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Project Summary

Environmental Considerations for Emerging Copper-Winning Processes

H. Dolezal, M. Hayashi, G. Potter, and J. O. Burckle

The weak SO_2 emissions from primary copper have been and continue to be the barrier to achieving SO_2 emission limitations in smelter localities. The ambient air quality standards are obtained only through the SCS (supplementary control system), that is, by production curtailment in lieu of constant emission controls. This document, one of a series that addresses the weak SO_2 emission problem, was undertaken to examine capabilities of several alternative smelting and hydrometallurgical metal-winning technologies for the production of copper. The investigation concentrated on the comparison of the degree of sulfur containment, energy consumption/savings and costs of many newer, commercially employed pyrometallurgical smelting processes in combination with various types of final controls for sulfur containment. The emerging technologies for pyro- and hydrometallurgical processes are briefly discussed but are not analyzed in great detail owing to the lack of basic data in the open literature.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The objective of this study was to depict the potential of modern copper-winning processes, to contribute to the solution of the weak sulfur dioxide (SO_2 problem, and to identify potential attributes or barriers to employing these processes within the industry. The evaluation primarily emphasized air pollution potential, energy requirements, and process economics. Thirteen processes were investigated in the first project phase (Table 1).

As the study progressed, the main emphasis became the evaluation of the energy and economic aspects of the five most developed pyrometallurgical processes, specifically the electric furnace, Noranda process, Outokumpu and INCO flash furnace processes, and variations on the conventional reverberatory furnace practice for SO_2 control. This approach became necessary, as the information required for analysis of the emerging hydrometallurgical and pyrometallurgical processes was not available. It was found that none of the emerging hydrometallurgical processes have been developed to the extent that meaningful analyses could be performed. It was also found that some of the newer smelting methods such as the three-furnace, oxygen-enriched reverberatory, converter smelting, top blown rotary converter, and DMA SO_2 processes have not yet been widely

Table 1. *Processes Evaluated*

Phase I - Review

Pyrometallurgical Processes	*Hydrometallurgical Processes*
Mitsubishi Three-Furnace System	*Hecla-El Paso*
Top Blown Rotary Converter (TBRC)	*Arbiter*
Converter Smelting	*Cymet*
Oxygen Enriched Reverberatory Smelting	*Duval "CLEAR"*
Reverb Smelting with DMA SO_2 Process	
Electric Furnace Smelting	
Outokumpu Flash Furnace	
INCO Flash Furnace	
Noranda Furnace	

Phase II - In-Depth Evaluation

Conventional reverberatory process (five scenarios)—(1) no SO_2 control, (2) with reverberatory gas vented up the stack and converter gas going to an acid plant, (3) with converter gas going to an acid plant and reverberatory gases going to a Bureau of Mines citrate process plant, (4) with both converter and reverberatory gases going to a Bureau of Mines citrate process plant, and (5) using a roaster with both roaster and converter gases going to an acid plant.

Electric arc furnace smelting (two scenarios)—(1) SO_2 control by an acid plant, and (2) SO_2 control by a Bureau of Mines citrate process plant.

Noranda process (three scenarios)—(1) SO_2 control by an acid plant, (2) SO_2 control by a Bureau of Mines citrate process plant, and (3) SO_2 control by direct reduction.

Outokumpu flash smelting (two scenarios)—(1) using preheated air with SO_2 control by an acid plant, (2) using preheated air with SO_2 control by a Bureau of Mines citrate process plant.

INCO flash smelting (two scenarios)—(1) using oxygen with SO_2 control by an acid plant, and (2) using oxygen with SO_2 control by direct reduction.

Table 2. *Chemical Composition of Standard Chalcopyrite Concentrate (Dry Basis)**

Constituent	*Composition, pct*
Cu	27.0
Fe	27.0
S	33.5
SiO_2	9.0
CaO	0.5
Other†	3.0

**Analysis of the standard concentrate was arrived at by averaging analyses of actual chalcopyrite concentrates used at a number of commercial smelters.*

†"Other" includes oxygen, MgO, Al_2O_3, and minor elements.

used, and information was insufficient for analysis. Quantitative data on emissions and effluents in the published literature were inadequate to account for the distribution of minor elements in any of the processes. Therefore, the field of candidate processes quickly narrowed to the five, based upon the availability of detailed technical and economic data. A total of 14 scenarios were investigated for these five processes, which are in commercial use (see Table 1). Reverberatory smelting with no controls was the scenario used for the base case.

Study Methodology

All of the processes evaluated were similar, in that they were pyrometallurgical operations that produced blister copper which was cast into anodes and electrorefined. To enable a direct comparison of the various processes, each was assumed to produce 100,000 tons of electrorefined copper per year, starting from a hypothetical standard concentrate, the composition of which is given in Table 2. This hypothetical concentrate is a composite based on feed materials used by smelters in the Western United States, excluding custom smelters that treat complex ores. The basis of the hypothetical composition is given in an Appendix to the report.

Energy requirements for the production of a ton of copper by each of the processes evaluated were estimated with the help of reports on energy use patterns prepared by Battelle Columbus Laboratories. Calculation methods equivalent to those used in the reports were used to make an itemized breakdown of total energy consumed in generating utilities and of the energy required for the raw materials. For raw materials, this included energy needed for mining and ore beneficiation, for smelting and refining of metals, for other raw materials used as part of the production process, and for transportation to processing and refining plants.

The material balance, energy requirements, and cost estimate calculations were produced by a computer estimating program, developed by the Bureau of Mines under a separate program, which incorporated historic cost information from Bureau files. The costs reported for the evaluations performed in this project were updated to 1980.

Flowsheets for each process evaluated were developed. A material balance for each scenario was then prepared. The material balance indicates constant values for the SO_2 content of smelter gases and represents the average flow for these fluctuating streams. Material balance flowsheets for the processes show how the major elements in the concentrates, fluxes, and products are distributed. Included after all smelting operations are electrostatic dust precipitators in which an estimated 10 percent dilution of the gas occurs because of leakage. Whenever available, information concerning the minor elements is given in the text.

Cost estimates were prepared for modifications of the smelting processes for the purpose of making relative comparisons of capital and operating costs. For this reason, some of the minor operations normally conducted in a smelter, such as recycle of dust and scrap, have been omitted to simplify the flowsheets and calculations. These estimates do not include any interest or other charges for invested capital or allowances for federal taxes and profit. Also included as part of the economic evaluation are estimates of the total energy requirements.

Findings and Conclusions

Estimated costs and energy requirements were prepared for recovering copper from chalcopyrite concentrates by some 14 scenarios of 5 basic processes. The resulting estimates are presented in Tables 3 and 4. The evaluation shows that sulfur retentions greater than 90 percent are technically achievable and that the elimination of the weak SO_2 stream by conversion to modern smelting furnaces combined with acid plant control are potentially the most effective method for SO_2 control and energy savings, while also being the most cost effective.

The costs, in mid-1980 dollars, range from a low of 34.6 cents per pound for a conventional smelter with no SO_2 controls to 49.4 cents per pound for a conventional smelter using the USBM citrate process to treat both the reverberatory and converter gases. If the conventional reverberatory smelter with no SO_2 controls is used as a standard for comparison, the various systems for controlling emissions will be found to increase capital investment over a range of 30 to 34 percent and costs for producing copper over a range of 5 to 43 percent. The lowest cost smelter with SO_2 controls was an INCO flash operation with an acid plant (36.4 cents per pound).

When smelters with acid plants for SO_2 control are compared using a reverberatory smelter with an acid plant as a standard, the Noranda, Outokumpu, and INCO versions require about 30 percent less energy. Sulfur dioxide controls based on the USBM citrate process or on direct reduction will increase energy requirements by factors ranging from 1.5 to 2.0.

Because of variations in local conditions, the effect of byproduct credits was not included in the computer program. The actual overall cost would depend on the availability of a market, either internal or external, for the acid and/or sulfur produced. In most cases, where the use or sale of byproducts is possible, costs would be reduced by some indeterminate amount that would depend on local conditions. It should be recognized, however, that in instances where little or no use or sale of byproducts is possible, costs would be increased owing to the cost of storage or disposal. In the cases where neutralization of sulfuric acid is necessary, the disposal cost could make a significant change in the economics of the process. In these evaluations no credits or penalties were applied for disposal of byproducts, so that all the processes could be compared on the same basis. However, a rough comparison of these effects was made based on assigned values of $20 per ton for sulfuric acid and $100 per ton for elemental sulfur. The effect of these byproduct values is shown in Table 5. As expected, byproduct values shift the unit production costs of copper to a lower range of 33 to 43.8 cents per pound, but they also have a leveling effect, in that costs for the Noranda smelter with an acid plant and the INCO and Outokumpu flash smelter with acid plants were in the lower end of the cost range (33.4 to 33.6 cents per pound).

When a reverberatory smelter without pollution controls is used as a standard for comparison with alternative processes, the following conclusions are reached:

- unit production costs in cents per pound of copper, without byproduct credit, will increase from 34.6 to a range of 36.4 to 49.4, with an INCO flash smelter in an acid plant giving the lowest increase,
- estimates for byproduct credit shift unit production costs to a lower range of 33.0 to 43.8 cents, with INCO, Noranda, and Outokumpu flash smelters in acid plants giving cost in the lower end of the range,
- sulfur retention increased from 2.4 percent to a range of 64.5 to 96.2 percent, with both an electric furnace in an acid plant and a reverberatory smelter treating reverberatory and converter gases in a citrate plant giving the highest retention, and
- energy requirements in million Btu per ton copper are 38.46 for the standard and range from 30.13 to 90.67, with both the Noranda and INCO smelters in acid plants using the least energy.

Table 3. *Estimated Capital Cost, Operating Cost, and Energy Requirements**

Process	*Type of SO_2 Control*	*Fixed Capital, Dollars*	*Working Capital, Dollars*	*Annual Operating Cost, Dollars*	*Energy Requirement, Million Btu/ton Cu*
Noranda process	*Acid plant*	*305,118,000*	*16,613,000*	*74,101,000*	*30.13*
Do.	*Citrate plant*	*341,002,000*	*21,185,000*	*92,978,000*	*66.90*
Do.	*Direct reduction*	*304,701,000*	*20,979,000*	*91,550,000*	*85.14*
Outokumpu flash	*Acid plant*	*300,992,000*	*16,639,000*	*74,122,000*	*30.88*
Do.	*Citrate plant*	*330,456,000*	*21,320,000*	*93,022,000*	*68.07*
INCO flash	*Acid plant*	*286,086,000*	*16,426,000*	*72,891,000*	*33.19*
Do.	*Direct reduction*	*311,605,000*	*22,049,000*	*96,065,000*	*90.67*
Electric smelting	*Acid plant*	*300,529,000*	*18,211,000*	*80,021,000*	*44.97*
Do.	*Citrate plant*	*315,140,000*	*22,027,000*	*95,350,000*	*81.69*
Reverberatory	*None*	*261,028,000*	*15,679,000*	*69,193,000*	*38.46*
Do.	*Converter gas to acid plant*	*313,267,000*	*18,250,000*	*80,747,000*	*43.56*
Do.	*Converter gas to acid plant, reverberatory gas to citrate plant*	*348,784,000*	*21,204,000*	*93,241,000*	*58.38*
Do.	*Converter and reverberatory gases to citrate plant*	*334,686,000*	*22,768,000*	*98,725,000*	*81.67*
Do.	*Roaster and converter gases to acid plant*	*307,077,000*	*17,918,000*	*79,257,000*	*41.93*

**Estimates are based on 1980 costs without allowance for escalation during construction period and do not include interest on invested capital, federal taxes, or profit. Capacity basis is 100,000 tons per year of electrorefined copper.*

Table 4. *Summary of Processes Evaluated**

Process	Type of SO_2 Control	Total Sulfur Retention†	Sulfur Recovered,† pct	Byproduct Produced, tpd		Estimated Overall Cost, cents/lb/Cu (No Byproduct Credit)
				Sulfuric Acid	Sulfur	
Noranda process	Acid plant	437.8	95.6	1,269.4	0	37.1
Do.	Citrate plant	437.5	95.5	0	410.5	46.5
Do.	Direct reduction	398.0	86.9	0	375.2	45.8
Outokumpu flash	Acid plant	364.6	95.9	1,050.6	0	37.1
Do.	Citrate plant	364.3	95.8	0	339.8	46.5
INCO flash	Acid plant	367.2	95.9	1,054.0	0	36.4
Do.	Direct reduction	333.8	87.2	0	311.6	48.0
Electric smelting	Acid plant	368.3	96.2	1,043.2	0	40.0
Do.	Citrate plant	357.3	93.3	0	337.1	47.7
Reverberatory	None	9.1	2.4	0	0	34.6
Do.	Converter gas to acid plant	246.9	64.5	690.8	0	40.4
Do.	Converter gas to acid plant, reverberatory gas to citrate plant	368.3	96.2	690.8	114.1	46.6
Do.	Converter and reverberatory gas to citrate plant	367.8	96.1	0	337.06	49.4
Do.	Roaster and converter gas to acid plant	292.5	76.4	823.0	0	39.6

*Estimates are based on 1980 costs without allowance for escalation during construction period and do not include interest on invested capital, federal taxes, or profit. Capacity basis is 100,000 tons per year electrorefined copper.

†Total sulfur retention includes sulfur in H_2SO_4, $CaSO_4$, slag, tailings, sulfur product, and $Na_2SO_4 \cdot 10H_2O$.

Table 5. *Estimated Effect of Byproduct Credit on Operating Cost*

Process	Type of SO_2 Control	Annual Operating Cost, Dollars	Byproduct* Credit, Dollars	Annual Operating Cost With Byproduct Credit, Dollars	Estimated Overall Cost, Cents/lb Cu		Reduction In Cost	
					No Credit	With Credit	Cents	Percent
Noranda process	Acid plant	74,101,000	6,956,000	67,145,000	37.1	33.6	3.5	9.4
Do.	Citrate plant	92,978,000	11,248,000	81,730,000	46.5	40.9	5.6	12.0
Do.	Direct reduction	91,550,000	10,281,000	81,259,000	45.8	40.6	5.2	11.4
Outokumpu flash	Acid plant	74,122,000	6,934,000	67,188,000	37.1	33.6	3.5	9.4
Do.	Citrate plant	93,022,000	11,213,000	81,809,000	46.5	40.9	5.6	12.0
INCO flash	Acid plant	72,891,000	6,956,000	65,935,000	36.4	33.0	3.4	9.3
Do.	Direct reduction	96,065,000	10,283,000	85,782,000	48.0	42.9	5.1	10.6
Electric smelting	Acid plant	80,021,000	6,885,000	73,136,000	40.0	36.6	3.4	8.5
Do.	Citrate plant	95,350,000	11,124,000	84,226,000	47.7	42.1	5.6	11.7
Reverberatory	None	69,193,000	–	69,193,000	34.6	34.6	0	0
Do.	Converter gas to acid plant	80,747,000	4,559,000	76,188,000	40.4	38.1	2.3	5.7
Do.	Converter gas to acid plant, reverberatory gas to citrate plant	93,241,000	8,325,000	84,916,000	46.6	42.5	4.1	8.8
Do.	Converter and reverberatory gas to citrate plant	98,725,000	11,123,000	87,602,000	49.4	43.8	5.6	11.3
Do.	Roaster and converter gas to acid plant	79,257,000	5,432,000	73,825,000	39.6	36.9	2.7	6.8

*Based on $20.00 per ton for H_2SO_4 and $100.00 per ton for elemental sulfur for a production basis of 100,000 tons per year of electrorefined copper.

H. Dolezal, M. Hayashi, and G. Potter are with the U.S. Bureau of Mines, Salt Lake City Research Center, Salt Lake City, UT; the EPA author **J. O. Burckle** (also the EPA Project Officer, see below) is with the Industrial Environmental Research Laboratory, Cincinnati, OH 45268.

The complete report, entitled "Environmental Considerations for Emerging Copper-Winning Processes," (Order No. PB 82-227-794; Cost: $12.00, subject to change) will be available only from:

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5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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