12.3 Primary Copper Smelting

12.3.1 General[1]

Copper ore is produced in 13 states. In 1989, Arizona produced 60 percent of the total U. S. ore. Fourteen domestic mines accounted for more than 95 percent of the 1.45 megagrams (Mg) (1.6 millon tons) of ore produced in 1991.

Copper is produced in the U. S. primarily by pyrometallurgical smelting methods. Pyrometallurgical techniques use heat to separate copper from copper sulfide ore concentrates. Process steps include mining, concentration, roasting, smelting, converting, and finally fire and electrolytic refining.

12.3.2 Process Description[2-4]

Mining produces ores with less than 1 percent copper. Concentration is accomplished at the mine sites by crushing, grinding, and flotation purification, resulting in ore with 15 to 35 percent copper. A continuous process called floatation, which uses water, various flotation chemicals, and compressed air, separates the ore into fractions. Depending upon the chemicals used, some minerals float to the surface and are removed in a foam of air bubbles, while others sink and are reprocessed. Pine oils, cresylic acid, and long-chain alcohols are used for the flotation of copper ores. The flotation concentrates are then dewatered by clarification and filtration, resulting in 10 to 15 percent water, 25 percent sulfur, 25 percent iron, and varying quantities of arsenic, antimony, bismuth, cadmium, lead, selenium, magnesium, aluminum, cobalt, tin, nickel, tellurium, silver, gold, and palladium.

A typical pyrometallurgical copper smelting process, as illustrated in Figure 12.3-1, includes 4 steps: roasting, smelting, concentrating, and fire refining. Ore concentration is roasted to reduce impurities, including sulfur, antimony, arsenic, and lead. The roasted product, calcine, serves as a dried and heated charge for the smelting furnace. Smelting of roasted (calcine feed) or unroasted (green feed) ore concentrate produces matte, a molten mixture of copper sulfide (Cu_2S), iron sulfide (FeS), and some heavy metals. Converting the matte yields a high-grade "blister" copper, with 98.5 to 99.5 percent copper. Typically, blister copper is then fire-refined in an anode furnace, cast into "anodes", and sent to an electrolytic refinery for further impurity elimination.

Roasting is performed in copper smelters prior to charging reverberatory furnaces. In roasting, charge material of copper concentrate mixed with a siliceous flux (often a low-grade copper ore) is heated in air to about 650°C (1200°F), eliminating 20 to 50 percent of the sulfur as sulfur dioxide (SO_2). Portions of impurities such as antimony, arsenic, and lead are driven off, and some iron is converted to iron oxide. Roasters are either multiple hearth or fluidized bed; multiple hearth roasters accept moist concentrate, whereas fluidized bed roasters are fed finely ground material. Both roaster types have self-generating energy by the exothermic oxidation of hydrogen sulfide, shown in the reaction below.

$$H_2S + O_2 \rightarrow SO_2 + H_2O + \text{Thermal energy} \qquad (1)$$

In the smelting process, either hot calcine from the roaster or raw unroasted concentrate is melted with siliceous flux in a smelting furnace to produce copper matte. The required heat comes from partial oxidation of the sulfide charge and from burning external fuel. Most of the iron and

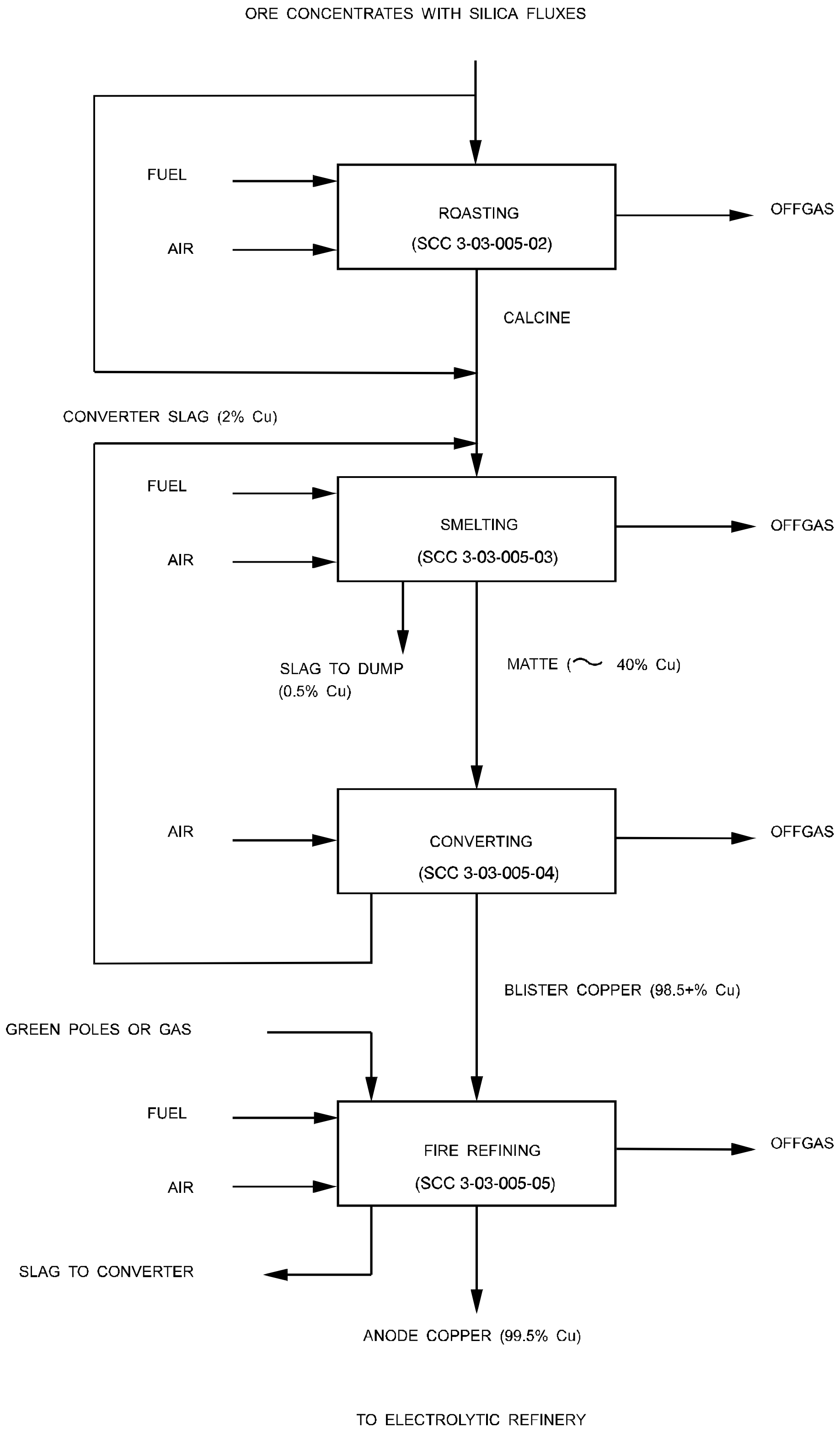

Figure 12.3-1. Typical primary copper smelter process.
(Source Classification Codes in parentheses.)

some of the impurities in the charge oxidize with the fluxes to form a slag on top of the molten bath, which is periodically removed and discarded. Copper matte remains in the furnace until tapped. Matte ranges from 35 to 65 percent copper, with 45 percent the most common. The copper content percentage is referred to as the matte grade. The 4 smelting furnace technologies used in the U. S. are reverberatory, electric, Noranda, and flash.

The reverberatory furnace smelting operation is a continuous process, with frequent charging and periodic tapping of matte, as well as skimming slag. Heat is supplied by natural gas, with conversion to oil during gas restrictions. Furnace temperature may exceed 1500°C (2730°F), with the heat being transmitted by radiation from the burner flame, furnace walls, and roof into the charge of roasted and unroasted materials mixed with flux. Stable copper sulfide (Cu_2S) and stable FeS form the matte with excess sulfur leaving as sulfur dioxide.

Electric arc furnace smelters generate heat with carbon electrodes that are lowered through the furnace roof and submerged in the slag layer of the molten bath. The feed consists of dried concentrates or calcine. The chemical and physical changes occurring in the molten bath are similar to those occurring in the molten bath of a reverberatory furnace. The matte and slag tapping practices are also similar.

The Noranda process, as originally designed, allowed the continuous production of blister copper in a single vessel by effectively combining roasting, smelting, and converting into 1 operation. Metallurgical problems, however, led to the operation of these reactors for the production of copper matte. The Noranda process uses heat generated by the exothermic oxidation of hydrogen sulfide. Additional heat is supplied by oil burners or by coal mixed with the ore concentrates. Figure 12.3-2 illustrates the Noranda process reactor.

Flash furnace smelting combines the operations of roasting and smelting to produce a high-grade copper matte from concentrates and flux. In flash smelting, dried ore concentrates and finely ground fluxes are injected together with oxygen and preheated air (or a mixture of both), into a furnace maintained at approximately 1000°C (1830°F). As with the Noranda process reactor, and in contrast to reverberatory and electric furnaces, flash furnaces use the heat generated from partial oxidation of their sulfide charge to provide much or all of the required heat.

Slag produced by flash furnace operations contains significantly higher amounts of copper than reverberatory or electric furnaces. Flash furnace slag is treated in a slag cleaning furnace with coke or iron sulfide. Because copper has a higher affinity for sulfur than oxygen, the copper in the slag (as copper oxide) is converted to copper sulfide. The copper sulfide is removed and the remaining slag is discarded.

Converting produces blister copper by eliminating the remaining iron and sulfur present in the matte. All but one U. S. smelter uses Pierce-Smith converters, which are refractory-lined cylindrical steel shells mounted on trunnions at either end, and rotated about the major axis for charging and pouring. An opening in the center of the converter functions as a mouth through which molten matte, siliceous flux, and scrap copper are charged and gaseous products are vented. Air, or oxygen-rich air, is blown through the molten matte. Iron sulfide is oxidized to form iron oxide (FeO) and SO_2. Blowing and slag skimming continue until an adequate amount of relatively pure Cu_2S, called "white metal", accumulates in the bottom of the converter. A final air blast ("final blow") oxidizes the copper sulfide to SO_2, and blister copper forms, containing 98 to 99 percent coppers. The blister copper is removed from the converter for subsequent refining. The SO_2 produced throughout the operation is vented to pollution control devices.

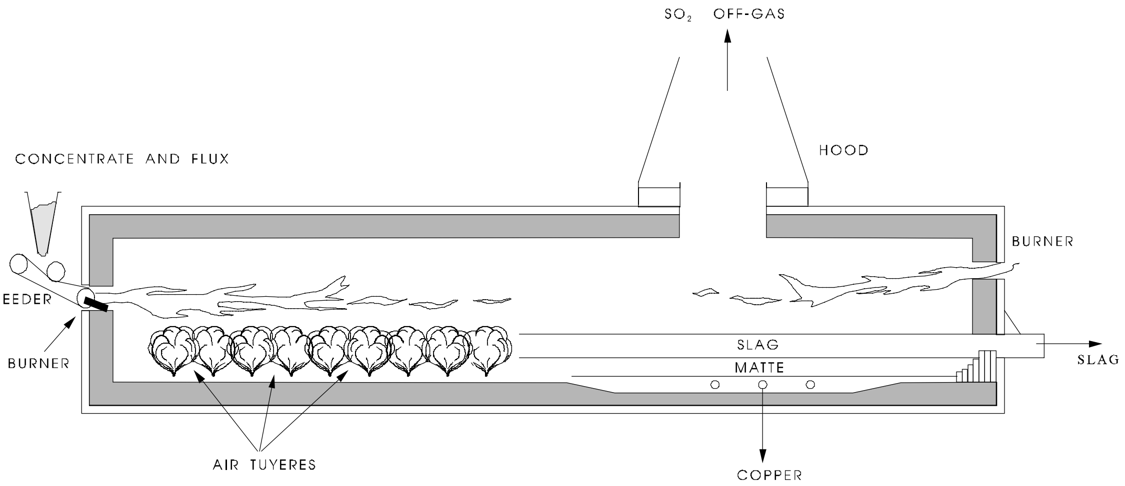

Figure 12.3-2. Schematic of the Noranda process reactor.

One domestic smelter uses Hoboken converters. The Hoboken converter, unlike the Pierce-Smith converter, is fitted with an inverted u-shaped side flue at one end to siphon gases from the interior of the converter directly to an offgas collection system. The siphon results in a slight vacuum at the converter mouth.

Impurities in blister copper may include gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulfur, tellurium, and zinc. Fire refining and electrolytic refining are used to purify blister copper even further. In fire refining, blister copper is usually mixed with flux and charged into the furnace, which is maintained at 1100°C (2010°F). Air is blown through the molten mixture to oxidize the copper and any remaining impurities. The impurities are removed as slag. The remaining copper oxide is then subjected to a reducing atmosphere to form purer copper. The fire-refined copper is then cast into anodes for even further purification by electrolytic refining.

Electrolytic refining separates copper from impurities by electrolysis in a solution containing copper sulfate (Cu_2SO_4) and sulfuric acid (H_2SO_4). The copper anode is dissolved and deposited at the cathode. As the copper anode dissolves, metallic impurities precipitate and form a sludge. Cathode copper, 99.95 to 99.96 percent pure, is then cast into bars, ingots, or slabs.

12.3.3 Emissions And Controls

Emissions from primary copper smelters are principally particulate matter and sulfur oxides (SO_x). Emissions are generated from the roasters, smelting furnaces, and converters. Fugitive emissions are generated during material handling operations.

Roasters, smelting furnaces, and converters are sources of both particulate matter and SO_x. Copper and iron oxides are the primary constituents of the particulate matter, but other oxides, such as arsenic, antimony, cadmium, lead, mercury, and zinc, may also be present, along with metallic sulfates and sulfuric acid mist. Fuel combustion products also contribute to the particulate emissions from multiple hearth roasters and reverberatory furnaces.

Gas effluent from roasters usually are sent to an electrostatic precipitator (ESP) or spray chamber/ESP system or are combined with smelter furnace gas effluent before particulate collection. Overall, the hot ESPs remove only 20 to 80 percent of the total particulate (condensed and vapor) present in the gas. Cold ESPs may remove more than 95 percent of the total particulate present in the gas. Particulate collection systems for smelting furnaces are similar to those for roasters. Reverberatory furnace off-gases are usually routed through waste heat boilers and low-velocity balloon flues to recover large particles and heat, then are routed through an ESP or spray chamber/ESP system.

In the standard Pierce-Smith converter, flue gases are captured during the blowing phase by the primary hood over the converter mouth. To prevent the hood from binding to the converter with splashing molten metal, a gap exists between the hood and the vessel. During charging and pouring operations, significant fugitives may be emitted when the hood is removed to allow crane access. Converter off-gases are treated in ESPs to remove particulate matter, and in sulfuric acid plants to remove SO_2.

Remaining smelter operations process material containing very little sulfur, resulting in insignificant SO_2 emissions. Particulate may be emitted from fire refining operations. Electrolytic refining does not produce emissions unless the associated sulfuric acid tanks are open to the atmosphere. Crushing and grinding systems used in ore, flux, and slag processing also contribute to fugitive dust problems.

Control of SO_2 from smelters is commonly performed in a sulfuric acid plant. Use of a sulfuric acid plant to treat copper smelter effluent gas streams requires that particulate-free gas containing minimum SO_2 concentrations, usually of at least 3 percent SO_2, be maintained. Table 12.3-1 shows typical average SO_2 concentrations from the various smelter units. Additional information on the operation of sulfuric acid plants is discussed in Section 8.10 of this document. Sulfuric acid plants also treat converter gas effluent. Some multiple hearth and all fluidized bed roasters use sulfuric acid plants. Reverberatory furnace effluent contains minimal SO_2 and is usually released directly to the atmosphere with no SO_2 reduction. Effluent from the other types of smelter furnaces contain higher concentrations of SO_2 and are treated in sulfuric acid plants before being vented. Single-contact sulfuric acid plants achieve 92.5 to 98 percent conversion of plant effluent gas. Double-contact acid plants collect from 98 to more than 99 percent of the SO_2, emitting about 500 parts per million (ppm) SO_2. Absorption of the SO_2 in dimethylaniline (DMA) solution has also been used in domestic smelters to produce liquid SO_2.

Particular emissions vary depending upon configuration of the smelting equipment. Tables 12.3-2 and 12.3-3 give the emission factors for various smelter configurations, and Tables 12.3-4, 12.3-5, 12.3-6, 12.3-7, 12.3-8, and 12.3-9 give size-specific emission factors for those copper production processes where information is available.

Roasting, smelting, converting, fire refining, and slag cleaning are potential fugitive emission sources. Tables 12.3-10 and 12.3-11 present fugitive emission factors for these sources. Tables 12.3-12, 12.3-13, 12.3-14, 12.3-15, 12.3-16, and 12.3-17 present cumulative size-specific particulate emission factors for fugitive emissions from reverberatory furnace matte tapping, slag tapping, and converter slag and copper blow operations. The actual quantities of emissions from these sources depend on the type and condition of the equipment and on the smelter operating techniques.

Fugitive emissions are generated during the discharge and transfer of hot calcine from multiple hearth roasters. Fluid bed roasting is a closed loop operation, and has negligible fugitive emissions. Matte tapping and slag skimming operations are sources of fugitive emissions from smelting furnaces. Fugitive emissions can also result from charging of a smelting furnace or from leaks, depending upon the furnace type and condition.

Table 12.3-1. TYPICAL SULFUR DIOXIDE CONCENTRATIONS IN OFFGAS FROM PRIMARY COPPER SMELTING SOURCES[a]

Unit	SO_2 Concentration (Volume %)
Multiple hearth roaster (SCC 3-03-005-02)	1.5 - 3
Fluidized bed roaster (SCC 3-03-005-09)	10 - 12
Reverberatory furnace (SCC 3-03-005-03)	0.5 - 1.5
Electric arc furnace (SCC 3-03-005-10)	4 - 8
Flash smelting furnace (SCC 3-03-005-12)	10 - 70
Continuous smelting furnace (SCC 3-03-005-36)	5 - 15
Pierce-Smith converter (SCC 3-03-005-37)	4 - 7
Hoboken converter (SCC 3-03-005-38)	8
Single contact H_2SO_4 plant (SCC 3-03-005-39)	0.2 - 0.26
Double contact H_2SO_4 plant (SCC 3-03-005-40)	0.05

[a] SCC = Source Classification Code.

Each of the various converter stages (charging, blowing, slag skimming, blister pouring, and holding) is a potential source of fugitive emissions. During blowing, the converter mouth is in the stack (a close-fitting primary hood is over the mouth to capture offgases). Fugitive emissions escape from the hood. During charging, skimming, and pouring, the converter mouth is out of the stack (the converter mouth is rolled out of its vertical position, and the primary hood is isolated). Fugitive emissions are discharged during roll out.

Table 12.3-2. (Metric Units). EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a,b]

Configuration[c]	Process	Particulate	EMISSION FACTOR RATING	Sulfur Dioxide[d]	EMISSION FACTOR RATING	References
Reverberatory furnace (RF) followed by converter (C) (SCC 3-03-005-23)	RF	25	B	160	B	4-10
	C	18	B	370	B	9,11-15
Multiple hearth roaster (MHR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-29)	MHR	22	B	140	B	4-5,16-17
	RF	25	B	90	B	4-9,18-19
	C	18	B	300	B	8,11-13
Fluid bed roaster (FBR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-25)	FBR	ND	ND	180	B	20
	RF	25	B	90	B	—[e]
	C	18	B	270	B	—[e]
Concentrate dryer (CD) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-27)	CD	5	B	0.5	B	21-22
	EF	50	B	120	B	15
	C	18	B	410	B	8,11-13,15

Table 12.3-2 (cont.).

Configuration[c]	Process	Particulate	EMISSION FACTOR RATING	Sulfur Dioxide[d]	EMISSION FACTOR RATING	References
Fluid bed roaster (FBR) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-30)	FBR	ND	ND	180	B	20
	EF	50	B	45	B	15,23
	C	18	B	300	B	3
Concentrate dryer (CD) followed by flash furnace (FF), cleaning furnace (SS) and converter (C) (SCC 3-03-005-26)	CD	5	B	0.5	B	21-22
	FF	70	B	410	B	24
	SS[f]	5	B	0.5	B	22
	C[e]	ND[g]	ND[g]	120	B	22
Concentrate dryer (CD) followed by Noranda reactors (NR) and converter (C) (SCC 3-03-005-41)	CD	5	B	0.5	B	21-22
	NR	ND	ND	ND	ND	—
	C	ND	ND	ND	ND	—

[a] Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of blister copper. SCC = Source Classification Code. ND = no data.

[b] For particulate matter removal, gaseous effluents from roasters, smelting furnaces, and converters usually are treated in hot ESPs at 200 to 340°C (400 to 650°F) or in cold ESPs with gases cooled to about 120°C (250°F before) ESP. Particulate emissions from copper smelters contain volatile metallic oxides that remain in vapor form at higher temperatures, around 120°C (250°F). Therefore, overall particulate removal in hot ESPs may range 20 to 80% and in cold ESPs may be 99%. Converter gas effluents and, at some smelters, roaster gas effluents are treated in single contact acid plants (SCAP) or double contact acid plants (DCAP) for SO_2 removal. Typical SCAPs are about 96% efficient, and DCAPs are up to 99.8% efficient in SO_2 removal. They also remove over 99% of particulate matter. Noranda and flash furnace offgases are also processed through acid plants and are subject to the same collection efficiencies as cited for converters and some roasters.

[c] In addition to sources indicated, each smelter configuration contains fire refining anode furnaces after the converters. Anode furnaces emit negligible SO_2. No particulate emission data are available for anode furnaces.

[d] Factors for all configurations except reverberatory furnaces followed by converters have been developed by normalizing test data for several smelters to represent 30% sulfur content in concentrated ore.

[e] Based on the test data for the configuration multiple hearth roaster followed by reverberatory furnaces and converters.

[f] Used to recover copper from furnace slag and converter slag.

[g] Since converters at flash furnace and Noranda furnace smelters treat high copper content matte, converter particulate emissions from flash furnace smelters are expected to be lower than those from conventional smelters with multiple hearth roasters, reverberatory furnaces, and converters.

Table 12.3-3 (English Units). EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a,b]

Configuration[c]	Process	Particulate	EMISSION FACTOR RATING	Sulfur dioxide[d]	EMISSION FACTOR RATING	References
Reverberatory furnace (RF) followed by converter (C) (SCC 3-03-005-23)	RF	50	B	320	B	4-10
	C	36	B	740	B	9,11-15
Multiple hearth roaster (MHR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-29)	MHR	45	B	280	B	4-5,16-17
	RF	50	B	180	B	4-9,18-19
	C	36	B	600	B	8,11-13
Fluid bed roaster (FBR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-25)	FBR	ND	ND	360	B	20
	RF	50	B	180	B	—[e]
	C	36	B	540	B	—[e]
Concentrate dryer (CD) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-27)	CD	10	B	1	B	21-22
	EF	100	B	240	B	15
	C	36	B	820	B	8,11-13,15
Fluid bed roaster (FBR) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-30)	FBR	ND	ND	360	B	20
	EF	100	B	90	B	15,23
	C	36	B	600	B	3
Concentrate dryer (CD) followed by flash furnace (FF), cleaning furnace (SS) and converter (C) (SCC 3-03-005-26)	CD	10	B	1	B	21-22
	FF	140	B	820	B	24
	SS[f]	10	B	1	B	22
	C[e]	ND[g]	ND[g]	240	B	22
Concentrate dryer (CD) followed by Noranda reactors (NR) and converter (C) (SCC 3-03-005-41)	CD	10	B	1	B	21-22
	NR	ND	ND	ND	ND	—
	C	ND	ND	ND	ND	—

[a] Expressed as lb of pollutant/ton of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of blister copper. SCC = Source Classification Code. ND = no data.

[b] For particulate matter removal, gaseous effluents from roasters, smelting furnaces and converters usually are treated in hot ESPs at 200 to 340°C (400 to 650°F) or in cold ESPs with gases cooled to about 120°C (250°F before) ESP. Particulate emissions from copper smelters contain volatile metallic oxides which remain in vapor form at higher temperatures, around 120°C (250°F). Therefore, overall particulate removal in hot ESPs may range 20 to 80% and in cold ESPs may be 99%. Converter gas effluents and, at some smelters, roaster gas effluents are treated in single contact acid plants (SCAPs) or double contact acid plants (DCAPs) for SO_2 removal. Typical SCAPs are about 96% efficient, and DCAPs are up to 99.8% efficient in SO_2 removal. They also remove over 99% of particulate matter. Noranda and flash furnace offgases are also processed through acid plants and are subject to the same collection efficiencies as cited for converters and some roasters.

[c] In addition to sources indicated, each smelter configuration contains fire refining anode furnaces after the converters. Anode furnaces emit negligible SO_2. No particulate emission data are available for anode furnaces.

Table 12.3-3 (cont.).

[d] Factors for all configurations except reverberatory furnaces followed by converters have been developed by normalizing test data for several smelters to represent 30% sulfur content in concentrated ore.

[e] Based on the test data for the configuration multiple hearth roaster followed by reverberatory furnaces and converters.

[f] Used to recover copper from furnaces slag and converter slag.

[g] Since converters at flash furnaces and Noranda furnace smelters treat high copper content matte, converter particulate emissions from flash furnace smelters are expected to be lower than those from conventional smelters with multiple hearth roasters, reverberatory furnaces, and converters.

Table 12.3-4 (Metric Units). PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR MULTIPLE HEARTH ROASTER AND REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Emission Factors	
	Uncontrolled	ESP Controlled[c]
15	47	0.47
10	47	0.47
5	47	0.46
2.5	46	0.40
1.25	31	0.36
0.625	12	0.29

[a] Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.
[c] Nominal particulate removal efficiency is 99%.

Table 12.3-5 (English Units). PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR MULTIPLE HEARTH ROASTER AND REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Emission Factors	
	Uncontrolled	ESP Controlled[c]
15	95	0.95
10	94	0.94
5	93	0.93
2.5	80	0.80
1.25	72	0.72
0.625	59	0.59

[a] Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.
[c] Nominal particulate removal efficiency is 99%.

Table 12.3-6 (Metric Units). SIZE-SPECIFIC EMISSION FACTORS FOR REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: E

Particle Size[b] (µm)	Cumulative Emission Factors	
	Uncontrolled	ESP Controlled[c]
15	NR	0.21
10	6.8	0.20
5	5.8	0.18
2.5	5.3	0.14
1.25	4.0	0.10
0.625	2.3	0.08

[a] Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99%.

Table 12.3-7 (English Units). SIZE-SPECIFIC EMISSION FACTORS FOR REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: E

Particle Size[b] (µm)	Cumulative Emission Factors	
	Uncontrolled	ESP Controlled[c]
15	NR	0.42
10	13.6	0.40
5	11.6	0.36
2.5	10.6	0.28
1.25	8.0	0.20
0.625	4.6	0.16

[a] Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99%.

Table 12.3-8 (Metric Units). SIZE-SPECIFIC EMISSION FACTORS FOR COPPER CONVERTER OPERATIONS[a]

EMISSION FACTOR RATING: E

Particle Size[b] (µm)	Cumulative Emission Factors	
	Uncontrolled	ESP Controlled[c]
15	NR	0.18
10	10.6	0.17
5	5.8	0.13
2.5	2.2	0.10
1.25	0.5	0.08
0.625	0.2	0.05

[a] Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99%.

Table 12.3-9 (English Units). SIZE-SPECIFIC EMISSION FACTORS FOR REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: E

Particle Size[b] (µm)	Cumulative Emission Factors	
	Uncontrolled	ESP Controlled[c]
15	NR	0.36
10	21.2	0.36
5	11.5	0.26
2.5	4.3	0.20
1.25	1.1	0.15
0.625	0.4	0.11

[a] Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99%.

Table 12.3-10 (Metric Units). FUGITIVE EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a]

EMISSION FACTOR RATING: B

Source Of Emission	Particulate	SO_2
Roaster calcine discharge (SCC 3-03-005-13)	1.3	0.5
Smelting furnace[b] (SCC 3-03-005-14)	0.2	2
Converter (SCC 3-03-005-15)	2.2	65
Converter slag return (SCC 3-03-005-18)	ND	0.05
Anode refining furnace (SCC 3-03-005-16)	0.25	0.05
Slag cleaning furnace[c] (SCC 3-03-005-17)	4	3

[a] References 17,23,26-33. Expressed as mass kg of pollutant/Mg of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Factors for flash furnace smelters and Noranda furnace smelters may be lower than reported values. SCC = Source Classification Code. ND = no data.

[b] Includes fugitive emissions from matte tapping and slag skimming operations. About 50% of fugitive particulate emissions and about 90% of total SO_2 emissions are from matte tapping operations, with remainder from slag skimming.

[c] Used to treat slags from smelting furnaces and converters at the flash furnace smelter.

Table 12.3-11 (English Units). FUGITIVE EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a]

EMISSION FACTOR RATING: B

Source Of Emission	Particulate	SO_2
Roaster calcine discharge (SCC 3-03-005-13)	2.6	1
Smelting furnace[b] (SCC 3-03-005-14)	0.4	4
Converter (SCC 3-03-005-15)	4.4	130
Converter slag return (SCC 3-03-005-18)	ND	0.1
Anode refining furnace (SCC 3-03-005-16)	0.5	0.1
Slag cleaning furnace[c] (SCC 3-03-005-17)	8	6

[a] References 17, 23, 26-33. Expressed as mass lb of pollutant/ton of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Factors for flash furnace smelters and Noranda furnace smelters may be lower than reported values. SCC = Source Classification Code. ND = no data.

[b] Includes fugitive emissions from matte tapping and slag skimming operations. About 50% of fugitive particulate emissions and about 90% of total SO_2 emissions are from matte tapping operations, with remainder from slag skimming.

[c] Used to treat slags from smelting furnaces and converters at the flash furnace smelter.

Table 12.3-12 (Metric Units). UNCONTROLLED PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE MATTE TAPPING OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	76	0.076
10	74	0.074
5	72	0.072
2.5	69	0.069
1.25	67	0.067
0.625	65	0.065

[a] Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.

Table 12.3-13 (English Units). UNCONTROLLED PARTICLE SIZE AND SIZE SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE MATTE TAPPING OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	76	0.152
10	74	0.148
5	72	0.144
2.5	69	0.138
1.25	67	0.134
0.625	65	0.130

[a] Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.

Table 12.3-14 (Metric Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE SLAG TAPPING OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	33	0.033
10	28	0.028
5	25	0.025
2.5	22	0.022
1.25	20	0.020
0.625	17	0.017

[a] Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.

Table 12.3-15 (English Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE SLAG TAPPING OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	33	0.066
10	28	0.056
5	25	0.050
2.5	22	0.044
1.25	20	0.040
0.625	17	0.034

[a] Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.

Table 12.3-16 (Metric Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM CONVERTER SLAG AND COPPER BLOW OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	98	2.2
10	96	2.1
5	87	1.9
2.5	60	1.3
1.25	47	1.0
0.625	38	0.8

[a] Reference 26. Expressed as kg of pollutant/Mg weight of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.

Table 12.3-17 (English Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM CONVERTER SLAG AND COPPER BLOW OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	98	4.3
10	96	4.2
5	87	3.8
2.5	60	2.6
1.25	47	2.1
0.625	38	1.7

[a] Reference 26. Expressed as lb of pollutant/ton weight of concentrated ore processed by the smelter.
[b] Expressed as aerodynamic equivalent diameter.

Table 12.3-18 (Metric Units). LEAD EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a]

Operation	EMISSION FACTOR[b]	EMISSION FACTOR RATING
Roasting[c] (SCC 3-03-005-02)	0.075	C
Smelting[d] (SCC 3-03-005-03)	0.036	C
Converting[e] (SCC 3-03-005-04)	0.13	C
Refining (SCC 3-03-005-05)	ND	ND

[a] Reference 34. Expressed as kg of pollutant/Mg of concentrated ore processed by smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weights of copper metal. Based on test data for several smelters with 0.1 to 0.4% lead in feed throughput. SCC = Source Classification Code. ND = no data.

[b] For process and fugitive emissions totals.

[c] Based on test data on multihearth roasters. Includes total of process emissions and calcine transfer fugitive emissions. The latter are about 10% of total process and fugitive emissions.

[d] Based on test data on reverberatory furnaces. Includes total process emissions and fugitive emissions from matte tapping and slag skimming operations. Fugitive emissions from matte tapping and slag skimming operations amount to about 35% and 2%, respectively.

[e] Includes total of process and fugitive emissions. Fugitives constitute about 50% of total.

Table 12.3-19 (English Units). LEAD EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a]

Operation	EMISSION FACTOR[b]	EMISSION FACTOR RATING
Roasting[c] (SCC 3-03-005-02)	0.15	C
Smelting[d] (SCC 3-03-005-03)	0.072	C
Converting[e] (SCC 3-03-005-04)	0.27	C
Refining (SCC 3-03-005-05)	ND	ND

[a] Reference 34. Expressed as lb of pollutant/ton of concentrated ore processed by smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weights of copper metal. Based on test data for several smelters with 0.1 to 0.4% lead in feed throughput. SCC = Source Classification Code. ND = no data.

[b] For process and fugitive emissions totals.

[c] Based on test data on multihearth roasters. Includes total of process emissions and calcine transfer Fugitive emissions. The latter are about 10% of total process and fugitive emissions.

[d] Based on test data on reverberatory furnaces. Includes total process emissions and fugitive emissions from matte tapping and slag skimming operations. Fugitive emissions from matte tapping and slag skimming operations amount to about 35% and 2%, respectively.

[e] Includes total of process and fugitive emissions. Fugitives constitute about 50% of total.

Occasionally slag or blister copper may not be transferred immediately to the converters from the smelting furnace. This holding stage may occur for several reasons, including insufficient matte in the smelting furnace, unavailability of a crane, and others. Under these conditions, the converter is rolled out of its vertical position and remains in a holding position and fugitive emissions may result.

At primary copper smelters, both process emissions and fugitive particulate from various pieces of equipment contain oxides of many inorganic elements, including lead. The lead content of particulate emissions depends upon both the lead content of the smelter feed and the process offgas temperature. Lead emissions are effectively removed in particulate control systems operating at low temperatures, about 120°C (250°F).

Tables 12.3-18 and 12.3-19 present process and fugitive lead emission factors for various operations of primary copper smelters.

Fugitive emissions from primary copper smelters are captured by applying either local ventilation or general ventilation techniques. Once captured, fugitive emissions may be vented directly to a collection device or can be combined with process off-gases before collection. Close-fitting exhaust hood capture systems are used for multiple hearth roasters and hood ventilation systems for smelt matte tapping and slag skimming operations. For converters, secondary hood systems or building evacuation systems are used.

A number of hazardous air pollutants (HAPs) are identified as being present in some copper concentrates being delivered to primary copper smelters for processing. They include arsenic, antimony, cadmium, lead, selenium, and cobalt. Specific emission factors are not presented due to lack of data. A part of the reason for roasting the concentrate is to remove certain volatile impurities including arsenic and antimony. There are HAPs still contained in blister copper, including arsenic, antimony, lead, and selenium. After electrolytic refining, copper is 99.95 percent to 99.97 percent pure.

References For Section 12.3

1. *Mineral Commodity Summaries 1992*, U. S. Department of the Interior, Bureau of Mines.

2. *Background Information For New Source Performance Standards: Primary Copper, Zinc And Lead Smelters, Volume I, Proposed Standards*, EPA-450/2-74-002a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.

3. *Arsenic Emissions From Primary Copper Smelters - Background Information For Proposed Standards, Preliminary Draft*, EPA Contract No. 68-02-3060, Pacific Environmental Services, Durham, NC, February 1981.

4. *Background Information Document For Revision Of New Source Performance Standards For Primary Copper Smelters*, EPA Contract No. 68-02-3056, Research Triangle Institute, Research Triangle Park, NC, March 31, 1982.

5. *Air Pollution Emission Test: Asarco Copper Smelter, El Paso, TX*, EMB-77-CUS-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1977.

6. Written communications from W. F. Cummins, Inc., El Paso, TX, to A. E. Vervaert, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1977.

7. AP-42 Background Files, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

8. *Source Emissions Survey Of Kennecott Copper Corporation, Copper Smelter Converter Stack Inlet And Outlet And Reverberatory Electrostatic Precipitator Inlet And Outlet, Hurley, NM,* EA-735-09, Ecology Audits, Inc., Dallas, TX, April 1973.

9. *Trace Element Study At A Primary Copper Smelter*, EPA-600/2-78-065a and 065b, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

10. *Systems Study For Control Of Emissions, Primary Nonferrous Smelting Industry, Volume II: Appendices A and B*, PB 184885, National Technical Information Service, Springfield, VA, June 1969.

11. *Design And Operating Parameters For Emission Control Studies: White Pine Copper Smelter,* EPA-600/2-76-036a, U. S. Environmental Protection Agency, Washington, DC, February 1976.

12. R. M. Statnick, *Measurements Of Sulfur Dioxide, Particulate And Trace Elements In Copper Smelter Converter And Roaster/Reverberatory Gas Streams*, PB 238095, National Technical Information Service, Springfield, VA, October 1974.

13. AP-42 Background Files, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC.

14. *Design And Operating Parameters For Emission Control Studies, Kennecott-McGill Copper Smelter*, EPA-600/2-76-036c, U. S. Environmental Protection Agency, Washington, DC, February 1976.

15. *Emission Test Report (Acid Plant) Of Phelps Dodge Copper Smelter, Ajo, AZ,* EMB-78-CUS-11, Office of Air Quality Planning and Standards, Research Triangle Park, NC March 1979.

16. S. Dayton, "Inspiration's Design For Clean Air", *Engineering And Mining Journal, 175*:6, June 1974.

17. *Emission Testing Of Asarco Copper Smelter, Tacoma, WA*, EMB-78-CUS-12, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

18. Written communication from A. L. Labbe, Asarco, Inc., Tacoma, WA, to S. T. Cuffe, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 20, 1978.

19. *Design And Operating Parameters For Emission Control Studies: Asarco-Harden Copper Smelter*, EPA-600/2-76-036j, U. S. Environmental Protection Agency, Washington, DC, February 1976.

20. *Design And Operating Parameters for Emission Control Studies: Kennecott, Hayden Copper Smelter*, EPA-600/2/76-036b, U. S. Environmental Protection Agency, Washington, DC, February 1976.

21. R. Larkin, *Arsenic Emissions At Kennecott Copper Corporation, Hayden, AZ*, EPA-76-NFS-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1977.

22. *Emission Compliance Status, Inspiration Consolidated Copper Company, Inspiration, AZ*, U. S. Environmental Protection Agency, San Francisco, CA, 1980.

23. Written communication from M. P. Scanlon, Phelps Dodge Corporation, Hidalgo, AZ, to D. R. Goodwin, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 18, 1978.

24. Written communication from G. M. McArthur, Anaconda Company, to D. R. Goodwin, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 2, 1977.

25. Telephone communication from V. Katari, Pacific Environmental Services, Durham, NC, to R. Winslow, Hidalgo Smelter, Phelps Dodge Corporation, Hidalgo, AZ, April 1, 1982.

26. *Inhalable Particulate Source Category Report For The Nonferrous Industry*, Contract 68-02-3159, Acurex Corp., Mountain View, CA, August 1986.

27. *Emission Test Report, Phelps Dodge Copper Smelter, Douglas, AZ*, EMB-78-CUS-8, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1979.

28. *Emission Testing Of Kennecott Copper Smelter, Magna, UT*, EMB-78-CUS-13, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

29. *Emission Test Report, Phelps Dodge Copper Smelter, Ajo, AZ*, EMB-78-CUS-9, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1979.

30. Written communication from R. D. Putnam, Asarco, Inc., to M. O. Varner, Asarco, Inc., Salt Lake City, UT, May 12, 1980.

31. *Emission Test Report, Phelps Dodge Copper Smelter, Playas, NM*, EMB-78-CUS-10, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1979.

32. *Asarco Copper Smelter, El Paso, TX*, EMB-78-CUS-7, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 25, 1978.

33. A. D. Church, *et al.*, *"Measurement Of Fugitive Particulate And Sulfur Dioxide Emissions At Inco's Copper Cliff Smelter"*, Paper A-79-51, The Metallurgical Society, American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), New York, NY.

34. *Copper Smelters, Emission Test Report—Lead Emissions*, EMB-79-CUS-14, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.