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World Copper Smelter Sulfur Balance—1988

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

kmt	thousand metric ton	mt/d	metric ton per day
mt	metric ton	mt/yr	metric ton per year

WORLD COPPER SMELTER SULFUR BALANCE—1988

By Stewart W. Towle[1]

ABSTRACT

In 1989, the U.S. Bureau of Mines initiated a contract to gather engineering, operating, and environmental cost data for 1988 for 30 major foreign primary copper smelters in market economy countries. Data were collected for 29 of the designated smelters together with information on applicable environmental regulations. Materials balance data obtained were used with available data for the eight U.S. smelters to determine the approximate extent of copper smelter sulfur emission control in 1988. A broad characterization of the status of sulfur emission control regulation was made. The 37 U.S. and foreign smelters represented roughly 73.2% of world and 89.3% of market economy primary copper production in 1988. The 29 non-U.S. smelters attained 55.3% control of their input sulfur in 1988. Combined with the 90.4% control of U.S. smelters, an aggregate 63.4% sulfur control existed. Roughly 1,951,100 mt of sulfur was emitted from the 37 market economy smelters in 1988. Identifiable SO_2 control regulations covered 72.4% of the 29 foreign smelters, representing 66.5% of smelting capacity. Including U.S. smelters, 78.4% of the major market economy smelters were regulated, representing 73.1% of smelting capacity. Significant changes since 1988 that may increase sulfur emission control are noted.

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INTRODUCTION

The Minerals Availability Program (MAP) of the U.S. Bureau of Mines monitors present and potential minerals supply and constraints that may affect such supply. Environmental, and health and safety regulations have increasingly affected the availability of minerals from both domestic and foreign sources. In 1989, the Bureau initiated a MAP contract to gather engineering, operating, and environmental cost data on major primary copper smelters outside the United States. Emphasis was placed on the regulatory requirements for those smelters and the effects of such regulation. Where smelters were integrated with a refinery, data were gathered for both operations. Thirty smelters were studied in Western market economy countries. The main selection criterion was a minimum production capacity of roughly 100,000 mt/yr of new copper production. Smaller smelters having either location proximity to the United States or new smelting process technology representative of current industry trends completed the selection list.

The firm of Pincock, Allen & Holt, Inc. was contracted to do the study. The year 1988 was selected as the base for operating data, costs, and regulatory status. Significant projected changes through 1994 also were covered. Data collection efforts included site visits, followup inquiries, and the development of information on applicable regulations from operators, governmental agencies, and other appropriate sources. The contractor produced a separate summary report for each smelter, or smelter-refinery complex, and a final report comparing the covered operations and the applicable regulations (*1*).[2] Data collection problems resulted in dropping the Lumbumbashi smelter in Zaire from the original list of 30 smelters and in obtaining less than the desired data from listed Canadian and Yugoslavian smelters. The 29 foreign smelting operations examined are listed in table 1. The smelting technologies used at each operation are listed in table 2.

[2]Italic numbers in parentheses refer to items in the list of references at the end of this report.

Table 1.—Foreign primary copper smelting operations examined—1988

Smelting operation	Smelter production, mt Cu	Smelter capacity, mt/yr Cu
1. Mount Isa, Australia	160,850	174,000
2. Port Kembla, Australia	34,033	40,000
3. Camacari, Brazil	147,800	190,000
4. Horne, Canada	180,000	220,000
5. Copper Cliff, Canada	115,000	118,000
6. Kidd Creek, Canada	105,000	100,000
7. Chuquicamata, Chile	392,000	460,000
8. Potrerillos, Chile	119,751	125,000
9. Caletones, Chile	373,000	375,000
10. Hernan Videl Lira,[1] Chile	77,349	75,000
11. Las Ventanas, Chile	107,095	95,000
12. Harjavalta, Finland	79,022	100,000
13. Besshi, Japan	158,000	185,000
14. Naoshima, Japan	170,520	198,000
15. Onahama, Japan	185,700	230,000
16. Saganoseki, Japan	261,200	300,000
17. Tamano, Japan	159,620	169,000
18. Cananea, Mexico	45,068	60,000
19. La Caridad, Mexico	75,824	180,000
20. Ilo, Peru	189,500	275,000
21. Pasar,[2] Philippines	132,183	135,000
22. Palabora, South Africa, Republic of	120,466	133,000
23. Onsan, Korea	123,135	150,000
24. Huelva, Spain	115,900	160,000
25. Ronnskar, Sweden	94,300	105,000
26. Hamburg, Germany, F.R.	221,500	240,000
27. Bor, Yugoslavia	146,300	160,000
28. Mufulira, Zambia	215,600	240,000
29. Nkana, Zambia	149,213	240,000
Totals	4,454,929	5,232,000

[1]Also known as Paipote.
[2]Also known as Isabel.

Source: Pincock, Allen & Holt, Inc.

This report presents conclusions based upon the project reports and additional U.S. smelter information to examine the 1988 status of sulfur dioxide (SO_2) emission control for major foreign market economy copper smelters and for such smelters as a whole, including U.S. smelters (table 3). This is done using sulfur balances.[3] The apparent state of regulation in 1988 applicable to such control is also examined. Finally, known major foreign smelter changes since 1988 are noted.

The status of smelter SO_2 emissions control and regulation of such emissions is of interest as a factor affecting the relative competitiveness of copper smelters. It also is of interest in examining global SO_2 atmospheric emissions. Environmental concerns have resulted in increased regulation of copper smelter emissions in the United States and in many countries abroad at real or perceived added production cost. As the global trend to increased environmental awareness continues with accompanying regulation of smelter emissions, regulation-related cost differences should narrow. The importance of copper smelters as a source of atmospheric SO_2 should also diminish.

[3]A sulfur balance is a chemical balance of sulfur entering a smelter with sulfur exiting the smelting process.

Table 2.—Smelting technology of foreign smelters examined—1988

Smelting operation	Refinery	Smelter technology
1. Mount Isa, Australia	No	Roast-Reverberatory. Isasmelt reactor: pilot.
2. Port Kembla, Australia	Yes	Blast furnace.
3. Camacari, Brazil	Yes	Outokumpu flash furnace.
4. Horne, Canada	No	Oxy-fuel reverberatory. Noranda reactor.
5. Copper Cliff, Canada	Yes	Inco flash furnace.
6. Kidd Creek, Canada	Yes	Mitsubishi continuous.
7. Chuquicamata, Chile	Yes	Oxy-fuel reverberatory. Teniente modified conv. Outokumpu flash furnace.
8. Potrerillos, Chile	Yes	Oxy-fuel reverberatory. Teniente modified conv.
9. Caletones, Chile	No	Oxy-fuel reverberatory. Teniente modified conv.
10. Hernan Videl Lira,[1] Chile	No	Reverberatory furnace.
11. Las Ventanas, Chile	Yes	Reverberatory furnace. Teniente modified conv.
12. Harjavalta, Finland	No	Outokumpu flash furnace.
13. Besshi, Japan	Yes	Do.
14. Naoshima, Japan	Yes	Roaster-Reverberatory. Mitsubishi continuous.
15. Onahama, Japan	Yes	Reverberatory furnace.
16. Saganoseki, Japan	Yes	Outokumpu flash furnace.
17. Tamano, Japan	Yes	Outokumpu flash (FSFE)[2].
18. Cananea, Mexico	No	Reverberatory furnace.
19. La Caridad, Mexico	No	Outokumpu flash furnace.
20. Ilo, Peru	No	Reverberatory furnace.
21. Pasar,[3] Philippines	Yes	Outokumpu flash (FSFE)[2].
22. Palabora, South Africa, Republic of	Yes	Reverberatory furnace with ConTop cyclone.
23. Onsan, Korea	Yes	Outokumpu flash furnace.
24. Huelva, Spain	Yes	Do.
25. Ronnskar, Sweden	Yes	Roast-Electric furnace. Kaldo furnace.
26. Hamburg, Germany, F.R.	Yes	Roast-Blast furnace. Outokumpu flash furnace.
27. Bor, Yugoslavia	Yes	Roast-Reverberatory.
28. Mufulira, Zambia	Yes	Electric furnace.
29. Nkana, Zambia	Yes	Reverberatory furnace.

[1]Also known as Paipote.
[2]Flash Smelting furnace with Furnace Electrodes.
[3]Also known as Isabel.

Source: Pincock, Allen & Holt, Inc.

Table 3.—U.S. primary copper smelting operations—1988

Smelting operation	Refinery	Smelter technology
1. Asarco, El Paso, TX	No	Roast-Reverberatory.
2. Asarco, Hayden, AZ	No	Inco flash furnace.
3. Copper Range, White Pine, MI	Yes	Reverberatory.
4. Cyprus Miami, Claypool, AZ	Yes	Electric furnace.
5. Kennecott Garfield, Magna, UT	Yes	Noranda reactor.
6. Magma, San Manuel, AZ	Yes	Reverberatory to July, then Outokumpu flash.
7. Phelps Dodge, Hurley, NM	No	Inco flash furnace.
8. Phelps Dodge, Hidalgo, NM	No	Outokumpu flash furnace.
Smelter capacity, 1988: 1,282,000 mt/yr Cu		
Smelter production, 1988: 1,043,000 mt Cu		

Source: U.S. Bureau of Mines.

SULFUR BALANCE DATA

The smelter sulfur balance is the generally recognized means used to measure SO_2 emission control. Smelter SO_2 emissions are not wholly measurable, so the practice is to use the difference between the measured smelter sulfur input from the materials balance and the measured sulfur content of solid and liquid smelter products to get the quantity of sulfur assigned to SO_2 emission. Sulfur emitted thus consists of the measured SO_2 emissions and any unaccounted sulfur balance loss as SO_2. Sulfur enters a smelter as a major natural constituent of the ore and concentrate feed materials. Fuels and fluxes may also contribute relatively minor amounts to input sulfur. On average, sightly more than 0.9 ton of sulfur was introduced for each ton of copper for the 37 smelters covered in this report. The major portion of the input sulfur enters process gas streams when oxidized in roasters and smelting furnaces to gaseous sulfur oxides, primarily SO_2. The SO_2-bearing furnace gases are either ducted to a treatment plant, such as an acid plant, or vented to atmosphere through a stack. A minor amount of the input sulfur, usually less than 5%, will be tied up, fixed, in smelter products such as discard slag, liquid discharges, and output copper. Variable minor amounts of sulfur as SO_2 also enter the atmosphere as leakage from furnaces and gas handling equipment or through oxidation of hot materials in open transfers between furnaces.

Materials balances from contractor reports were used to calculate sulfur balances for the foreign smelters (*1*). If sufficient hard data were not available from a report, an engineering estimate was made to produce such a balance for the smelter. In some cases, the contractor balance did not specifically cover sulfur. Nonetheless, it proved possible to use the contractor's materials balances, acid production figures, operating data, and estimates of the sulfur content of by-products and waste to derive sulfur balances for each of the 29 smelters examined. Two of the smelters examined had shared acid production facilities for co-sited smelters producing metals other than copper. Only that portion of the sulfur assignable to the copper circuits of those two operations was considered in this report. As the data collection contract required only a ± 20% accuracy, the derived balances are of comparable or slightly lower accuracy. Inasmuch as certain of the collected data are proprietary, only an aggregated presentation of the extent of smelter SO_2 emissions can be made.

Actual U.S. smelter sulfur balance data for 1988 for the States of New Mexico and Arizona were obtained from state regulatory agencies covering five of the eight operating U.S. primary smelters (*2-3*). Estimates were made for the other three smelters based upon data gathered for a 1989 article on domestic smelters (*4*).

Copper production of the 29 foreign smelters examined was about 4,455 kmt in 1988. U.S. production was 1,043 kmt, giving a total of 5,498 kmt copper for the 37 major market economy smelters. This combined total was roughly 73.2% of world production and 89.3% of market economy production as estimated by the Bureau in the 1988 Minerals Yearbook (*5*). As a result, sulfur balance data for these 37 smelters can be used to approximate the level of copper smelter SO_2 emission control for the entire Western market economy segment of world copper production. These 37 major Western copper smelters produced at 77% of capacity in 1988 (*1*, *5*). The overall level of copper smelter SO_2 emission control can be considered to be roughly constant for different capacity utilizations, but some variance will occur as control is not proportional at some plants and operational interruptions may occur.

Table 4 and figures 1 and 2 show the extent of sulfur control for 1988 and the total estimated emission for the major Western copper smelters. Sulfur is partially controlled by smelting process fixation in products such as slag or treated liquid discharges. However, the major control is through treatment of process gas streams to produce byproduct sulfuric acid or, infrequently, liquefied SO_2. U.S. copper smelter SO_2 emission control for 1988 was 90.4% in meeting U.S. regulatory requirements. The 29 foreign smelters examined had an aggregate SO_2 control of 55.3% in 1988. Overall, the combined group of Western market economy smelters, United States and foreign, fixed 63.4% of total sulfur input. Emissions from these 37 Western smelters, as a group, totaled 1,951,100 mt of sulfur, equivalent to 3,898,200 mt of SO_2.

Differences in the extent of sulfur control among these market economy copper smelters are primarily due to differences in the extent of regulation of smelter SO_2 emissions. This is addressed in the next section. Japan, the United States, and Western European nations are recognized for stringent regulation of SO_2 emissions. Other nations with copper smelters have also adopted similar control regulations, or regulations governing ambient air concentrations. The presence of a market for sulfuric acid may also result in increased control through production of acid for economic reasons. The evolutionary change in smelting process from the predominant reverberatory smelter to newer, high-intensity processes, such as flash furnace smelting, Mitsubishi Continuous, or Noranda, results in the production of strong SO_2 gases, which frequently must be treated to permit safe release.

Table 4.—Copper smelter sulfur balance—1988

Smelters	Production, mt Cu	Sulfur input, mt	Sulfur fixed, mt	Control, %
United States . . .	1,043,000	1,242,500	1,123,800	90.4
Foreign group . .	4,454,900	4,095,400	2,263,000	55.3
Total	5,497,900	5,337,900	3,386,000	63.4
Sulfur emitted . .			1,951,100	

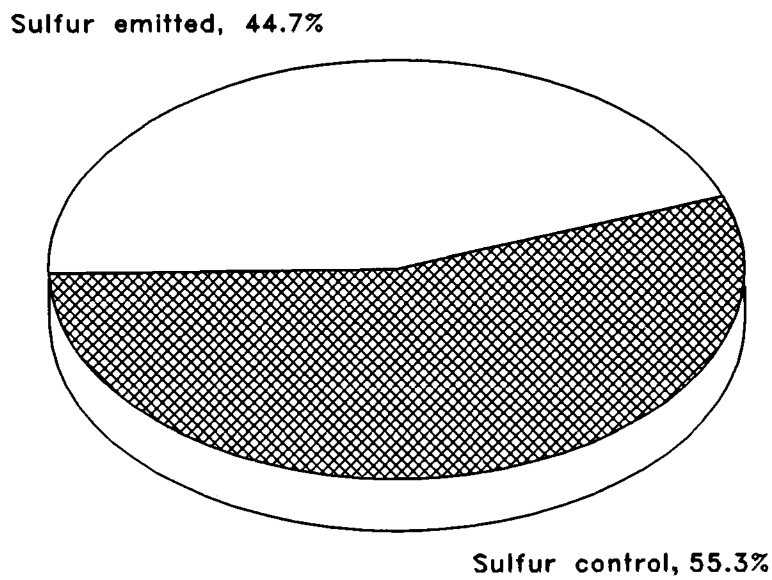

Figure 1.—Copper smelter sulfur balance—foreign smelters.

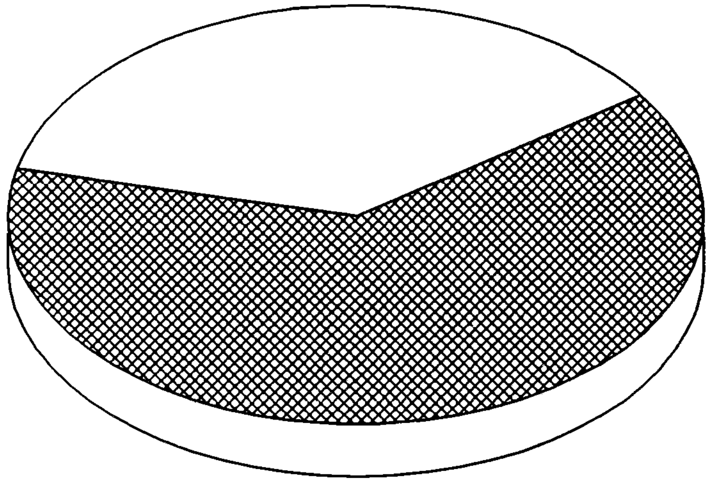

Figure 2.—Copper smelter sulfur balance—with U.S. smelters.

REGULATION OF SMELTER SO_2 EMISSION

Sulfur dioxide and its derivative products have long been considered air pollutants of concern to human health, not only in the United States but also in other industrialized nations (*6*). Heightened environmental concerns eventually led to regulations governing SO_2 emissions and ambient air concentrations of the gas. The start of major governmental regulation in the United States and abroad generally dates from the 1960's. The Clean Air Act of 1970 marked the start of present regulation for the United States (*7*). Pincock, Allen & Holt, Inc. examined the extent of governmental regulations controlling SO_2 emissions as part of the contract (*1*). The contractor attempted to define the regulating authority as well as the nature and requirements of regulations applicable to the copper smelters.

A necessary caveat for this discussion of regulation of smelter SO_2 emissions is recognition that the survey did not include in-depth analysis of the regulations found or of their effective application. The contractor also had difficulty at times in identifying applicable regulations, interpreting the regulations found, and in establishing their applicability in 1988. Air pollution regulation was only one part of the overall smelter regulatory picture compiled by the contractor. A degree of judgment became necessary in certain cases to establish whether a smelter did or did not operate under air pollution regulation. It is possible that certain generic antipollution environmental regulations were not recognized. An attempt was made to establish positively that regulations were in place and that they specifically applied to the study copper smelters in making the following comparisons.

Governmental regulation of smelter SO_2 emissions was found to be fairly widespread, with the majority of copper smelters examined operating under some form of control requirements. These regulatory requirements usually were in one of the following forms: quantity limitations for SO_2 emissions, nonexceedance of ambient air standards, or a combination of both requirements. In 1988, it appears that 21, or 72.4%, of the 29 foreign copper smelters were operating under recognizable SO_2 control regulations. This represented 66.5% of the total copper smelting capacity of the foreign smelters (fig. 3). Adding the eight regulated U.S. copper smelters, the percentage of regulated Western smelters increases to 78.4% and the total regulated capacity to 73.1% (fig. 4). As discussed in the next section of this report, technical changes to many of these smelters have surely increased SO_2 control since 1988.

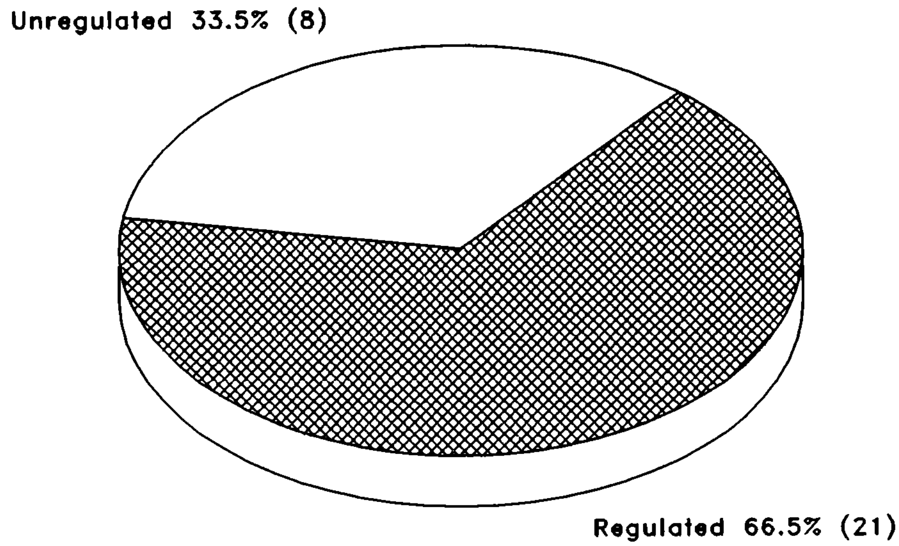

Figure 3.—Regulated capacity of foreign copper smelters (number of smelters in parentheses).

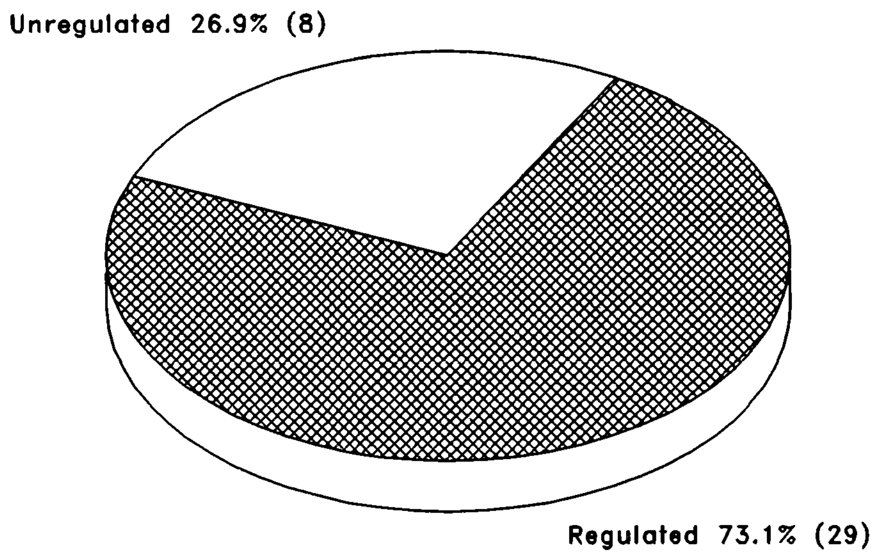

Figure 4.—Regulated capacity of U.S. and foreign copper smelters (number of smelters in parentheses).

MAJOR SMELTER CHANGES SINCE 1988

The first relatively unrestrained production year after an extended, multiyear (1982-87) period of economic problems in the copper industry was 1988. In the period just prior to 1988, the primary copper industry was characterized by excess market supplies and depressed prices. Copper demand since 1988 has been positive, resulting in a high degree of smelter utilization. New smelters are to be constructed, and a number of major changes have been made in existing smelters to meet industry smelting requirements and increased environmental protection requirements.

Although not a primary subject of this report, the contractor study showed increasing environmental protection requirements not only among those countries previously lacking effective regulation, but also in certain countries already known to have strong regulation. It is most likely in the environmental and economic climate now prevalent that new smelters not only will choose to use newer technology such as flash smelting, but also will have the means to fix, or control, a high percentage of their sulfur input. A number of the older smelters covered by the contractor study also have undertaken modification or technological change to maintain economic viability and to meet current or projected environmental protection requirements. It is evident that change from the use of the long-dominant reverberatory furnace is continuing. Newer technologies gaining recognition in Western copper smelters are the Outokumpu and Inco flash smelting processes, Mitsubishi Continuous, Noranda Reactor, ConTop, Isasmelt, and Teniente Modified Converter.

The major changes underway, or planned, for the 29 foreign market economy smelters after 1988 are presented in brief outline in table 5. These changes are those determined at the time each smelter was visited by the contractor. Some other changes have been reported since, but remain either tentative or undefined, so have not been included. Major changes for the U.S. smelters are noted in table 6. A quantitative estimate of the effects that the changes have had on the 1988 SO_2 control balance is beyond the scope of this report; however, it is certain that a substantial increase in control of copper smelter SO_2 emissions has occurred since 1988 and will continue.

Table 5.—Foreign primary copper smelter changes since 1988

Smelter	1988 sulfur fixation method	Smelter change
Mount Isa	None	Smelter expansion and retrofit to Isasmelt technology. No fixation.
Port Kembla	None	Smelter expansion and retrofit to Noranda process. Acid plant and fugitive gas equipment added.
Horne	None	SO_2 reduction of 50% mandated. Installed acid plant and shut down the reverberatory furnace.
Copper Cliff	SO_2 liquefaction of flash furnace gas	SO_2 reduction of 60% mandated. The nickel-copper processes converted to Inco flash furnace technology. Flash converting for copper. New acid plant.
Chuquicamata	Acid plants	Complex multiprocess smelter in expansion, adding Outokumpu flash furnace and acid plant capacity.
Caletones	Small 150 mt/d acid plant	Added 1,500 mt/d acid plant for El Teniente converter.
Las Ventanas	None	Smelter expansion using El Teniente converter. Added acid plant.
Paipote	Small 200 mt/d acid plant	Smelter capacity expansion using El Teniente converter.
Harjavalta	Acid plants and SO_2 liquefaction	Under decree to further decrease emissions (3.5% in 1988).
Naoshima	Acid plants, gas scrubbing	Smelter replaced with single Mitsubishi Continuous process plant.
La Caridad	Acid plant	Acid plant on line mid-1988.
Ilo	None	Recent decree to add acid plant.
Pasar	Acid plant	Smelter expansion.
Palabora	Acid plant, gas scrubbing	ConTop cyclone, installed in 1988, decommissioned in 1990.
Onsan	Acid plant, SO_2-SO_3 liquefaction, gas scrubbing	Smelter completed expansion program underway in 1988.
Ronnskar	Acid plant, SO_2 liquefaction	Smelter restructured in 1988-89 with shutdown of certain operations. Under decree to further reduce SO_2 emissions.
Nkana	Acid plant for converter gas	Smelter retrofit to El Teniente technology started in 1988.

Table 6.—U.S. primary copper smelter changes since 1988

Smelter	1988 sulfur fixation method	Smelter change
Asarco, El Paso	Acid plant	Smelter expansion and retrofit to ConTop technology.
Cyprus Miami	..do.	Conversion from electric furnace to Isasmelt technology.
Kennecott, Garfield	..do.	Replace Noranda technology with Outokumpu in a new smelter.
Magma, San Manuel	..do.	Completed retrofit to Outokumpu furnace in 1988.

CONCLUSIONS

Completion of a recent Bureau contract, which examined 29 major market economy foreign copper smelters, permitted evaluation of the extent of sulfur emission control and regulation of major primary copper smelters in 1988. The 29 foreign smelters examined, together with the 8 operating U.S. smelters, represented roughly 73.2% of world and 89.3% of Western market economy primary copper smelter production in 1988. The major foreign smelters attained 55.3% control of their input sulfur in 1988. U.S. smelters attained 90.4% control in meeting U.S. regulatory requirements. Sulfur control for the combined group of Western copper smelters was 63.4% in 1988. Roughly 1,951,100 mt of sulfur was emitted from these smelters.

Identifiable SO_2 control regulations covered 72.4% of the 29 foreign smelters, representing 66.5% of their total smelting capacity. Including the 8 U.S. smelters, 78.4% of the 37 major Western market economy smelters were regulated, representing 73.1% of total smelting capacity. Significant changes in the smelter technology used have occurred since 1988 that should serve to have further increased the control of sulfur emissions from major Western primary copper smelters.

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