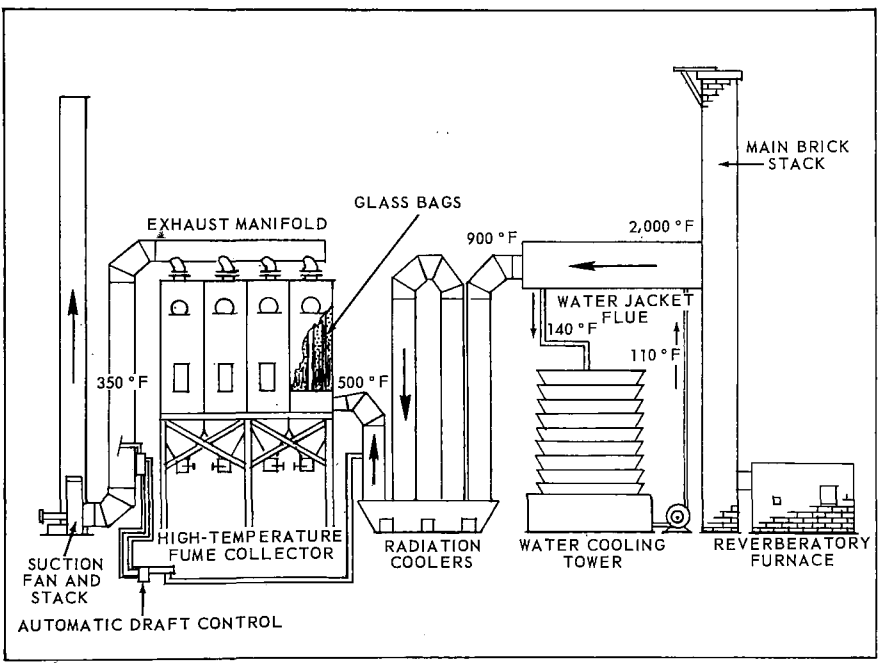


Figure 10. Sketch of small baghouse for zinc fume (Allen et al., 1952).

It appears to be common practice to install two similar dust collection units for a given situation at a plant rather than to install one single large unit. This not only offers some degree of emergency capacity but also offers flexibility in operation. Plants using a blast furnace or cupola normally tie the fume collection ductwork into a common system with the refining furnace emissions.

The necessity of locating baghouses at some distance from the furnaces may be considered an advantage because of the radiation

cooling that results, but at times this can be detrimental. Heat dissipation is inconsistent between summer and winter conditions, and condensation may result at the baghouse during a sudden cold snap. As the gases reach the dew point the dust becomes wet and forms mud in the hoppers or on the bags; resistance to airflow increases so rapidly that the baghouse is no longer functional. Furnace burners are sometimes left on to maintain heat in the system and thereby prevent condensation.

Following the water spray cooling there is usually a variable length of ductwork, depending upon the plant layout, before a section of U-tube or hairpin coolers. These coolers, as in Figure 11, may be bypassed during periods when the operation or weather is drastically changed and less cooling is required.

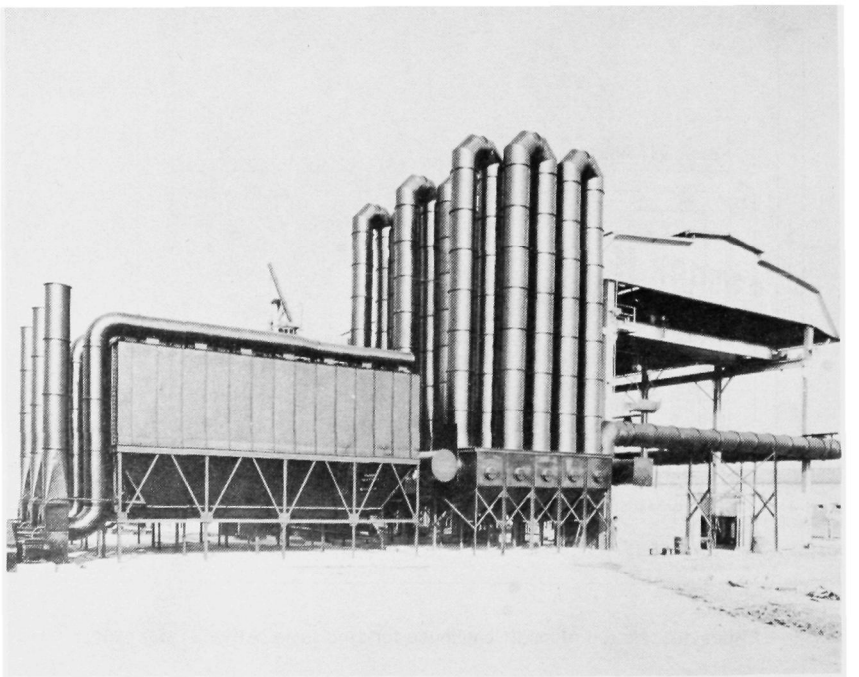


Figure 11. A dust collecting system for secondary smelting and melting plant. (Courtesy H. Kramer and Company)

In spite of all the methods used for cooling before the baghouse itself, it has been found generally necessary to provide an emergency bypass at the inlet to the baghouse so that fresh air may be bled into the exhaust gases. The fan volume is roughly constant, and hence, if the dilution air damper opens, it means lower draft at the furnace. This is a disadvantage to proper capture of fumes but is sometimes necessary to avoid burning the bags during an emergency or unusual period of high gas temperature.

BAGHOUSE OPERATION

While baghouses have been found to be the most successful device for collecting large quantities of zinc oxide, there has been no universal acceptance of a particular filter fabric. These fabrics must be able to withstand fairly high temperatures in spite of the dilution and precooling of gases. They must also withstand considerable physical abuse and vibration.

The filtration efficiency of either felt or woven fabrics is not based on direct entrapment, since the space between fibers is larger than the diameter of particles involved. The cake of collected dust on the fabric develops very rapidly, and high collection efficiency is usually attained soon after installation. The intermittent removal of the filter cake from the fabric is a prime consideration in baghouse design. Zinc oxide has a tendency to cling to fabrics, but mechanical techniques for dislodging the filter cake have been used successfully.

The use of glass fabric in baghouses allows higher temperature operation (550° F continuous) than the use of synthetic organic fabrics. The inherently low mechanical strength of glass fabric requires cleaning methods of a lower intensity than that of the mechanical shaking methods used with the synthetics, which are stronger. This basic difference has resulted in wide differences of opinion among various operators over which approach is "best." Good systems are based on both approaches, but the majority of the baghouses reported in operation are fitted with synthetic organic fabric and mechanical shakers.

Baghouses are generally considered satisfactory for controlling zinc oxide fumes provided they are not overloaded. Normal pressure drop ranges from 2 to 6 inches of water. Filter ratios of 2.0 to 2.7 cfm per square foot of filter area is the approximate range established in the industry.[9,16] The lower ratio is more appropriate with heavy dust loadings and continuous-duty service. Variations of from 1.7 to 3.5 cfm per square foot have been reported by BBII members, owing partially to the fabrics involved and partially to the differences of opinion and experience from one operator to the next.

The life of the bags can be extended by careful attention to the cleaning schedules and by use of various types of automatic cleaning equipment. Since the rate of buildup of particulate matter on the filter surface varies considerably (this being due to the variations of the process, differences in alloys, furnaces, operation, and so on), automatic systems controlled by pressure-limiting devices rather than by cleaning at fixed intervals of time have possible advantages.

The baghouse should have a sufficient number of compartments so that one compartment can be bypassed while the others continue to operate and thus permit replacement of broken bags or allow for unusual cleaning requirements. The use of four compartments normally satisfies this requirement. The temperature at which flue gases enter the baghouse affects the life of the bag severely. Maximum temperatures recommended by the Industrial Gas Cleaning Institute [17] for several of the more commonly used fabrics are shown in the following tabulation.

Filter fabric	Maximum continuous operating temperature, °F
Cotton	180
Dacron, heat-set	275
Glass fiber	550
Orlon, heat-set	260
Wool, treated	200

The various techniques for gas cooling add more or less to the total weight of exhaust gases. Radiation cooling adds none, and water sprays, a moderate amount, but air dilution causes a major increase in total air handling, especially when it reduces gas temperatures to less than 300° F. A typical gas-cleaning system delivers a nearly constant air volume at the fan regardless of the temperature. The draft at the furnace, since it is at the far end of the system from the fan, is affected if there are significant changes in the gas-cooling system.

The original purpose of the process is, of course, to produce high-quality ingots. This sometimes requires a variation in temperatures and quantity of these exhaust gases. As mentioned previously, the concentration of dust emitted from the furnace varies considerably. During the refining step, in which compressed air is being blown beneath the molten bath, a large change occurs both in the volume of gases and the concentration of fumes in those gases. During periods when scrap metal is added to the furnace, large amounts of fumes are generated. Since the capacity of the collection system may be inadequate for extremely large volumes of fumes, dust laden gases may escape through furnace doors or other openings in the furnace into the plant and, eventually, into the atmosphere. The entire refining cycle is complex. During some periods there are very few emissions, relatively cooler temperatures, and a minimum volume of gases. Conversely, during other periods the emissions are very great, the volume of gases is high, and the temperatures are maximum. Insofar as possible, these variations should be incorporated within the design of the collection system so that plant operations may be continued at full capacity under any conditions.

INSTRUMENTATION

Standard baghouse instrumentation design in zinc oxide applications is not strikingly unusual, but certain safeguards are essential

if satisfactory operation is to be maintained for continued periods of time. A typical system would usually allow fresh air to be bled into the exhaust gases leaving the furnace in order to provide for complete combustion. This is not normally controlled except on the basis of the draft maintained at that point. The hot gases from the furnace are frequently cooled by water sprays activated in proportion to the temperature of the gases. Standard recorders are employed, and a series of cam-actuated switches turn on one or more series of sprays. Either in place of, or in addition to, the spray chambers, there may be coolers using metal fins, water jackets, or a simple length of ductwork. Each of the aforementioned devices is used for primary cooling of the extremely hot gases to below 1,000° F. Final cooling is usually accomplished by means of U-tube radiation coolers. These are simply hairpin lengths of pipe installed vertically and exposing a large duct surface area. These tubes (Figure 11) are usually about 30 feet tall and may be bypassed by hand setting various gates or by automatic instrumentation. Hand adjustment is the common practice. These allow for major changes in operation or weather but do not compensate for quick changes. Just upstream of the baghouse is an atmospheric damper, controlled automatically by a standard temperature sensor so that it will gradually open if the temperature exceeds a preset limit. If the temperature of the gases entering the baghouse is still greater than can be withstood by the bag material, there is usually either an emergency shutdown device that will cut off the fans completely or a means for bypassing the hot gases around the baghouse.

In addition to the automatic equipment and controls the use of maximum-indicating thermometers in each compartment of the baghouse has been found desirable. An operator can thereby check the temperature extremes in any section over a period of time such as one shift or 1 day. This provides important information in regard to maintenance of the bags and their subsequent replacement.

Differential pressure gages are commonly used across each compartment of the filter. Wide differences in pressure drop between compartments is an indication of operational difficulty. Static pressure of differential pressure gages placed at intervals in the dust system can pinpoint duct plugging and save time in system maintenance.

MAINTENANCE

Upon installation of air pollution control equipment, an effective program of maintenance of the entire dust collection system should be instituted without delay. Provisions should be made for spotting broken bags in the baghouse at once. Mechanical equipment and various automatic and manual control devices in this, as in any other system, should be checked frequently by maintenance personnel.

The installation of instrumentation and relatively automatic equipment does not guarantee continuous or satisfactory operation.

Maintenance of an air pollution control system is a continuous (perhaps even full-time) job. Even the best "automatic" equipment requires regular maintenance. In addition to providing satisfactory operation, good maintenance has frequently been found to save money in the long run.

Permanent records are desirable for evaluating changes in conditions, unusually high temperatures, or any other problems that develop. When the maintenance operator is not familiar with differential pressure gages or some basic operations of the temperature controls, the entire system will soon be degraded. This is usually reflected in insufficient gas volume for proper operation of the furnaces, as in Figure 12. This forces the plant either to operate with fume losses or to curtail production.

Figure 12. Fume loss at furnace doors resulting from insufficient gas volume in dust collection system.

Owing to the flammability of unburned zinc or hydrocarbons associated with the scrap metal, care must be continually emphasized to prevent fires within the baghouse. Bridging of the dust in hoppers is particularly serious, for the bulk of dust insulates the exothermic reaction, and an entire section of bags can be lost in a fire.

Maintaining duct velocities within 2,500 to 3,000 feet per minute (fpm) is desirable. This is often not seen in practice, some velocities being reportedly down to 1,500 fpm on occasion. These low velocities cause buildups of dust in the duct, overheating if the radiant heat loss is needed to dissipate heat and reduce system gas volume, leading to poor system operation.

COSTS

The capital costs of air pollution control systems in the brass- and bronze-smelting industry are frequently higher than a casual

appraisal might indicate. Any time a system must be installed in an existing plant there will be extra costs to "fit it in" without major structural changes or interruption of the process. These factors can increase costs, in specific instances, far beyond the cost of the same capacity system installed as part of a new plant.

Data available on air pollution control costs at brass and bronze smelters indicate a broad range of installation costs. Two published figures are $3.50 per cfm[7] and $6.25 per cfm[15] for systems that accomplish the same basic purpose (1969 dollars). Data from BBII member companies suggest that a cost of $5.00 per cfm might be "typical" for an installed system, the baghouse itself representing about 40 percent of the total cost.

The costs of maintenance and operation of an air pollution control system are a very real consideration in the industry. Costs were supplied by four smelters: $2.00, $0.90, $1.50, and $1.73 per ton of ingots produced. The accountants for these companies were in accord on the procedures used in this calculation and, as nearly as possible, the costs are reported on a comparable basis. The costs include operations and maintenance, personnel salaries, maintenance supplies, electricity, water, gas, the fringe benefits applicable to salaries, and credits for value of byproduct material. The amortization of the capital cost of the system is not included.

EMISSIONS DATA — NAPCA TESTS

The most nearly complete test data available for brass- and bronze-smelting operations were collected by the National Air Pollution Control Administration, Abatement Program, Engineering Section, during 1968. These tests were conducted with the cooperation of BBII firms for the specific purpose of providing data for this report. Test results are given in Tables 5 through 12.

Test methods are outlined in the Appendix. The tests were meticulously conducted by a large crew of trained personnel. Variations and occasional anomalies in these results emphasize the difficulty of collecting "representative" data from a process as highly variable as secondary smelting. The test-by-test data and operational observations are noted as follows.

Test A

A heat of red brass 85-5-5-5 (copper, zinc, tin, lead) was made in a 17-1/2-ton-rated rotary furnace. A total of 33,334 pounds of scrap and 500 pounds of flux were charged to the furnace during the 6.5-hour charging period. Air blowing, slagging, and heating were performed during the 6.8-hour refining cycle. The pouring cycle lasted 1.3 hours.

During this test, only the 17-1/2-ton rotary furnace was operating. Inlet samples were collected during each period. A single

sample was taken at the baghouse outlet over the entire heat.

The exhaust system captured an estimated 90 to 95 percent of the particulate generated at the furnace.

Table 5. ROTARY FURNACE PARTICULATE EMISSIONS - TEST A

Cycle	Length, hr	Emissions, furnace[a]		Baghouse outlet[b]	
		lb/hr	Cycle total, lb	lb/hr	Total, lb
Charge[c]	6.50	30.05	195		
Refine	6.80	42.75	291		
Pour	1.28	9.54	12		
Total	14.58		498	1.78	25.9

[a]Furnace emission factor: 29.9 lb/ton.

[b]Collection efficiency: 94.8 percent.

[c]Total charge: 33,334 lb. Alloy produced: BBII Alloy No. 4A; 85-5-5-5.

Test B

At the same system as Test A, three 1-hour samples were collected at the baghouse exit. During collection of the first two samples, the 17-1/2-ton rotary was being charged, and the cupola and a 7-1/2-ton rotary furnace were being preheated. During the third test the 17-1/2-ton rotary was refining, the 7-1/2-ton rotary was charging, and the cupola was in full operation.

The air pollution control system controlled the emissions from five rotary furnaces and a cupola. The gases from all five production units pass through a common spray chamber, past an air-bleed damper, into an Orlon fabric baghouse, a 150-horsepower fan, and out a stack. The baghouse has a rated capacity of 43,000 cfm at 220° F. There are 20,866 square feet of filter area in this shaker-type, six-compartment baghouse. The design filter ratio during shaking is 2.46/1.

Measured gas temperatures at the baghouse varied between 140° F and 190° F. Pressure drop at the baghouse varied from 3-1/2 to 4-1/2 inches of water. Measured stack gas volume was 34,000 scfm (70° F).

Table 6. ATMOSPHERIC PARTICULATE EMISSIONS FROM BAGHOUSE ON ROTARY FURNACES - TEST B

Sample	Baghouse outlet	
	gr/scf	lb/hr
B-1	0.018	5.18
B-2	0.011	3.32
B-3	0.021	6.39

Test C

A heat of 85-5-5-5 red brass was made in a 100-ton reverberatory furnace. A total of 105,000 pounds of metal was charged to the furnace over a period of 6.7 hours. Oxygen was supplied to the burners for 5.3 of these hours to increase the melting rate. During a 9.3-hour refining period there was intermittent air blowing, and 500 pounds of fluxes were added. Pouring took 3.5 hours.

This air pollution control system serves three 100-ton reverberatory furnaces. The gases pass through a common spray chamber and then through a set of U-tube radiation coolers. From this point, the 450° F to 650° F gases are mixed with bleed-in air, go through the baghouse and a 75-horsepower fan, and pass to the stack. The 16-compartment shaker-type baghouse is fitted with heat-set Orlon bags. The total filter area is 7,360 square feet and the rated capacity is 19,000 cfm at 220° F. The design filter ratio, with one compartment out for cleaning, is 2.75/1.

Measured gas temperature at the baghouse inlet cycled between 200° F and 220° F. The measured gas volume averaged 15,000 scfm (70° F). Baghouse pressure drop varied from 4 to 5 inches of water.

One inlet sample was taken during each of these three furnace periods: charging, refining, and pouring. A continuous baghouse outlet sample was taken over the entire heat.

Table 7. REVERBERATORY FURNACE PARTICULATE EMISSIONS - TEST C

Cycle	Length, hr	Emissions, furnace[a]		Baghouse outlet[b]	
		lb/hr	Cycle total, lb	lb/hr	Total, lb
Charge[c]	6.73	194.2	1,308		
Refine	9.30	159.3	1,482		
Pour	3.53	12.8	45		
Total	19.56		2,835	3.32	64.8

[a]Furnace emission factor: 53.7 lb/ton.

[b]Collection efficiency: 97.7 percent.

[c]Total charge: 105,500 lb. Alloy produced: BBII Alloy No. 4A; 85-5-5-5.

Test D

A set of two 1-hour samples was taken at the stack of the system described in Test C. Two reverberatory furnaces were operating during these tests. Both furnaces were melting during the first test and both were charging during the second test.

Table 8. ATMOSPHERIC PARTICULATE EMISSIONS FROM BAGHOUSE ON REVERBERATORY FURNACES - TEST D

Sample	Baghouse outlet	
	gr/scf	lb/hr
D-1	0.025	5.13
D-2	0.031	6.37

Test E

At the system described in Test A, samples were taken while only the cupola was in operation. The cupola was charging at 20-minute intervals at the rate of 5,900 pounds per hour, including coke and flux.

Gas temperature at the baghouse was 145° F to 200° F and the volume was 44,000 scfm. The filter ratio was 2.11/1.

Table 9. CUPOLA PARTICULATE EMISSIONS - TEST E[a]

Sample	Inlet		Outlet	
	gr/scf	lb/hr	gr/scf	lb/hr
E-1	0.68	216	0.027	8.38
E-2			0.030	9.25
E-3			0.020	6.38
Average	0.68	216	0.026	8.00

[a]Charging rate: 5900 lb/hr. Collection efficiency: 96.4 percent. Furnace emission factor: 73.2 lb/ton.

Test F

A reverberatory furnace rated at 60 tons was tested over a full cycle, with three baghouse inlet samples (charge, refine, pour) and a single baghouse outlet sample.

Furnace gases pass to a spray chamber and then to U-tube coolers. Air-bleed dampers are located at the U-tubes. The baghouse, with a rated capacity of 22,000 cfm at 180° F, has 5,940 square feet of Dacron fabric. The design filter ratio is 3.87/1. A 75-horsepower fan is used in the system.

Measured stack gas volume was 18,000 scfm (70° F) during this testing period. Capture efficiency is estimated at 80 to 85 percent.

Table 10. REVERBERATORY FURNACE PARTICULATE EMISSIONS - TEST F

Cycle	Length, hr	Emissions, furnace[a]		Baghouse outlet[b]	
		lb/hr	Cycle total, lb	lb/hr	Total, lb
Charge[c]	8.5	500.1	4,250.8		
Refine	10.3	681.1	7,015.3		
Pour	3.3	8.5	28.1		
Total	22.1		11,294.2	2.17	47.9

[a]Furnace emission factor: 156.9 lb/ton. 81-3-7-9.

[b]Collection efficiency: 99.6 percent.

[c]Total charge: 144,000 lb. Alloy produced: BBII Alloy No. 5A; 81-3-7-9.

Test G

One of three 4-ton-per-hour rotary furnaces in this system was tested over a full cycle. The air pollution control system consists of a spray chamber, U-tube coolers with air-bleed dampers, a Dacron fabric baghouse, 60-horsepower fan, and stack. The shaker-type baghouse has 9,700 square feet of Dacron fabric bags. The rated capacity is 24,800 cfm at 150° F. for a filter ratio of 2.56/1.

The exhaust system capture of pollutants was about 80 to 85 percent during this test. This should be considered when the calculated emission factor is evaluated.

Table 11. ROTARY FURNACE PARTICULATE EMISSIONS - TEST G

Cycle	Length, hr	Emissions, furnace[a]		Baghouse outlet	
		lb/hr	Cycle total, lb	lb/hr	Total, lb
Charge[b]		c			
Refine	6.1	101.2	617.3		
Pour	1.1	6.9	7.6		
Total	7.2		624.9	d	d

[a]Furnace emission factor: 147 lb/ton.

[b]Total charge: 8,500 lbs. Alloy produced: BBII Alloy No. 6C; 63-1-1-35.

[c]Charge and refine run as one test.

[d]Collection efficiency: No data available.

Tests H and I

A cupola and two reverberatory furnaces were serviced by a single air pollution control system at this location. Only the cupola was in operation during these tests. The charge rate was about 4,200 pounds per hour, including coke and flux.

This control system had originally been designed to service the two reverberatory furnaces. Spray chambers provided the initial cooling, followed by U-tube coolers. A 75-horsepower fan drew gases through a shaker-type baghouse with 10,560 square feet of Dacron fabric. When the cupola emissions were added to the system, the discharge gases from a sand catcher were tied into the system between the spray chamber and the U-tube coolers. A booster blower was installed in this ductwork branch to ensure adequate suction at the cupola. In testing this installation the space limitations precluded sampling at the cupola outlet, and so samples were taken at the outlet of the sand catcher.

The test data showed that stack volume was twice the inlet volume for Test H (auxiliary blower on) and three times the inlet volume for Test I (auxiliary blower off). These major discrepancies are attributed to leaks in the baghouse structure. With leakage volumes of this magnitude it can be assumed that particulate matter would be mixing with the stack gases downstream of the bags. This would lower the apparent efficiency of the baghouse, and may explain the low reported efficiencies.

Table 12. BLAST FURNACE PARTICULATE EMISSIONS - TESTS H AND I

	Test H	Test I
Charging rate	4,200 lb/hr	4,200 lb/hr
Emission rate	42.3 lb/hr	35.1 lb/hr
Baghouse outlet	6.5 lb/hr[a]	9.3 lb/hr[a]
Collection efficiency	84.6 %[a]	73.5 %[a]
Furnace emission factor	20.1 lb/ton[b]	16.8 lb/ton[b]

[a]High lb/hr and low efficiency data probably due to baghouse leaks allowing particulates to enter gas stream.

[b]Not actual furnace emissions - samples taken after preliminary collector due to space limitations.

Detailed results of these tests can be found in the Appendices. A few spot checks for SO_2, NO_2, H_2S, hydrocarbons, and halogens indicate that all these gases exist in concentrations of below 1 ppm.

OTHER DATA

Although these test data are the most nearly complete available, other useful sources of emission information are available. Most of this information comes from BBII member companies and represents actual conditions in the industry as of 1968.

The analysis of typical collected dust is shown in Table 4.[9] Table 13 summarizes information from questionnaires completed by BBII member companies. Table 14 contains some of the available information on existing baghouses.[5] Zinc oxide ranges from 60 to

Table 13. AIR POLLUTION CONTROL EQUIPMENT IN USE IN THE INDUSTRY

Furnace type	Number	Approximate capacity, tons	Control equipment
Reverberatory	2	80	Baghouse
	6	75	Baghouse
	4	70	None
	7	60	Baghouse
	2	30	None
	2	30	Baghouse
	3	25	None
	1	12	Baghouse
	3	12	None
Rotary	5	35	Baghouse
	2	15	None
	1	10	Baghouse
	1	10	None
	2	5	Baghouse
	3	4	Baghouse
	1	4	None
	3	2.7	Baghouse
	1	2-1/2	None
	2	2	Baghouse
	4	2 (?)	None
Electric	1	4	Baghouse
	1	3	Baghouse
	3	1/2	Baghouse
	2	1/2	Scrubber
Crucible	4	1	None
	2	3/4	None
	2	1/2	None
	2	0.4	None
	2	3/8	None
	2	1/4	None
	1	600 lb	None
	1	100 lb	None
Sweat	4	-	None
	1	-	Afterburner and baghouse
Cupola	4		Baghouse
	1	-	None
	1	-	Wet collector
Wire burning	1	-	Afterburner chamber
Rotary dryer	1	-	None
Incinerator	1	-	Afterburner
Raw material concentrator	1	-	Cyclone
	2	-	None
Slag furnace	1	25	Baghouse
Undesignated	1	5	None
	1	2	None
	2	1	None

Table 14. BAGHOUSE INFORMATION SUMMARY - BRASS AND BRONZE INGOT INSTITUTE

Size of baghouse, cfm	No. of bags - diameter, in.	Bag material	Type and size of furnaces vented to the baghouse	Material collected in baghouses				Frequency of bag replacement
				lb/ton charged	lb/ton produced	% ZnO	% PbO	
2 units - 24,000 ea (design) 18,000 (actual)	1,944 - 6	Orlon and Dacron	2 Rev-60 tons/ht ea 2 Rot-2 tons/ht ea 4 Elec-1@4 tons/ht 3@1/2 ton/ht	58	67	63	8	18 months
3 units - 13,000 ea (design)	2,268 - 6	Dacron	2 Rev-60 tons/ht ea 2 Rot-4 tons/ht ea 1 Cupola	60	68	78	7.5	10 to 15 months
10,000 cmf (design)	100 - 15	Glass	1 Radiator sweater					
27,500 (design) 18,000 (actual)	324 - 8	Orlon and Dacron	4 Rev-60 tons/ht ea					4 months
30,000 (design) 29,000 (actual)	528 - 8	Orlon and Dacron	3 Rot-4 tons/ht ea	60[a]	88[a]	72[a]	8[a]	6 months
	320 - 5	Orlon	No flow diagram provided; equipment layout not ascertainable					12 months
	900 - 8	Orlon	3 Rev-30-75 tons/ht ea 1 Rot-10 tons/ht	55	NR	58	3	12 months
Square-filter type 26,000 (design)	400 - 10	Orlon	Cupola 2 Rev-80 tons/ht ea 5 Rot-7-1/2-35 tons/ht ea	NR	NR	65	5 to 6	6 months
Multiple-bag type	1,500 - 6	Orlon	No flow diagram provided; layout of equipment not ascertainable					
Custom-designed 12,500 cfm/chamber (No. of chambers not reported)	416 - 18	Wool	3 Rev-2-75 tons/ht ea 3 Rot-2.7 tons/ht ea 3 Crucible-0.25 tons/ht ea 1 elec-3 tons/ht 1 Cupola-no tonnage reported	NR	NR	55	NR	51 months
30,000 (design and actual)	1,200 - 5	Orlon	3 Rev-2-30 tons/ht ea 1 - 12 tons/ht ea					
50,000 (design and actual)	800 - 8	Orlon	1 Slug-15-25 tons/ht ea	NR	NR	NR	NR	12 months

[a]Not stipulated if these figures are total figures for the three units.

95 percent of the material collected, and lead oxide normally ranges from 6 to 8 percent. Apparently, about 3 percent of the total material charged to the furnaces is eventually collected in the baghouses in operation. Tables 15 and 16 are not directly applicable, because they refer to the brass and bronze foundry industry, but these give some indication of the extreme variations that might be expected from various ingot compositions and operations. Table 17 indicates that some of the wet scrubber control devices serving zinc oxide fumes are not particularly efficient.

During the refining process it has been indicated that 160 cfm of compressed air (typical for 50-ton reverberatory furnace) will volatilize and oxidize up to 750 pounds of zinc per hour in the metal bath.[7] This "blowing" may continue from a few minutes to several hours during a 24-hour heat, depending upon the impurities present and the alloy being produced. Based upon the total volume of gases expected from this furnace, at baghouse conditions, this could result in a ZnO concentration of roughly 20 grains per cubic foot at the furnace.

Foundry operation does not use the refining step (and several other factors are different), but the loss of zinc oxide fume at melting and pouring temperatures for brass is related. It has been indicated that particulate emission, for the whole melting cycle, varied from 0.05 grain per cubic foot for a low-frequency induction furnace to 1.3 for a 300-pound oil-fired tilting crucible. During the last stages of the heating cycle, values were as high as 4.1 for an oil-fired tilting crucible.[18]

Regardless of the total gas flow, temperatures, and variations with alloy, time, and so forth, the daily discharge of emissions from a 100,000-pound reverberatory brass ingot furnace is about 3,000 to 4,000 pounds.[6,7] Some material will exist at rather small concentrations along with the very large concentrations that may occur from time to time.

Table 15. DUST AND FUME DISCHARGE FROM BRASS-MELTING FURNACES[8]

Type of furnace	Composition of alloy, %					Type of control	Fuel	Pouring temperature, °F	Process wt, lb/hr	Fume emission, lb/hr
	Cu	Zn	Pb	Sn	Other					
Rotary	85	5	5	5	-	None	Oil	No data	1,104	22.5
Rotary	76	14.7	4.7	3.4	0.67 Fe	None	Oil	No data	3,607	25
Rotary	85	5	5	5	-	Slag cover	Oil	No data	1,165	2.73
Electric induction	60	38	2	-	-	None	Electric	No data	1,530	3.47
Electric induction	71	28	-	1	-	None	Electric	No data	1,600	0.77
Electric induction	71	28	-	1	-	None	Electric	No data	1,500	0.54
Cylindrical reverberatory	87	4	0	8.4	0.6	None	Oil	No data	273	2.42
Cylindrical reverberatory	77	-	18	5	-	None	Oil	2,100	1,267	26.1
Cylindrical reverberatory	80	-	13	7	-	Slag cover	Oil	2,100	1,500	22.2
Cylindrical reverberatory	80	2	10	8	-	None	Oil	1,900 to 2,100	1,250	10.9
Crucible	65	35	-	-	-	None	Gas	2,100	470	8.67
Crucible	60	37	1.5	0.5	1	None	Gas	1,800	108	0.05
Crucible	77	12	6	3	2	Slag cover	Gas	No data	500	0.822

Table 16. BRASS-MELTING FURNACE AND BAGHOUSE COLLECTOR DATA[8]

Case	A	B	C
Furnace data:			
Type of furnace	Crucible	Crucible	Low-frequency induction
Fuel used	Gas	Gas	Electric
Metal melted	Yellow brass	Red brass	Red brass
Composition of metal melted, %			
Copper	70.6	85.9	82.9
Zinc	24.8	3.8	3.5
Tin	0.5	4.6	4.6
Lead	3.3	4.4	8.4
Other	0.8	1.3	0.6
Melting rate, lb/hr	388	343	1,600
Pouring temperature, °F	2,160	2,350	2,300
Slag cover thickness, in.	1/2	1/2	3/4
Slag cover material	Glass	Glass	Charcoal
Baghouse collector data:			
Volume of gases, cfm	9,500	9,700	1,140
Type of baghouse	Sectional tubular	Sectional tubular	Sectional tubular
Filter material	Orlon	Orlon	Orlon
Filter area, ft^2	3,836	3,836	400
Filter velocity, fpm	2.47	2.53	2.85
Inlet fume emission rate, lb/hr	2.55	1.08	2.2[a]
Outlet fume emission rate, lb/hr	0.16	0.04	0.086
Collection efficiency, %	93.7	96.2	96.0

[a]Includes pouring and charging operations.

Table 17. EFFICIENCIES OF WET SCRUBBER CONTROL DEVICES SERVING BRASS-MELTING FURNACES[8]

Type of scrubber	Water rate, gpm	Flue gas volume, scfm	Particulate matter, gr/scf		Total dust, lb/hr		Efficiency, %
			In	Out	In	Out	
Venturi with wet cyclone	7.6	860	2.71	0.704	19.95	7.04	65
Dynamic wet	20.0	770	0.905	0.367	5.97	3.00	50
Dynamic wet	50.0	1,870	1.76	0.598	28.2	13.2	53

REFERENCES

1. Ingot Brass and Bronze BBII, Chicago, Illinois, March 1960.

2. Copper Scrap Consumers, Mineral Industry Surveys, U. S. Department of the Interior, Bureau of Mines (Monthly).

3. Bulletin NF-66 National Association of Secondary Material Industries, 330 Madison Avenue, New York, N. Y.

4. Papers presented at NASMI'S First Air Pollution Control Workshop, Pittsburgh, Pa. June 1967. Air Pollution Control in the Secondary Metal Industry. Pub. as a membership service by National Association of Secondary Material Industries, Inc., 330 Madison Avenue, New York, N. Y.

5. Spendlove, Max J. Methods for Producing Secondary Copper. United States Department of the Interior, Bureau of Mines. IC Bureau of Mines Information Circular 8002. 1961

6. Allen, Glenn L., Viets, Floyd H., and McCabe, Louis C. Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County, Calif. United States Department of the Interior. April 1952. Bureau of Mines Information Circular 7627.

7. Schwartz, Harry E., H. Kramer and Company; Kallan, Leo E.; and Stein, Arnold, Los Angeles County Air Pollution Control District. Controlling Atmospheric Contaminants in the Smelting and Refining of Copper-Base Alloys. J.APCA V5 N1 May 1955.

8. Air Pollution Engineering Manual, Air Pollution Control District, County of Los Angeles. Public Health Service Publication No. 999-AP-40, pp. 270-284, 1967.

9. Questionnaire survey and personal interviews; BBII member companies, 1967-8.

10. National Air Pollution Control Administration, Source Testing Unit, Unpublished data, 1968.

11. Hemeon, W. C. L. Plant and Process Ventilation, The Industrial Press, N. Y., 1963.

12. DallaValle, J.M. Exhaust Hoods, The Industrial Press, New York, 1952.

13. Industrial Ventilation Manual, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1967.

14. Kepner, H.F., Romanoff, Wm., and Thieme, C.O., Recovery of Dust and Oxide at a Secondary Metal Brass Smelter.

15. Landis, T.A. The Application of Bag Filters to Metallic Fumes in a Non-Ferrous Smelting Plant. April 1956.

16. The Fuller Engineer V17 N1.

17. Industrial Gas Cleaning Institute, Rye, New York.

18. Cleary, G.J.M. and Palmer, D.G., Particulate Emissions from Brass Foundries, Australasian Eng. (Sydney) 55-6, 58 (August, 1967).

APPENDICES

A. NAPCA SAMPLING PROCEDURES

B. NAPCA TEST DATA

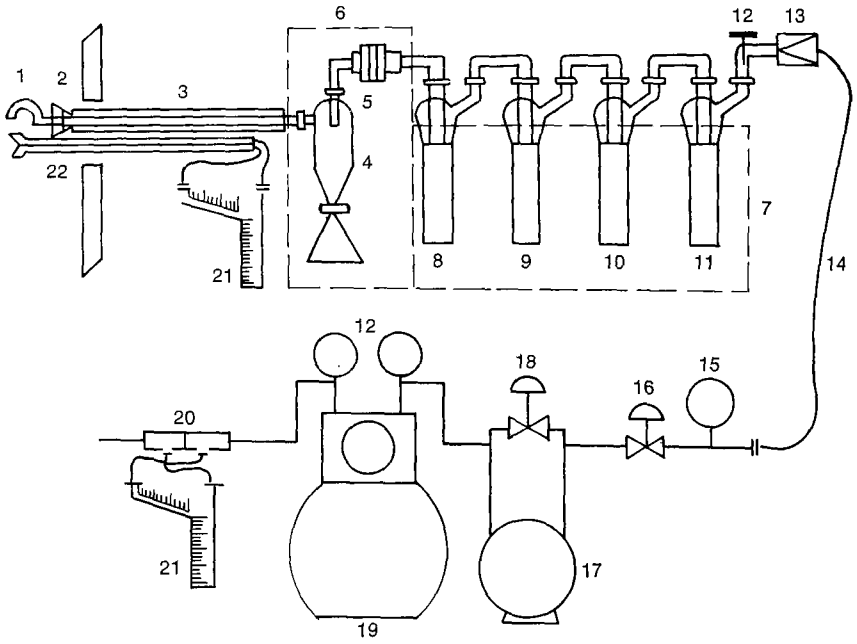
C. MEMBERS OF BRASS AND BRONZE INGOT INSTITUTE

APPENDIX A.
NAPCA SAMPLING PROCEDURE

Methods and Equipment

To conduct the particulate and gas sampling, an initial velocity traverse, spot checks for moisture content, and continuous stack temperature values were needed at each sampling site. The initial velocity traverse was obtained by measuring the pressure drop across an S-type pitot tube with an inclined/vertical manometer as the pitot tube traversed two mutually perpendicular stack diameters. The manometer was housed in the particulate meter box and was connected to the pitot tube by a flexible umbilical cord. Moisture content of the effluent was obtained by determining the weight of water that was adsorbed by a preweighed silica gel tube when a measured amount of stack gas was passed through the tube. The moisture sample was taken from the stack with a gas probe, from which it passed directly into the silica gel tube. The sample was then conveyed through an umbilical cord into the gas meter box, where it was forced through a dry gas meter by a vacuum pump to determine the sample volume. Continuous stack temperatures were taken with a bimetallic thermometer with a temperature range of 0° F to 600° F.

Particulate sampling was carried out with the particulate train, which consists of a probe, the particulate sample box, an umbilical cord, and the particulate meter box (see Figure A-1). The sample was taken from the stack effluent through the probe nozzle, then through the heated probe and into the particulate sample box. In the sample box, the large particulates ($>$ 5 microns) were collected in a glass cyclone while the smaller particulates ($<$ 5 microns) were collected on a glass fiber filter. Also contained in the sample box was a set of four Greenburg-Smith impingers in an ice bath to trap condensible organic matter and moisture. Only the second impinger had the original impinger tip; the other three tips had been removed to decrease the pressure drop. The first impinger was filled with 50 milliliters of distilled water to absorb the organic matter. The second and third impingers were left empty to trap moisture. The fourth impinger was filled with 175 grams of silica gel to absorb any remaining moisture. From the last impinger, the sample was conveyed to the particulate meter box by a flexible umbilical cord. The meter box contains a dry gas meter to determine volumetric flow, a calibrated orifice across an inclined/vertical manometer to determine the instantaneous sampling rate, a vacuum pump, and the electrical controls for sampling. By using an on-off valve and a bypass valve, the gas sample velocity in the nozzle was adjusted to coincide with the stack gas velocity so that sampling could be conducted isokinetically.



1. PROBE TIP
2. COUPLING
3. PROBE
4. CYCLONE
5. FILTER HOLDER
6. HEATER BOX
7. ICE BATH BOX
8. IMPINGER
9. IMPINGER
10. IMPINGER
11. IMPINGER
12. THERMOMETER
13. CHECK VALVE
14. VACUUM TUBING
15. VACUUM GAUGE
16. NEEDLE VALVE
17. VACUUM PUMP
18. BY-PASS VALVE
19. DRY GAS METER
20. CALIBRATED ORIFICE
21. DUAL MANOMETER
22. PITOT TUBE

Figure A-1. Standard PHS particulate sampling train.

Total particulate was the sum of the following:

1. The weight of the particulate on the filter

2. The weight of the particulate in the cyclone

3. The weight of the particulate residue from the probe, cyclone, filter, and impinger acetone washings

4. The weight of the particulate found in an ether-chloroform extraction of the impinger water and

5. The weight of the particulate residue after the impinger water is evaporated.

All weights were reported to the nearest 0.1 milligram.

Gas sampling included tests for concentrations of CO, CO_2, SO_2, O_2, and hydrocarbons, all of which were conducted simultaneously from a specially instrumented mobile van. The gas samples were taken from the effluent by a probe, through a heated filter to remove any particulates present, and then through a water knockout. The samples were then conveyed through an umbilical cord into the van, where the gases were analyzed. Tests for concentrations of CO, CO_2, and SO_2 were carried out by nondispersive infrared analyzers; O_2 concentrations were found with a paramagnetic oxygen and analyzer; and hydrocarbon concentrations were found with a flame ionization analyzer. Concentration of each gas, expressed in either percentages or parts per million, were then recorded automatically by a 12-channel recorder.

Modifications

Particulate size was not expected to exceed 5 microns downstream from the baghouses. Thus, the cyclone collector in the particulate sample box, which collects particulates larger than 5 microns, was not needed at the sampling points downstream from the baghouses. The cyclone was removed, and the standard filter was replaced with a long-neck filter. This modification not only eliminated unnecessary equipment but also simplified the stream flow and reduced the amount of glassware that had to be cleaned.

APPENDIX B. NAPCA TEST DATA

Valid inferences can best be drawn from test data when the original data are supplied. The test data summarized in the body of the report are presented in detail in Tables B-1 through B-6

Table B-1. NAPCA TEST DATA: KEY

Test	Process	Location	Sample No.
A	Rotary	Inlet	1
		Inlet	2
		Inlet	3
		Outlet	4
B	Rotary	Outlet	5
		Outlet	6
		Outlet	7
C	Reverberatory	Inlet	8
		Inlet	10
		Inlet	11
		Outlet	12
D	Reverberatory	Outlet	13
		Outlet	14
		Outlet	15
E	Cupola	Inlet	16
		Outlet	19
		Outlet	20
		Outlet	21
F	Reverberatory	Inlet	22
		Inlet	23
		Inlet	24
		Outlet	25
G	Rotary	Inlet	26
		Inlet	27
H	Cupola	Inlet	28
		Inlet	30
I	Cupola	Outlet	29
		Outlet	31

Table B-2. PARTICULATE RESULTS

Sample No.	Probe and cyclone		Probe, cyclone, and filter		Total (includes water residue)	
	gr/scf[a]	lb/hr	gr/scf	lb/hr	gr/scf	lb/hr
1	0.003	0.764	0.104	29.85	0.105	30.05
2	0.013	3.82	0.139	41.98	0.141	42.75
3	0.005	1.54	0.027	8.48	0.030	9.54
4	0.0004	0.132	0.0052	1.613	0.0057	1.78
5	0.005	1.33	0.012	3.49	0.018	5.18
6	0.004	1.17	0.007	2.04	0.011	3.32
7	0.003	0.843	0.010	3.21	0.021	6.39
8	0.534	61.22	1.69	193.4	1.69	194.2
10	0.634	76.13	1.33	159.2	1.33	159.3
11	0.045	6.71	0.085	12.77	0.085	12.81
12	0.002	0.563	0.014	3.16	0.014	3.32
14	0.012	2.42	0.025	5.15	0.025	5.13
15	0.007	1.38	0.018	3.63	0.031	6.37
16	0.064	20.17	0.665	211.2	0.680	215.9
19	0.010	3.04	0.012	3.84	0.027	8.38
20	0.009	2.78	0.015	4.67	0.030	9.25
21	0.006	1.80	0.011	3.40	0.020	6.38
22	1.2662	67.51	7.0036	373.42	9.3799	500.12
23	-[b]				11.5779	681.11
24	0.0196	0.94	0.0729	3.51	0.1771	8.54
25	0.0036	0.56	0.0125	1.93	0.0140	2.17
26	0.1707	16.79	1.0242	100.72	1.0291	101.2
27	0.0119	1.59	0.0440	5.89	0.0517	6.93
28	0.1005	11.4	0.3619	41.07	0.3729	42.33
29	0.2136	19.49	0.3534	32.24	0.3845	35.07
30	0.0199	4.46	0.0235	5.24	0.0292	6.52
31	0.0215	5.55	0.0226	5.85	0.0359	9.29

[a]Standard cubic foot, i.e., dry gas at 70 °F and 29.92 in. Hg.

[b]Dashes indicate samples were mixed.

Table B-3. MOISTURE CONTENT AND GAS VOLUME

Sample No.	Percent H_2O	scfm
1	2.3	33,510
2	2.3	35,278
3	2.9	36,765
4	2.6	13,999
5	4.5	33,926
6	3.1	33,807
7	3.2	36,121
8	10.9	13,374
10	7.2	14,020
11	3.1	17,559
12	5.0	27,049
14	3.0	24,107
15	5.0	23,882
16	2.0	37,066
19	2.3	36,112
20	1.7	36,556
21	3.7	37,384
22	23.9	6,222
23	16.7	6,864
24	8.5	5,623
25	4.5	18,052
26	1.7	11,475
27	1.8	15,633
28	2.7	13,245
29	1.7	10,644
30	1.1	26,058
31	1.8	30,159

Table B-4. LABORATORY DATA[a]

Sample No.	Solvent extract of impinger water, mg	Impinger water residue, mg	Impinger acetone wash, mg	Cyclone probe wash, mg	Filter holder wash, mg	Filter particulate, mg	Total particulate, mg	Silica gel moisture, g
1	1.5	4.0	3.7	41.0	23.9	873.5	947.6	66.2
2	2.8	20.8	3.6	144.1	3.6	1,437.4	1,612.3	62.9
3	1.8	8.0	15.9	17.7	0.6	63.7	107.7	20.3
4	0.4	0.1	27.8	14.6	17.7	135.8	196.4	125.7
5	0.2	6.6	6.5	13.7	8.8	15.6	51.4	14.8
6	0.0	5.3	5.3	11.0	4.9	2.8	29.3	10.5
7	1.7	17.0	6.4	6.8	5.1	12.7	49.7	11.8
8	4.4	3.8	3.0	4,604.2	46.7	9,938.9	14,601.0	42.6
9	-[b]	-			-		-	-
10	2.7	1.2	14.5	8,476.4	-	9,234.6	17,729.4	67.8
11	1.8	3.0	14.2	287.0		245.2	551.2	33.6
12	2.8	2.7	13.9	95.8	21.0	426.8	562.7	128.1
13	-[c]	1.6	7.6	10.1	7.0	-[d]	Void	7.5
14	0.2	0.9	5.1	21.3		18.9	46.4	8.1
15	2.8	0.5	4.5	12.1	19.5	16.0	55.4	7.5
16	4.0	12.8	4.5	129.6	11.5	1,223.2	1,385.6	13.5
17		-	-	-	-	-	-	-
18			-	-			-	-
19	3.1	18.0	3.9	17.6	3.4	0.7	46.7	8.4
20	2.7	21.1	6.3	16.5	1.5	4.9	53.0	10.5
21	1.7	14.0	6.5	10.7	0.2	3.0	36.1	19.0
22	4.0	7.0	12,000.0	6,400.0		29,000.0	47,411.0	50.0
23	4.0	1,500.0	-[e]	33,000.0		45,000.0	79,504.0	49.0
24	35.0	11.0	540.0	110.0		300.0	996.0	137.0
25	8.0	12.0	32.0	120.0		300.0	472.0	27.0
26	2.0	7.0	28.0	1,300.0		6,500.0	7,837.0	38.0
27	0.0	5.0	8.0	20.0		54.0	87.0	5.0
28	1.0	3.0	7.0	100.0		260.0	371.0	4.0
29	0.0	0.0	8.0	28.0		5.0	41.0	5.0
30	1.0	1.0	14.0	110.0		72.0	198.0	1.0
31	0.0	2.0	11.0	21.0		1.0	35.0	4.0

[a]All blanks have been subtracted. Samples 1 through 21: acetone blank, 0.0 mg/200 ml; chloroform-ether blank, 1.1 mg/175 ml; water blank, 1.8 mg/100 ml. Samples 22 through 31: acetone blank, 1.9 mg/200 ml; chloroform-ether blank, 0.9 mg/225 ml; water blank, 1.0 mg/230 ml.

[b]No sample received.

[c]Sample lost in laboratory.

[d]Part of filter missing from field.

[e]Impinger acetone wash and cyclone probe wash were mixed.

Table B-5. GAS ANALYSES

Sample No.	CO, ppm	CO_2, %	O_2, %	Hydrocarbons, ppm
1	6.9	1.11	18.0	0.16
2	10.8	0.28	18.2	0.16
3	7.5	0.14	18.5	0.37
4	8.6	0.63	18.2	0.25
5	49.4	0.65	17.0	0.17
6	27.1	0.63	17.0	0.17
7	91.0	1.43	17.5	0.30
8	42.2	1.39	18.1	0.03
10	7.7	0.70	17.8	0.02
11	27.6	0.54	17.8	0.05
12	23.2	0.89	17.9	0.03
13	93.5	1.25	16.8	0.14
14	963	1.45	16.4	0.14
15	556	1.76	16.1	0.12
16	1,575	1.40	18.9	0.49
19	1,575	1.40	18.9	0.49
20	1,832	1.41	18.9	0.34
21	3,232	1.35	19.0	0.36
22				
23	27	0.40	19.1	
24	9	0.34	18.9	
25	20	0.57	19.0	
26				
27				
28	1,100	0.49	19.4	
29	500	0.21	19.4	
30	1,100	0.49	19.4	
31	500	0.21	19.4	

Table B-6. GASEOUS EMISSIONS FROM BRASS- AND BRONZE-SMELTING FURNACES[a]

Furnace	Test	O_2, %	CO_2, %	CO, ppm	SO_2, ppm	NO_2, ppm	H_2S, ppm	Hydrocarbons as CH_4, ppm	Total halogens, ppm
Rotary	A	18.2	0.63	8.6	[b]			0.25	
	G				10	<0.1	<1		<1
Reberberatory	C	17.9	0.89	23.2				0.03	
	F	19.0	0.57	20	<1	<0.1	<1		<1
Blast	E	18.9	1.39	2,200 (150.2 lb/T)				0.40	
	H	19.4	0.49	1,100 (72.5 lb/T)	1	0.1	<1		<1
	I	19.4	0.21	500 (38.2 lb/T)	1	0.1	<1		<1

[a]O_2, CO_2, CO, and CH_4, data are integrated samples over one cycle of the furnace; SO_2, NO_2, H_2S and Halogen data are detector tube samples.

[b]Blanks indicate data not available.

APPENDIX C. MEMBERS OF BRASS AND BRONZE INGOT INSTITUTE

300 WEST WASHINGTON STREET, CHICAGO, ILLINOIS

Ajax Metal Division of
H. Kramer and Company
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Cincinnati 32, Ohio

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Chicago 23, Illinois

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Mars, Pennsylvania

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Cleveland 9, Ohio

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S-G Metals Industries, Inc.
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Kansas City 18, Kansas

United States Metal Products Company
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Erie, Pennsylvania

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