United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA 4[illegible]/3-83-003
February 1983

Air

EPA

Review of New Source Performance Standards for Primary Copper Smelters

NSPS

Review of New Source Performance Standards for Primary Copper Smelters

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

February 1983

CONTENTS

STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

PRIMARY COPPER SMELTERS: REVIEW OF STANDARDS

BACKGROUND

Existing Standard

The current standard of performance for primary copper smelters, promulgated January 15, 1976 (41 FR 2338), limits SO_2 emissions from new, modified, or reconstructed roasters, smelting furnaces, or copper converters to 0.065 percent by volume (650 ppm). Reverberatory smelting furnaces are specifically exempted from this emission limit during periods when the total smelter charge contains a high level of volatile impurities (i.e., a total smelter charge with greater than 0.2 weight percent arsenic, 0.1 weight percent antimony, 4.5 weight percent lead, or 5.5 weight percent zinc, on a dry basis). This exemption was included in the standard because the cost of controlling SO_2 emissions from reverberatory smelting furnaces was considered to be unreasonable and because alternative smelting technologies were not available at reasonable cost to process high-impurity materials.

Developments Since Promulgation of the Existing Standard

After promulgation of the existing standard, the exemption for reverberatory furnaces smelting high-impurity materials was the subject of petitions filed by the Natural Resources Defense Council (NRDC) and by the American Smelting and Refining Company (ASARCO). The NRDC petition alleged that available control techniques for reducing SO_2 and particulate emissions from reverberatory smelting furnaces processing high-impurity materials had not been investigated adequately.

The ASARCO petition claimed that the exemption was economically unreasonable because it requires a new or modified reverberatory furnace processing high-impurity materials to suspend operations when such materials are not available.

In response to the petitions, EPA entered into negotiations with NRDC and ASARCO that led to a court approved settlement of the petitions in March 1982. Terms of the settlement were that EPA would review the standard and make whatever changes were considered appropriate.

In addition to the terms of this settlement, a number of other factors also suggested that a review of the standard was in order. When the current standard was promulgated, analysis indicated it would have little or no impact on the ability of existing primary copper smelters to expand production. This analysis was based on the use of a "bubble," which would have allowed increased emissions from modified existing facilities, such as an expanded smelting furnace, to be offset by an emission reduction from other existing facilities, such as roasters or copper converters. As long as the plant's overall emission level did not increase, the modified facilities would not be subject to the standard. This bubble, however, was subjected to litigation and rejected by the court in ASARCO vs EPA, 578.F.2d.319 (1978). As a result, a reassessment of the impact of the existing standard on the ability of an existing primary copper smelter to expand production is appropriate.

Also, emission tests conducted since promulgation of the standard show that fugitive SO_2 and particulate matter emissions are generated in varying quantities from numerous smelting operations. The significant quantities of these emissions indicated a need to consider fugitive emission limitations for copper smelting operations.

Consequently, a review of the existing standard of performance was undertaken to (1) reexamine the current exemption for reverberatory furnaces processing high-impurity materials, (2) assess the feasibility of controlling particulate matter emissions from reverberatory furnaces processing high-impurity materials, (3) reevaluate the impact of the current standard on the ability of existing smelters to expand production, and (4) assess the technical and economic feasibility of controlling fugitive emissions at primary copper smelters.

Draft copies of background information that formed the bases for the discussions in this report were provided to the litigants and intervenors for comment. Analysis of the information contained in the responses indicates that no changes reached in the conclusions contained herein are required.

Overview of the Copper Smelting Process

The conventional copper smelting process generally consists of two or three distinct operations: roasting, smelting, and converting. In roasting, the copper ore concentrates, which consist primarily of copper, iron, and sulfur, are heated in the presence of air to drive off a portion of the sulfur as sulfur dioxide (SO_2) gas. Roasting may or may not be included at a copper smelter, depending on factors such as the sulfur and volatile impurity levels (e.g., arsenic, antimony) contained in the copper ore concentrates processed by the smelter.

Two different types of roasters are used by the industry: multihearth roasters and fluid-bed roasters. Multihearth roasters generally are used when removal of volatile impurities during roasting is a prime consideration and when the composition of the copper ore concentrates processed may fluctuate widely. Either multihearth or fluid-bed roasters are used when removal of "excess" sulfur during roasting is a prime consideration. The SO_2 concentration in the offgases from these two types of roasters differs substantially, with that for multihearth roasters generally in the range of 4 to 5 percent and that for fluid-bed roasters generally in the range of 9 to 15 percent. Offgas volume is from 550 to 1,700 normal cubic meters per minute (Nm^3/min) (20,000 to 60,000 standard cubic feet per minute [scfm]) for multihearth roasters and 300 to 1,300 Nm^3/min (10,000 to 45,000 scfm) for fluid-bed roasters.

The roasted materials (calcine) or the raw copper ore concentrate (if roasting is not used) then are melted in a smelting furnace to form two molten layers: a slag layer and a matte layer. All of the rock and a portion of the iron combine with the fluxing agents to form the slag layer which is drawn off and discarded. The matte layer, composed of copper, iron, and sulfur, is transferred in ladles to the converters for further processing.

Three different types of smelting furnaces are used by the industry: reverberatory furnaces, electric furnaces, and flash furnaces. The reverberatory smelting furnace is a rectangular structure typically 11 meters (36 feet) wide and 40 meters (130 feet) long. Calcine or raw copper ore concentrates are fed into the furnace through the roof or sidewalls and smelted by heat generated by combustion of fossil fuel (i.e., natural gas, oil, or coal) introduced through burners in the end wall. Matte is removed through ports in the sidewalls. Typical SO_2 concentration in the offgases is low, between 0.5 and 2.0 percent, and the volume of offgas ranges between 1,700 and 4,500 Nm^3/min (60,000 and 160,000 scfm).

The electric smelting furnace is a rectangular structure typically 10 meters (33 feet) wide and 35 meters (115 feet) long. With electric smelting furnaces, calcine or raw copper ore concentrates are charged through the furnace roof and melted by the heat generated by passing an electric current through the molten bath. The electric current is provided by a series of electrodes that passes through the roof of the furnace and extends into the molten bath maintained in the furnace. Typical SO_2 concentrations in the offgas are between 4 and 6 percent. Offgas volume is usually between 400 and 800 Nm^3/min (15,000 and 30,000 scfm).

In contrast to the reverberatory and electric smelting furnaces, which use fossil fuel and electrical energy, respectively, to melt their charge, the flash furnace uses the heat generated by "combustion" or oxidation of some of the sulfur contained in the copper ore concentrate. The flash furnace is a rectangular structure typically 7 meters (23 feet) wide and 20 to 25 meters (65 to 80 feet) long. Dried copper ore concentrates, together with fluxing material and preheated air, and a mixture of oxygen and air or oxygen alone are injected into the furnace. A portion of the sulfur contained in the charge is oxidized to SO_2, generating sufficient heat to melt the charge. Depending on the amount of oxygen used, the offgases contain from 10 to 80 percent SO_2, with offgas volume ranging from 125 to 2,250 Nm^3/min (4,600 to 80,000 scfm).

As mentioned earlier, the matte produced in the smelting furnace is transferred to copper converters for further processing. In the converters, air is blown through the molten matte to oxidize the remaining iron and sulfur. The iron combines with fluxing agents to produce a slag, which is removed from the converter. The remaining sulfur is eliminated as SO_2 in the offgases. The product of converting is blister copper approximately 99 percent pure.

Unlike roasting and smelting, which are continuous operations, converting is a batch process. Converting is a cyclic process consisting of charging, blowing, and removal of slag and blister copper. An average converter cycle is about 12 hours. The volume and SO_2 concentration of the offgases fluctuates widely depending on the operation taking place.

Generally, from two to four converters are required to process the matte produced in a single smelting furnace. These converters are located in a converter aisle. Operation of the converters may be scheduled to smooth out the fluctuation in offgas flow from the converter aisle as a whole. Offgases from the converter aisle contain from 4.0 to 6.5 percent SO_2. Offgas volumes vary from 1,700 to 3,400 Nm^3/min (60,000 to 120,000 scfm).

Sulfuric acid plants are used to control SO_2 emissions at domestic smelters by converting the SO_2 to sulfuric acid. The offgas streams produced by each of the copper smelting operations generally are classified as either strong SO_2 streams, which contain SO_2 in concentrations greater than 3.5 percent, or weak SO_2 streams, which contain SO_2 in concentrations less than 3.5 percent. A strong gas stream can be processed in a sulfuric acid plant for removal of the SO_2 without adding heat (i.e., autothermal operation), whereas a weak gas stream requires the addition of heat to be processed in an acid plant. Weak gas streams, however, may be mixed with strong gas streams, and the mixed stream sent to a sulfuric acid plant for processing without adding heat, providing the SO_2 concentraton of the mixed gas stream is above 3.5 percent.

REVERBERATORY FURNACE EXEMPTION--SO_2 CONTROL

Copper smelting and refining operations must produce a copper end-product with minimal levels of impurities such as arsenic and antimony. Impurity removal occurs at each stage of the smelting process: roasting, smelting, and converting.

As mentioned above, the existing standard exempts reverberatory smelting furnaces that process high-impurity materials (i.e., those processing a total charge with more than 0.2 weight percent arsenic, 0.1 weight percent antimony, 4.5 weight percent lead, or 5.5 weight percent zinc). This exemption was provided in the existing standard because the cost of controlling SO_2 emissions from reverberatory smelting furnaces was considered unreasonable and because alternative smelting technologies capable of processing high-impurity materials were considered too costly or not demonstrated. Since the existing standard was promulgated, however, there have been a number of developments in the area of alternative smelting technologies and the control of weak SO_2 streams.

Alternative Smelting Technologies

Three alternative smelting technologies were examined during the review of the existing standard to determine their suitability for processing high-impurity materials: flash smelting, electric smelting, and continuous smelting.

Flash smelting. Two flash smelting furnace designs were studied: Inco and Outokumpu Oy. Analysis of the data and information collected show that while both furnace designs are capable of processing copper concentrates with a higher than average impurity levels, experience to date has been insufficient to judge whether they are capable of processing materials with impurity levels in excess of those specified in the exemption to the existing standard.

Outokumpu Oy has developed a procedure for removing impurities prior to flash smelting. In this process, dried and preheated concentrates are fed to a rotary kiln in an atmosphere of sulfur and nitrogen. Arsenic and antimony sulfides in the feed are vaporized and recovered from the offgas by condensation. Laboratory tests indicate in excess of 99 percent arsenic removal from concentrates containing up to 11.4 percent arsenic and from 50 to 80 percent antimony removal from concentrates containing up to 1.5 percent antimony.

Small-scale pilot tests in a 10- to 100-kilograms-per-hour (kg/h) (22- to 220-pounds-per-hour [lb/h]) facility indicate that the use of sulfidizing roasting prior to the flash smelting could result in impurity elimination comparable to that obtained by multihearth roasting followed by reverberatory furnace smelting. Although promising, Outokumpu Oy feels that full-scale pilot tests of the technology in a 1,000-kg/h (2,200-lb/h) facility is required before it could be commercialized.

Electric furnace smelting. Although electric furnace smelting is considered technically demonstrated for processing high-impurity materials, the costs associated with the use of this technology, due to the high cost of electrical power, are considered unreasonable.

Continuous smelting furnaces. While the continuous smelting furnace technologies have processed some high-impurity materials, they have not been shown to be capable of producing copper of acceptable quality from materials with impurity levels in excess of those specified in the existing standard. Therefore, continuous smelting furnace technologies are not considered demonstrated for processing high-impurity materials.

Weak SO_2 Offgas Stream Control

Offgases from reverberatory smelting furnaces have an SO_2 content too low to be processed directly in a sulfuric acid plant without the addition of large amounts of heat. Other alternatives available for the control of these offgases include application of flue gas desulfurization systems (FGD) directly to the weak SO_2 offgas stream (which either remove the SO_2 in the form of a throwaway by-product or provide a strong SO offgas stream); use of oxygen in the reverberatory furnace to increase SO_2 concentration; and blending the offgases with strong SO_2 offgas from converters and/or roasters.

Flue gas desulfurization. Since promulgation of the existing standard, several FGD systems have been applied to weak metallurgical SO_2 offgas streams, including copper smelter streams, on either a pilot- or a full-scale basis. Two types, a calcium-based system and a magnesium-oxide-based system, have been applied to full-scale reverberatory furnace offgas streams at a copper smelter in Japan. A third system, ammonia-based, has been used commercially to remove SO_2 from weak SO_2 offgas streams produced at lead and zinc smelters.

The calcium-based system removes and "fixes SO_2" from the weak SO_2 offgas stream as a solid or slurry. There has been no application of this system at copper smelters in the United States; however, a calcium-based system has been successfully controlling a weak SO_2 offgas stream (<0.6 percent) from a molybdenum roaster in Arizona since 1972.

The most significant application of calcium-based FGD technology has been at a copper smelter in Japan. Operating experience at this smelter has demonstrated that calcium-based FGD systems are capable of removing SO_2 from reverberatory furnace offgas. System reliability is high, over 99 percent, while an SO_2 absorption efficiency of 99.5 percent has been achieved. Analyses indicate that calcium-based FGD systems can accommodate the fluctuations in flow and SO_2 content of reverberatory furnace offgas streams while maintaining a minimum 90-percent SO_2 removal efficiency. Consequently, calcium-based FGD's are considered demonstrated for control of SO_2 emissions contained in reverberatory furnace SO_2 offgas streams.

The magnesium oxide (MgO) scrubbing system absorbs the SO_2 present in weak SO_2 offgas streams in a MgO slurry to form hydrated crystals of $MgSO_3$ and $MgSO_4$. These crystals are then dried and calcined to generate a strong SO_2 offgas stream (i.e., ~10 percent SO_2) that can be treated directly in a sulfuric acid plant. The MgO system has been applied to copper reverberatory furnace offgases on a full-scale basis at the Japanese smelter referred to earlier. An MgO system processes a portion of the gases generated by the reverberatory furnaces at this smelter. Offgases that exit the MgO absorber generally exhibit an SO_2 concentration of about 200 ppm, reflecting a 99-percent SO_2 removal efficiency. Experience has shown that the MgO system has considerable capability to handle fluctuations in the reverberatory furnace offgas SO_2 concentration. Thus, the MgO system is also considered demonstrated for the control of weak SO_2 offgas streams from reverberatory furnaces.

The Cominco process absorbs the SO_2 contained in weak SO_2 offgas streams in an ammonia solution to form ammonium bisulfite. The ammonium bisulfite is then reacted with sulfuric acid to form ammonium sulfate, SO_2, and water. The SO_2 is stripped from solution to generate a strong SO_2 offgas stream (i.e., ~25 percent SO_2) for treatment in an SO_2 control facility, such as a sulfuric acid plant. While the Cominco system has not been applied to offgases from copper smelting reverberatory furnaces, it has been applied to other pyrometallurgical offgas streams with characteristics similar to those from copper smelter reverberatory furnaces. Offgases from a lead sintering plant and a zinc roaster, for example, have been treated by the Cominco process at a lead smelter in Canada. The system has exhibited SO_2 removal efficiencies ranging from 91 to 98 percent and has shown that it can accommodate the fluctuations encountered in both flow rate and SO_2 concentration normally associated with copper smelting reverberatory furnaces while maintaining an SO_2 removal efficiency of at least 90 percent. Thus, the ammonia-based Cominco system is also considered demonstrated for controlling weak SO_2 offgas stream from copper reverberatory furnaces.

While the use of each of the scrubbing systems described above produces solid and liquid waste materials, disposal methods currently in use at numerous SO_2 scrubbing installations demonstrate that techniques are available for the disposal of these waste products in an environmentally acceptable manner.

Use of oxygen. The use of oxygen in a reverberatory furnace involves the substitution of commercial oxygen for some or all of the combustion air fed to the furnace. A number of techniques related to the use of oxygen in reverberatory furnaces have been developed and are in use at a number of locations outside the United States. These techniques increase the SO_2 concentration in reverberatory furnace offgas by reducing the amount of nitrogen introduced with the combustion air and by reducing fuel consumption. Production capacity of the reverberatory furnace also increases, with increases of up to 122 percent reported with this furnace modification. In addition, the use of oxygen also results in a reduction in the size and cost of downstream gas handling and processing equipment because of reduced offgas volumes. Three distinct means of oxygen use in reverberatory furnaces currently in use or under development were reviewed: oxygen enrichment, oxy-fuel burners, and oxygen sprinkle.

Oxygen enrichment involves increasing the oxygen content of the combustion air introduced to the reverberatory furnace. An increase in the oxygen/nitrogen ratio of the combustion air from 21:79 to 25:75 can result in an increase in the SO_2 concentration of the reverberatory furnace offgas after gas treatment and cleaning of 0.9 percentage points. Experience on full-scale and pilot-scale demonstrations indicate that this performance can be sustained with no adverse effects on the reverberatory furnace. Consequently, oxygen enrichment is considered a demonstrated technique for increasing SO_2 concentrations in reverberatory furnace offgases.

Oxygen enrichment will not necessarily increase the SO_2 content of reverberatory furnace offgas to the level necessary to operate a sulfuric acid plant autothermally. On the other hand, its use does increase the SO_2 concentration of reverberatory furnace offgases to a level that facilitates blending of these offgases with other strong streams (i.e., roasters and/or converters) and subsequent treatment in a sulfuric acid plant. Oxygen enrichment can be used with conventional burner systems and sidewall charging systems.

The use of oxy-fuel burners on reverberatory furnaces involves the use of commercial oxygen to provide 100 percent of the oxygen required for fuel combustion in these burners. Fuel and oxygen are introduced through vertically positioned, roof-mounted burners rather than the conventional horizontally positioned, end-wall burners. Increases in reverberatory furnace offgas SO_2 concentrations in the range of 2.5 to 5.5 percentage points have been reported. Experience on full-scale demonstrations at both copper and nickel smelters indicate that this performance can be sustained with no adverse effect on the reverberatory furnace. Oxy-fuel burners, therefore, are considered a demonstrated technique for increasing the SO_2 concentration of the reverberatory furnace offgases above the minimum level required for autothermal operation of a sulfuric acid plant.

The oxygen-sprinkle system differs from other oxygen enhancement systems in that it results in reverberatory furnace operation on the same principle as a flash furnace. This system is currently under development at a copper smelter in Arizona. Oxygen-sprinkle smelting is expected to result in SO_2 concentration of 15 to 30 percent in the reverberatory furnace offgas. Although preliminary results appear promising, this system cannot be considered demonstrated at this time.

Offgas blending. Offgas blending involves mixing the reverberatory furnace offgases with converter and/or roaster offgases to produce a blended stream that can be treated in a sulfuric acid plant. Although no copper smelter in the United States is currently using this technique as a means of controlling reverbatory furnace offgases, it is considered a demonstrated control technique for reverberatory furnaces. Variations in converter offgas flow rate and SO_2 concentration can result in SO_2 concentrations in the blended gas stream below that required for autothermal sulfuric acid plant operation. In such cases, supplementary heat must be supplied to the sulfuric acid plant.

Blending with multihearth roaster offgases may result in production of "black" sulfuric acid in the acid plant due to contamination with trace amounts of organic flotation agents not completely decomposed in the roaster. Although "black" acid must generally be sold at a price lower than that for clear acid, the income from the sale of this acid covers transportation and sales costs.

REVERBERATORY FURNACE EXEMPTION--PARTICULATE EMISSION CONTROL

The existing standard does not address control of particulate matter emissions from reverberatory furnaces which are exempt from SO_2 emission limitations when they process high-impurity materials. Lack of such a requirement has no impact when such materials are not being processed. In this situation, SO_2 emissions from new, modified, or reconstructed reverberatory furnaces must be controlled to comply with the existing standard and particulate matter emissions are removed from the reverberatory furnace offgas stream during the gas treatment and conditioning associated with the control of SO_2 emissions.

Fabric filtration is a well-demonstrated technology for control of particulate matter emissions. Although fabric filtration has not been used by the domestic copper smelting industry to control particulate matter emissions from reverberatory furnaces, it has been used to control particulate matter emissions from fluid-bed and multihearth roasters, electric furnaces, and converters at copper smelters. For example, a fabric filter used to remove particulate matter emissions from a gas stream composed of offgases from a fluid-bed roaster, an electric furnace, and several converters at a domestic copper smelter was tested in 1980. The fabric filter operated at approximately 110° C (230° F) and processed about 4,700 Nm^3/min (165,000 scfm) of gas. A spray chamber was used to cool the gases prior to their entry to the baghouse. Emission tests results indicated a particulate matter removal efficiency of 99.7 percent and an average outlet grain loading of 47 mg/Nm^3 (0.020 grain/dry scf).

Electrostatic precipitators (ESP's) also may be used for reverberatory furnace particulate matter emission control. ESP's are well demonstrated throughout the domestic copper smelting industry for control of particulate matter in offgases from reverberatory furnaces, roasters, and converters. Tests at domestic copper smelters indicate show that ESP's are capable of achieving a removal efficiency of 96.7 percent and outlet grain loadings on the order of 98 mg/Nm^3 (0.04 grain/dry scf).

The presence of volatile metal oxides that remain in the vapor phase at gas-stream temperatures between 315° to 430° C (600° to 800° F), but which condense in the range of 120° to 300° C (250° to 570° F) and below necessitates gas cooling to achieve efficient removal of particulate matter emissions from reverberatory furnace offgases. This was confirmed by particulate matter emission tests at the reverberatory furnace ESP outlets of four domestic copper smelters. These data indicate that particulate matter removal efficiency, as measured by EPA Method 5, decreases to less than 50 percent if the reverberatory furnace offgas stream is not cooled to 110° C (230° F) or less prior to the control device.

In summary, both fabric filters and ESP's are considered demonstrated control techniques for control of particulate matter emissions from reverberatory furnace offgases.

CAPACITY EXPANSION AT EXISTING SMELTERS

Standards of performance apply to new or modified sources of air pollution. At the time of promulgation of the existing standard, the definition of "modification" was amended by authorizing a "bubble" under which sources of air pollution could alter facilities within the source to increase capacity and not be considered "modified" if total emissions from the source did not increase. The analysis of the impact of the existing standard on the ability of domestic copper smelters to expand production was based on the use of this "bubble." This amendment to the definition of modification was litigated, however, and rejected by the court [ASARCO v. EPA 578 F.2d.319 (1978)].

Under the current modification provisions, which apply to all standards of performance, many physical or operational changes to an existing facility are considered modifications. A domestic copper smelter may expand capacity and not be subject to the modification provisions if the cost of the physical or operational change as a percentage of the original cost of the facility exceeds the annual guideline repair allowance specified in the latest edition of "Internal Revenue Service Publication 534." In addition, a facility may expand capacity and not be subject to the modification provision if the offgas stream from the facility is partially controlled so that there is no increase in emissions from the facility.

Traditionally, domestic primary copper smelters have satisfied increased demand by expanding existing facilities. Generally, the capacity of the smelting furnace is the primary factor limiting production at a copper smelter. Roaster and converter capacities normally exceed that of the smelting furnace and generally can accommodate increased throughputs of up to 20 percent.

To analyze the impact of the existing standard on the ability of domestic copper smelters to expand production, a number of expansion scenarios (i.e., an expansion option coupled with an alternative control technique to achieve preexpansion levels) for each domestic smelter configuration were identified. The expansion options selected include the use of oxygen enrichment, oxy-fuel burners, the conversion of existing green-charge smelting furnaces to calcine charge (i.e., use of roasting at reverberatory and electric furnaces that do not currently employ roasting), and the replacement of reverberatory furnaces with flash furnaces. Capacity expansions for these options range from as little as 10 to 20 percent to as much as 100 percent.

Emission controls selected for the expansion scenarios include the application of FGD systems, offgas stream blending, and sulfuric acid plants. In scenarios involving reverberatory furnaces, a sufficient fraction of the reverberatory furnace weak SO_2 offgas stream is treated by the control system to ensure that emissions from the furnace following expansion are equal to or less than emissions from the furnace prior to expansion. For scenarios in which only strong SO_2 offgas streams are involved, the strong streams are treated directly in a sulfuric acid plant. Increased emissions from existing converters and/or roasters are treated in the same control facility following the expansion as they were before the expansion. Emissions from new converters and/or roasters are treated in a sulfuric acid plant. A detailed description of the expansion scenarios analyzed is included in the Background Information Document (BID).

FUGITIVE EMISSIONS

The existing standard does not limit fugitive emissions from primary copper smelters. Emission tests at several domestic smelters indicate that multihearth roasters and converters are the major sources of particulate matter emissions, while copper converters are the major source of SO_2 emissions.

Capture of SO_2 and particulate matter fugitive emissions, with release of these emissions to the atmosphere through "tall" stacks, is generally necessary at new smelters to comply with State, local, and Occupational Safety and Health Administration (OSHA) workplace and ambient air requirements. Capture of these fugitive emissions results in a high volume of gas with low concentrations of particulate matter and SO_2. Control systems such as ESP's and fabric filters, which are not necessarily required by State or local regulations, are available for the removal of the particulate matter from these gas streams. Systems for removal of SO_2, however, have not been demonstrated. Consequently, analysis of the alternatives for control of fugitive emissions from copper smelters focused on control of particulate matter emissions.

Calcine discharge and transfer are the primary sources of fugitive particulate matter emissions from multihearth roaster operations. Calcine is normally discharged from the bottom of the roaster and distributed through a hopper to vehicles (larry cars) for transportation to the smelting furnace. Various systems of enclosing the hopper and larry car coupled with local hoods have been used to capture fugitive emissions. Visible emission observations of systems now in use for the capture of fugitive emissions from calcine discharge operations at four domestic copper smelters indicate that these systems have a capture efficiency of about 90 percent.

Converter fugitive emissions occur during converter charging, skimming, pouring, and blowing operations. During the first three operations, the mouth of the converter is no longer under the primary hood used to capture process emissions and, as a result, significant amounts of emissions are discharged to the atmosphere. During blowing operations, substantial quantities of emissions escape from around the primary hood. Two systems have been demonstrated for capture of these converter fugitive emissions: air curtain/secondary hood and building evacuation (general ventilation).

An air curtain and secondary hood system for capture of converter fugitive emission is currently in use at a Japanese copper smelter. Visible emission observations evaluating the performance of this system indicate a capture efficiency of about 90 percent. In addition, an air curtain and secondary hood system is currently being installed at one converter at a domestic copper smelter. The system will be undergoing testing and evaluation during 1983. If the outcome of these tests indicates the system is successful in capturing fugitive emissions, similar systems may be installed on the other converters at this smelter.

A building evacuation system is currently being used at one domestic copper smelter to capture fugitive emissions from the converter aisle. Based on visual observations of the system, engineering judgment indicates that this system has a capture efficiency of about 95 percent.

Regardless of the capture system used, removal of particulate matter emissions from the fugitive gas streams prior to discharge to the atmosphere requires the use of either an ESP or a fabric filter. Tests on the fabric filter serving the building evacuation system mentioned above indicate a 99-percent removal of particulate matter from the captured fugitive gas stream. Tests conducted on the fabric filter serving the multihearth roaster calcine discharge at one of the domestic copper smelters mentioned earlier also indicated a 99-percent removal of particulate matter from the captured fugitive gas stream is achievable.

No test data are available on control of particulate matter contained in the fugitive gas stream captured by an air curtain/secondary hood system on a converter. Particulate matter grain loading in this stream, however, would lie between that of the converter fugitive gas stream captured by a building evacuation system and that of a roaster calcine discharge fugitive gas stream. Consequently, the use of a fabric filtration system on fugitive particulate matter emissions captured by an air curtain/secondary hood should also achieve 99.0 percent control.

ECONOMIC ANALYSIS

Basis of Analysis

As international markets and trade have grown and expanded, foreign copper smelters, particularly those in Japan, have begun to compete with domestic smelters for sources of copper ore concentrates. Perhaps the most vivid example of this competition is the current agreement between Anaconda Company and a consortium of Japanese copper smelting companies to ship copper ore concentrates previously processed at Anaconda's smelter in Montana to Japan for processing. This agreement illustrates the point that if the cost of producing copper in domestic smelters rises above the cost of producing copper in foreign smelters, the domestic copper industry could begin to focus on the mining and milling of copper ores. Concentrates would then be shipped to foreign smelters for processing rather than to domestic smelters. The cost of producing copper in foreign smelters, therefore, can be used as a yardstick against which to measure the impact of the increased costs of producing copper at new or modified domestic smelters due to compliance with the standard of performance.

The Japanese currently have established themselves as the lowest cost copper producers in the world. Consequently, their costs establish the yardstick or "trigger" beyond which domestic smelters would no longer be able to compete with Japanese smelters for the processing of domestic copper ore concentrates.

Table I summarizes the best estimates available to EPA of key components of Japanese smelting and refining costs for the case in which copper ore concentrates are purchased in the United States and

TABLE I. KEY COMPONENTS OF JAPANESE SMELTING AND REFINING COSTS

	(¢/kg)
Freight for concentrate	29.5
Smelting	23.5
Refining	17.6
Freight to United States	5.9
Profit margin	6.5
Total cost plus profit margin	83.0

shipped to Japan for smelting and refining with the resulting copper being returned to the United States for sale. The 83.0¢/kg (37.7¢/lb) cost of producing copper from domestic copper ore concentrates at Japanese smelters (including freight, smelting, refining, and profit margin) represents the "trigger." Should compliance with the standard of performance at new or modified domestic copper smelters increase domestic costs above this trigger, the standard would impose severe constraints on the ability of domestic smelters to expand production.

In addition to the existing standard, domestic copper smelters must comply with the national ambient air quality standard (NAAQS) for SO_2 in the vicinity of the smelter. This has proven to be a difficult and costly task, and the Clean Air Act has been amended to extend the time frame for the domestic copper smelting industry to progress to eventual compliance. Up to this point, smelters generally have achieved control of strong SO_2 offgas streams through the use of sulfuric acid plants. Weak SO_2 streams, however, are being discharged to the atmosphere with little or no SO_2 emission control.

Most domestic smelters discharge weak SO_2 streams through "tall" stacks, suspending or curtailing operations when necessary to comply with the NAAQS for SO_2. While existing copper smelters will eventually have to control weak SO_2 offgas streams to comply with the Clean Air Act, the current status of SO_2 control at existing copper smelters was selected as the "baseline" against which to assess the impact of the existing standard of performance. Therefore, the baseline for the economic analysis assumes full control of all strong SO_2 offgas streams and capture, but no control, of all weak SO_2 offgas streams. Although this overstates the impact of the existing standard of performance, it clearly represents an absolute minimum, in terms of emission control, that any new, modified, or reconstructed copper smelter would have to achieve in the absence of the standard of performance.

Deletion of Reverberatory Furnace Exemption

The cost of smelting high-impurity materials in a new greenfield reverberatory furnace smelter under the baseline (i.e., control of SO_2 emissions from the multihearth roaster and converter, no control of SO_2 or particulate matter from the reverberatory furnace, and no particulate matter control on captured converter fugitive gas streams) is estimated to be 97.8¢/kg (44.5¢/lb) of copper. In addition to the cost of emission control, this cost includes transportation, smelting, and refining costs. The existing standard of performance imposes no additional costs beyond this baseline cost because of the exemption for reverberatory furnaces processing high-impurity materials.

The use of oxy-fuel burners on the reverberatory furnace at a new greenfield smelter to increase the concentration of SO_2 in the reverberatory furnace offgas followed by gas stream blending and a sulfuric acid plant is the most cost-effective and, coincidentally, the least-cost SO_2 control alternative for controlling SO_2 emissions from the reverberatory furnace. If the exemption is removed, control of SO_2 in the reverberatory furnace offgas stream would add 2.8¢/kg (1.3¢/lb) of copper, increasing the total cost to 100.6¢/kg (45.7 ¢/lb). If the exemption is retained for SO_2 emissions, but particulate matter emission limitations are established for the reverberatory furnace offgas streams based on the use of ESP's or fabric filters, 1.5¢/kg (0.7¢/lb) of copper would be added to the baseline cost, increasing total cost to 99.3¢/kg (45.1¢/lb). The cost effectiveness for control of SO_2 in reverberatory furnace offgas streams is \$53/Mg (\$48/ton) of SO_2, and the cost-effectiveness for control of particulate matter in reverberatory furnace offgas streams is \$126/Mg (\$115/ton) of particulate matter.

The costs of producing copper in a new greenfield smelter processing high-impurity materials without controls on the reverberatory furnace, however, exceeds the Japanese trigger cost by 14.8¢/kg (6.7¢/lb). Such a smelter, therefore, would not be competitive in the world market, and, as a result, a new smelter of this configuration is very unlikely to be built in the United States.

Existing reverberatory furnaces processing high-impurity materials could become affected facilities subject to the existing standard of performance if smelting capacity were increased through a capital expenditure and emissions from the reverberatory furnace increased. An examination of the various alternatives for expanding the capacity of reverberatory furnace smelters processing high-impurity materials indicates that capacity expansions of about 20 percent are technically feasible through the use of oxygen enrichment of the combustion air in the reverberatory furnace.

If the exemption is retained, the costs of the incremental copper production associated with a 20-percent expansion at an existing reverberatory furnace smelter processing high-impurity materials under the baseline would be about 59.5¢/kg (27.0¢/lb). The existing standard of performance would impose no additional costs beyond the baseline due to the reverberatory furnace exemption. If the exemption for reverberatory furnaces processing high-impurity materials were deleted, the additional SO_2 emissions from the reverberatory furnace due to the expansion could be controlled to avoid the modification provisions associated with standards of performance at an incremental cost of 5.6¢/kg (2.5¢/lb) of copper, increasing the total cost of the incremental copper production to 65.1¢/kg (29.6¢/lb). Cost-effectiveness for the added controls would be $74/Mg ($67/ton) of SO_2 removed. Retention of the reverberatory furnace exemption for SO_2 emissions but establishment of a particulate matter emission limitation for the reverberatory furnace would require partial control of particulate matter emissions to avoid the modification provisions. The cost of controlling particulate matter emissions from the reverberatory furnace to preexpansion levels would add 3.8¢/kg (1.7¢/lb) of copper, increasing the total cost of the incremental copper produced to 63.1¢/kg (28.7¢/lb) of copper. Cost-effectiveness for these controls is \$126/Mg (\$115/ton) of particulate matter removed. In all three cases--no control, partial SO_2 control, and partial particulate matter control of emissions from the reverberatory furnace--the cost of the incremental copper production remains less than the trigger. Deletion of the exemption for reverberatory furnaces processing high-impurity materials, therefore, would have little impact on the expansion capability of the domestic copper smelting industry to process high-impurity materials.

With or without the exemption, the copper production costs of new reverberatory furnace smelters processing high-impurity materials are not competitive on world markets. Only small expansions of up to 20 percent at existing reverberatory furnace smelters processing high-impurity materials are technically feasible. These expansions are competitive on the world market and would remain so whether the exemption were retained or deleted.

Impact of Existing Standard on Expansion Capacity

The impact of the existing standard on the expansion capability of the domestic copper smelting industry to process high-impurity materials is discussed above. Consequently, the following discussion focuses on the impact of the existing standard on the expansion capability of the domestic copper smelting industry to process low-impurity materials.

New smelters. Three basic smelting technologies are available for new smelter construction: reverberatory furnaces; electric furnaces; and flash furnaces. Because of the limited availability of the large blocks of electric power and the high costs of this power, electric furnace smelting generally is not considered a viable option for new smelters. In addition, a substantial cost differential exists between flash furnace smelting and reverberatory furnace smelting (i.e., 61.0¢/kg [27.7¢/lb] versus 97.8¢/kg [44.5¢/lb]). Consequently, new smelters in the United States for processing materials with low-impurity levels undoubtedly will employ flash furnace smelting technology.

As mentioned above, the copper production costs of a new flash furnace smelter are about 61.0¢/kg (27.7¢/lb) of copper under the baseline. The existing standard of performance imposes no additional costs. Because the costs of producing copper at this type of smelter are considerably below the trigger cost, the existing standard imposes no constraints on the construction of new flash furnace smelters for increasing domestic copper smelter capacity.

Existing smelters. Domestic smelters employ three basic smelting technologies for processing low-impurity materials: reverberatory furnace smelting; electric furnace smelting; and flash furnace smelting. To analyze the impact of the existing standard on the expansion capability of the domestic copper industry to process low-impurity materials, it is convenient to subdivide reverberatory furnace smelting into two subgroups: smelters that roast ore concentrates prior to the reverberatory furnace and smelters that charge raw (green) ore concentrates directly into the reverberatory furnace. Thus, the domestic copper smelting industry can be characterized by four basic smelting configurations, which represent the following portions of domestic smelter capacity: roaster-reverberatory furnace-converter, 43 percent; reverberatory furnace-converter, 24 percent; electric furnace-converter, 9 percent; and flash furnace-converter, 24 percent.

Roaster-reverberatory furnace-converter smelting. Capacity expansions of up to 20 percent are technically feasible at smelters of this configuration through the use of oxygen enrichment of the combustion air in the reverberatory furnace. In addition, capacity expansions of up to 100 percent are technically feasible by replacing a reverberatory furnace and multihearth roasters with a flash furnace, and capacity expansion of up to 60 percent are technically feasible by replacing a reverberatory furnace and fluid-bed roasters with a flash furnace.

The incremental copper production costs associated with a 20-percent expansion, under the baseline, range from 42.4¢/kg (19.3¢/lb) to 59.5¢/kg (27.0¢/lb) of copper. Smelters employing multihearth roasters are at the upper end of the scale; those employing fluid-bed roasters are at the lower end.

The incremental copper production costs under the baseline for smelters employing multihearth roasters is 46.4¢/kg (21.1¢/lb) of copper for a 50-percent expansion through replacement of the roasters and the reverberatory furnace with a flash furnace and 50.4¢/kg (22.9¢/lb) for a 100-percent expansion. Incremental copper production costs under the baseline for a 60-percent expansion at a fluid-bed roaster smelter are 48.0¢/kg (21.8¢/lb) of copper.

For the 20-percent expansion scenario, the existing standard of performance essentially requires partial control of SO_2 in the reverberatory furnace offgas stream to avoid the modification provision and can be attained at a cost-effectiveness of $47/Mg ($43/ton) to $166/Mg ($151/ton) of SO_2. The cost-effectiveness for reverberatory furnaces with fluid-bed roasters is at the lower end of the scale and the cost-effectiveness for smelters with multihearth roasters is at the higher end.

The cost of partial SO_2 control of the reverberatory furnace for 20 percent expansion ranges from 2.1¢/kg (1.0¢/lb) to 5.6¢/kg (2.5¢/lb) of copper. When this cost is added to the costs of the expansion under the baseline, the total incremental copper production costs range from 44.5¢/kg (20.2¢/lb) to 65.1¢/kg (29.6¢/lb), with fluid-bed roaster smelters at the lower end of this range and multihearth roaster smelters at the upper end.

The existing standard would have no impact on the 50-percent, 60-percent, and 100-percent expansion scenarios because replacement of the reverberatory furnace and roasters with a flash furnace eliminates all weak offgas streams. The resulting flash furnace strong offgas stream would be controlled under the baseline.

The incremental copper production costs associated with the 20-percent expansion scenario remain well below the trigger cost. In addition, the incremental copper production costs associated with the 50-, 60-, and 100-percent expansion scenarios are well below the trigger cost. Consequently, the existing standard does not preclude capacity expansions at existing roaster-reverberatory furnace-converter smelters.

Reverberatory furnace-converter smelting. Capacity expansions of up to 20 percent are technically feasible at smelters of this configuration through the use of oxygen enrichment of the combustion air in the reverberatory furnace. In addition, capacity expansions of up to 100 percent are technically feasible by replacing the reverberatory furnace with a flash furnace.

The incremental copper production costs for the 20-percent expansion scenarios under the baseline are about 57.7¢/kg (26.2¢/lb) of copper. The cost-effectiveness of partial SO_2 control of the reverberatory furnace to avoid consideration as a modification subject to the existing standard is about $138/Mg ($126/ton). The control costs are about 4.8¢/kg (2.2¢/lb) of copper. The existing standard, therefore, effectively increases the incremental copper production costs associated with this 20-percent expansion scenario to about 62.5¢/kg (28.4¢/lb) of copper.

The incremental copper production costs for a 50-percent expansion scenario based on replacement of the reverberatory furnace with a flash smelting furnace are about 49.5¢/kg (22.5¢/lb) and about 52.7¢/kg (24.0¢/lb) for a 100-percent expansion scenario. The existing standard would have no impact on either of these expansion scenarios because replacement of the reverberatory furnace with a flash furnace eliminates all weak offgas streams. The resulting flash furnace strong offgas stream would be controlled under the baseline.

The existing standard does not increase the incremental copper production costs associated with the 20-percent expansion scenario above the trigger cost. In addition, the incremental copper production costs associated with the 50- and 100-percent expansion scenarios are well below the trigger. Therefore, the existing standard does not preclude capacity expansions at existing reverberatory furnace-converter smelters.

Electric furnace-converter smelting. This smelter configuration can be expanded by up to 40 percent by converting the smelting furnace to calcine charging through the use of roasting. The incremental copper production costs associated with this expansion scenario under the baseline are 88.1¢/kg (40.0¢/lb). The existing standard would impose no additional costs beyond the baseline. However, the incremental copper production costs associated with this scenario exceed the trigger cost and, as a result, expansion of existing smelters using electric furnace-converter technology is considered unlikely.

Flash furnace smelting. This smelting configuration can be expanded by up to 20 percent through the use of oxygen enrichment of the combustion air in the flash furnace. The incremental copper production costs associated with this expansion scenario, under the baseline, are about 49.9¢/kg (22.7¢/lb), which is substantially under the trigger cost. The existing standard imposes no additional costs beyond the baseline and, as a result, does not constrain expansion of existing flash furnace smelters.

Impact of fugitive particulate matter control. The existing standard does not require the control of fugitive emissions. Multi-hearth roaster and converter operations, however, result in significant fugitive particulate matter emissions. As mentioned earlier, new copper smelters will employ flash smelting rather than electric furnace or reverberatory furnace smelting due to the substantial cost advantages associated with flash smelting. Although flash smelting employs copper converters, this process does not require roasters. Consequently, fugitive emission control at new smelters will focus on copper converters. Control systems are available for the control of fugitive particulate matter emissions from converters at new flash furnace smelters at a cost effectiveness of $1,970/Mg ($1,790/ton) of particulate matter removed. Including the cost of a system to control particulate matter from fugitive converter offgases would increase smelting costs at a new flash furnace smelter by 1.3¢/kg (0.1¢/lb) of copper. This would increase the total cost of copper production to about 62.3¢/kg (28.3¢/lb). Because these costs are well below the trigger cost, including requirements for control of fugitive particulate matter emissions in the existing standard would not preclude the construction of new flash furnace smelters.

No fugitive particulate matter control costs would be imposed on any of the existing smelters expansion scenarios discussed above because none of the expansion scenarios involve the construction of new multihearth roaster or copper converters. Consequently, revisions of the existing standard to require fugitive particulate matter emission control from multihearth roasters and copper converters would have no impact on expansion of existing smelters.

CONCLUSIONS

Growth Outlook

Domestic primary copper smelter annual production peaked at 1,600,000 Mg in 1973. Since reaching that peak, production levels have fallen below the 1973 level and have shown no signs of returning to it. The absence of growth in copper smelter production as a result of a flat demand curve for copper in recent years suggests that demand is not likely to increase significantly over the next 5 years.

Current domestic copper smelting capacity in place is about 1,700,000 Mg of blister copper per year. Possible shutdowns through 1988 could amount to about 225,000 Mg. Announced expansions through the same period amount to about 25,000 Mg. The net effect of these changes would leave the domestic copper smelting industry with a capacity of about 1,500,000 Mg in 1988. Average copper production over 5 previous typical years, not including the periods of low production due to the 1980 strike and the 1982 recession, was 1,400,000 Mg. Thus, it appears that, barring unforeseen upward increases in demand, the demand for copper over the next 5 years can be met by existing domestic copper smelting capacity without the need for smelter expansion.

Reverberatory Furnace Exemption

As previously discussed, the cost of producing copper from high-impurity materials at a new reverberatory furnace smelter exceeds the trigger cost by about 15¢/kg (7¢/lb) of copper under the baseline. Therefore, the construction of a new domestic reverberatory furnace smelter for processing high-impurity materials is highly unlikely to occur whether the reverberatory furnace exemption is deleted or retained.

Existing reverberatory furnace smelters processing high-impurity materials, on the other hand, could expand capacity by up to 20 percent at a cost substantially below the trigger cost. Deletion of the reverberatory furnace exemption would increase the cost of producing copper slightly but not to the extent that it would exceed the trigger cost.

The primary sources of domestic high-impurity materials are copper ores mined in the Northwest and lead smelter by-products. Over the past two decades, growth and expansion of copper ore mining capacity has concentrated in the Southwest. Most of the copper ores mined in the Southwest, however, are characterized by low impurity levels. Because future growth and expansion of copper ore mining capacity will probably continue to occur in the Southwest, the copper ore concentrates produced by growth or expansion in copper ore mining will most likely contain low impurity levels. In addition, the domestic primary lead industry projects a decline in production, with a resulting decrease in lead smelter by-products that could be processed in domestic copper smelters. Thus, there appears to be no need for additional smelter capacity to process high-impurity materials.

With no anticipated increase in demand for copper over the next 5 years and, more specifically, no anticipated need for additional capacity to process high-impurity materials, the question of whether to delete or retain the exemption for reverberatory furnaces processing high-impurity materials appears academic. Therefore, it appears appropriate to leave the standard as it is and reexamine the question of the exemption during the next review of the standard.

Smelter Expansion

Although there is no increase in the demand for copper expected over the next 5 years, any unexpected increases in demand through 1988 could be satisfied by an expansion of existing smelting capacity. As discussed above, the existing standard allows for the expansion of existing smelters through the use of oxygen enrichment of the combustion air in the smelting furnace or replacement of existing reverberatory furnaces with flash smelting furnaces at smelters processing low-impurity materials. Domestic smelting capacity could be increased from 200,000 Mg to 900,000 Mg through the use of these techniques. As a result, potential annual smelting capacity at existing smelters ranges between 1,700,000 and 2,400,000 Mg, well above the projected demand of about 1,400,000 Mg/yr over the next 5 years.

The existing standard also imposes no constraints on expansion of domestic smelting capacity through construction of new greenfield smelters. Consequently, there is no need to revise the existing standard to accommodate expansion of domestic copper smelting capacity.

Fugitive Particulate Matter Emissions

Revising the existing standard of performance to require control of fugitive particulate matter emissions from multihearth roasters and copper converters would have little or no impact on the cost of producing copper. In none of the cases examined would the cost of fugitive particulate matter control cause copper production costs to exceed the trigger costs.

Fugitive particulate matter emission control technology is demonstrated. Fugitive particulate matter emission capture technology, however, is still evolving. Over the past 5 years, fugitive particulate matter emission capture systems have been installed on copper converters at a few domestic smelters to evaluate their performance. To date, however, these systems generally have failed to live up to expectations.

More recently, a new fugitive particulate matter emission capture system, modeled on a design that has been employed successfully at a number of Japanese copper smelters has been installed for testing on one copper converter at a domestic smelter. This system holds great promise for capture of fugitive particulate matter emissions and its performance will be evaluated in a joint program between EPA and the smelter during 1983. Until the tests are completed and evaluated, no basis is available for developing emission limits. While design specifications probably could be developed at this time, equipment specifications tend to constrain innovation and inhibit cost improvement. As a result, standards based on equipment design specifications generally are considered as a last resort.

For this reason and because of the lack of growth projected for the domestic copper industry over the next 5 years, it is considered appropriate to defer incorporating fugitive particulate matter emission limitations until the next review of the standard. At that time it is anticipated that sufficient data will be available to support the development of specific limits for fugitive particulate matter emissions from primary copper smelters.