Control Aspects of the Mitsubishi Continuous Process

Moto Goto, Eiki Oshima, and Mineo Hayashi

The Mitsubishi process for the continuous smelting and converting of copper holds many advantages over conventional processes, where reactions must be conducted in numerous steps and melts must be tapped frequently from the furnaces. The furnaces operate like steady-state reactors with constant melt volume, composition, and temperature. Therefore, optimal control of the process is straightforward, with one operator controlling smelting and converting simultaneously. Recent improvements in temperature control by using newly developed sensors have extended furnace campaign life, and enhanced control over melt compositions has helped further stabilize operations. Applications of the environmentally clean smelting technology are increasing internationally.

INTRODUCTION

Thirty years ago, the combination of a reverberatory furnace with two or more Peirce-Smith converters represented the industry standard for processing concentrates to blister copper. At that time, Mitsubishi Materials Corporation started developing a cleaner and more continuous process, offering easier control, gains in energy and furnace efficiencies, labor reduction, and lower gas emissions. Recognizing that the oxygen partial-pressure level needed for concentrates smelting is different from that required for matte converting, it was decided to use two separate furnaces for these operations. The furnace design featured operation at a constant bath level, with solids and oxygen-enriched blowing air entering through vertically mounted overhead lances and the steady delivery or removal of molten materials by launder. Equivalent quantities of slag, matte, and blister were discharged by overflow or siphon. Tapping was no longer required, and the use of sloping launders to transfer molten materials made ladles and overhead cranes redundant.[1,2]

It is simpler to conduct operations and exercise good process control than it is in conventional batch processes.

The Mitsubishi process exemplifies bath smelting and converting; reactions do not occur in the gas phase above the melt. Instead, they are confined to a small and well-agitated melt zone underneath the lances, where the energy released by the sulfur, iron, and oxygen brings all of the particulates quickly into the melt. This feature permits the design of more compact and gas-tight furnaces, with little carryover of solids.

The first Mitsubishi continuous smelter was commissioned at Naoshima in Japan in March 1974. The initial capacity of 48,000 tonnes per year (t/y) was quickly doubled. Commercial-scale operation of the process was confirmed and much technical know-how accumulated. At Naoshima in May 1991, a new 200,000 t/y continuous smelter was commissioned, replacing the outputs from the older reverberatory and the original continuous plants. Almost seven years into production, the new operation demonstrates high smelter on-line time and savings in cost, plant complement, and reduced emissions.[3,4]

Texas Gulf selected the technology for their smelter at Timmins, Northern Ontario, where operations started in 1981.[5] The nameplate capacity is 130,000 t/y due to a phased expansion in the mid-1980s based on Naoshima's proven use of higher oxygen enrichment levels. Recent overseas projects are detailed in the sidebar.

PROCESS FUNDAMENTALS

The schematic operational concept of Mitsubishi's three furnaces—smelting slag cleaning, and converting—is shown in Figure 1. An important characteristic of the process is that the molten phases in both the smelting and converting furnaces have a constant volume and uniform composition and are kept at constant temperature. Thus, it is simpler to conduct operations and exercise good process control than it is in conventional batch processes. Slags overflow continuously at their best fluidity, and furnace off-gas volumes are steady and high in SO_2 strength.

By contrast, in conventional smelters

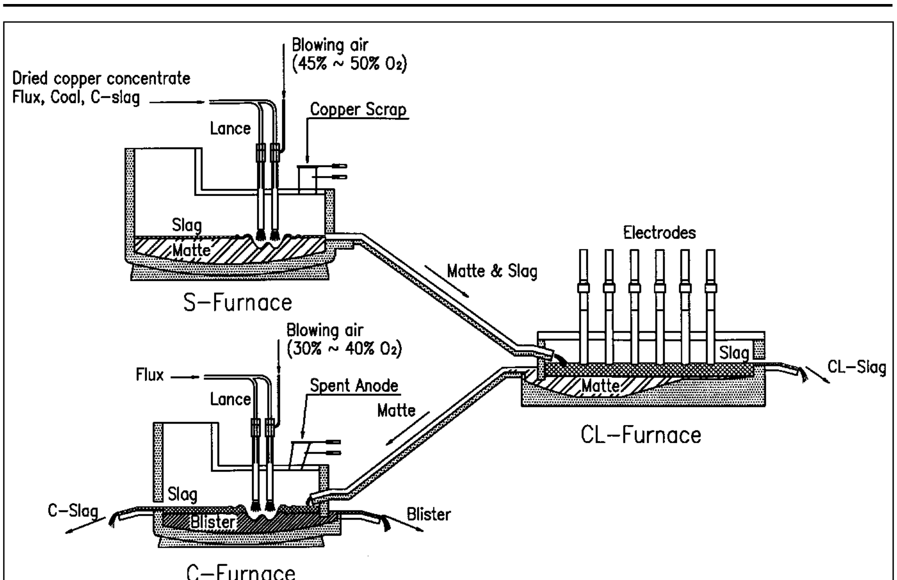

Figure 1. A schematic operational concept of the Mitsubishi furnace line.

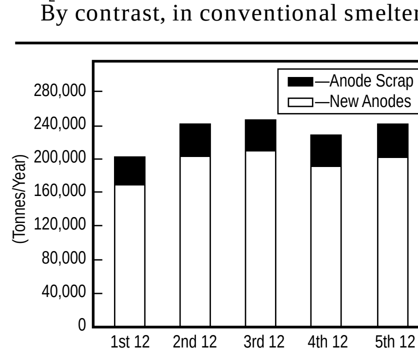

Figure 2. The trend of annual anode production at Naoshima.

Table I. Hourly Plant Data in 1996 on Key Elements at Naoshima Smelter

	Total No. of Readings	Average (%)	Standard Deviation
Matte Grade	7,762	68.57	0.85
Copper Content			
Discard Slag	7,741	0.69	0.11
Converting Furnace Slag	7,694	13.42	1.60

using Peirce-Smith converters, the batchwise operation has a negative impact on the entire smelter and gas-handling system. Good operation depends highly on the skills of the operators, because the composition and temperature of molten materials in the furnace change as the reaction proceeds. Moreover, the furnaces are subjected to frequent melt charging and emptying, causing significant mechanical and thermal damage. Thereby, the furnace must be relined once every several months and mandates usually three to five converters in combination with one smelting furnace. Concerns over dust and gas emissions originating at the Peirce-Smith converter suggest that replacement by a cleaner and continuous operation will become an important trend in the near future.

In the smelting furnace, the molten bath is mostly matte with a thin layer of slag on top. The feed materials are injected directly into the matte phase together with oxygen-enriched air via vertical lances at velocities of around 200 m / s. As the distance between the tip end of the lance and melt surface is kept around 700 mm, there is no time for the solid materials to be ignited before they are captured by the matte. Then, they are rapidly melted by the effective heat transfer between solid and liquid phases in this turbulent region of the bath. Oxygen reacts with the iron sulfide in the matte, and the oxidized iron combines with flux to form fayalite slag. The major reactions are represented by[7]

$$FeS\ (matte) + 3/2O_2 = FeO + SO_2$$

$$2FeO + SiO_2 = 2FeO \cdot SiO_2\ (slag)$$

All reactions occur in the bath at constant oxygen partial pressure, resulting in a uniform melt composition. This is an important difference between bath smelting and flash smelting. In the case of flash smelting, the feed materials are melted and oxidized step-by-step above the bath in the reaction shaft, where some iron is over oxidized, causing excess magnetite to accrue in the settler.[8]

In the converting furnace, there are two phases, blister copper and slag. Slag overflows, and blister is siphoned out continuously from the furnace. The blister copper is not saturated with sulfur; hence, a separate white metal layer does not coexist under normal operational conditions. The molten matte is fed to the furnace through a side launder some distance from the point where oxygen is supplied by the lances, as shown in Figure 1. Part of the matte reacts instantly with the Cu_2O in the slag while the remainder dissolves in the blister.

$$3FeS\ (matte) + 10Cu_2O\ (slag) = Fe_3O_4\ (slag) + 20Cu\ (blister) + 3SO_2$$

$$Cu_2S\ (matte) + 2Cu_2O\ (slag) = 6Cu\ (blister) + SO_2$$

In the central part of the bath, oxygen blown through the lances oxidizes the sulfur and part of the blister copper to regenerate Cu_2O.

$$Cu_2S\ (blister) + O_2 = 2Cu\ (blister) + SO_2$$

$$4Cu\ (blister) + O_2 = 2Cu_2O\ (slag)$$

Although the reactions between matte and slag and the direct oxidation of blister copper take place in different locations, the melt turbulence generated by the lances ensures that the two melt phases are of uniform composition. The melt temperature is controlled mainly by the addition of solid coolant, such as converter slag, or by adjusting oxygen enrichment in the blowing air. As the converting furnace is stationary, the slag must be fluid enough to overflow evenly. The high oxygen potential used at matte converting makes this very difficult to achieve with a fayalite slag, therefore,

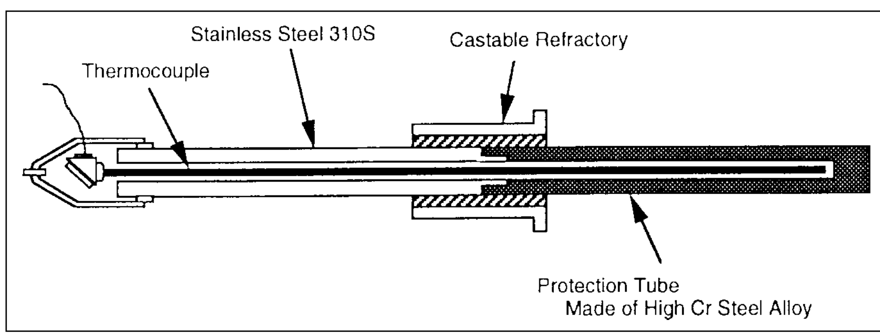

Figure 4. A submerged thermocouple.

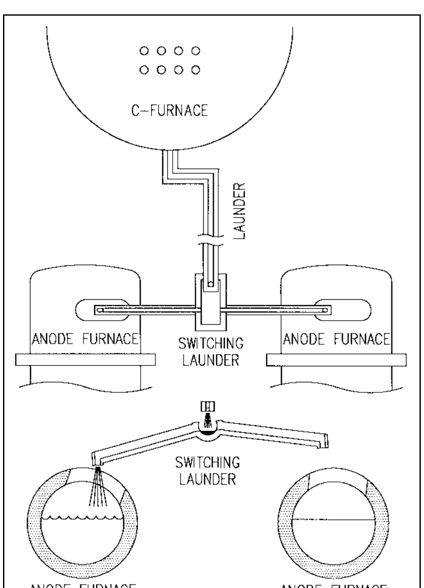

Figure 3. The connection of the converting furnace to the anode furnaces.

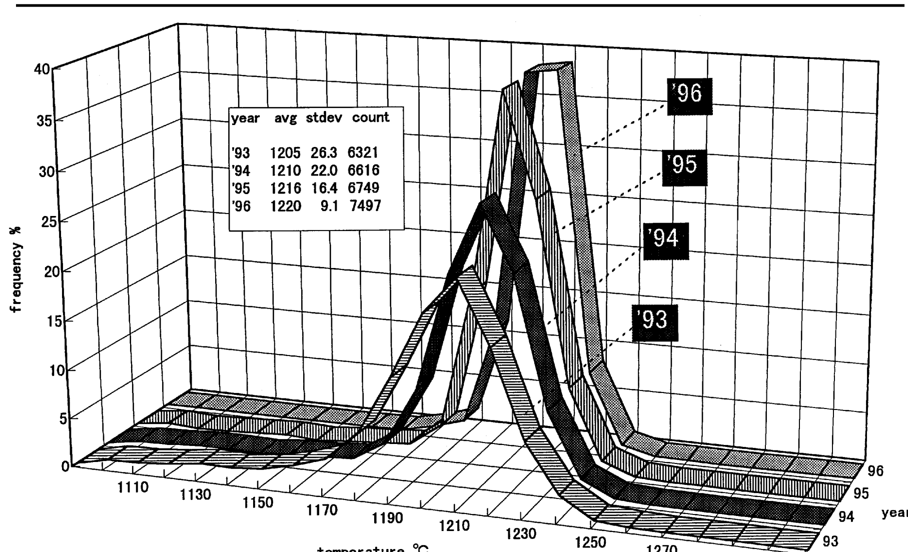

Figure 5. The improvement of the smelting outlet melt temperature at Naoshima (1993–1996).

Table II. Oxygen Requirements to Increase the Matte and Converting Furnace Slag by 1%

	1% Change	Required Oxygen per Tonne of Melt	Amount of Melt Held in Furnace	Furnace Oxygen Requirement
Smelting Furnace	Matte grade (68 → 69%)	5.62 Nm^3/tonne matte	Matte 440 tonnes	2,473 Nm^3
Converting Furnace	Copper content in the slag (15 → 16%)	1.07 Nm^3/tonne slag	Slag 30 tonnes	32 Nm^3
		0.72 Nm^3/tonne blister	Blister 300 tonnes	216 Nm^3
				Total 248 Nm^3

limestone was selected. The development of this Cu_2O-CaO-Fe_3O_4 slag was fundamental to the establishment of the Mitsubishi process. The ternary lime-ferrite slag absorbs more magnetite than a fayalite slag.[9]

OPERATIONAL PERFORMANCE AT NAOSHIMA

The new Mitsubishi furnace line, with 200,000 tonnes of annual anode production capacity, was put into operation at Naoshima in May 1991. The actual annual anode production rates are shown in Figure 2. At start-up, there were some initial problems in the off-gas trains, feed preparation area, and furnace refractories. However, they were mostly overcome within several months, and the production rate reached designed levels by the second year.

During the start-up period, the sidewall and bathline bricks in both the smelting and converting furnaces showed signs of early damage. This was corrected by increasing the number of copper jackets in the sidewall and controlling melt temperatures more closely.

It has been confirmed that the time interval for partial bathline brick repair has been lengthened to once every few years. In the smelting furnace, it is still necessary to partially replace some of the hearth bricks underneath the lances. Here, the bricks are eroded by some of the solids in the furnace feed. In the converting furnace, there is no erosion and the hearth bricks are currently expected to last more than ten years.

The converting furnace continuously delivers blister directly to the anode furnaces as shown in Figure 3. Once one anode furnace is filled, the switching launder is tilted to feed the other; in this way, the constant flow of blister copper from the converting furnace is not interrupted.

When using Peirce-Smith converters, the generation of a significant amount of inplant reverts, such as ladle skulls or spillage from the converter, is inevitable. With the Mitsubishi process, ladles are not needed, and only a very small amount of anode furnace slag and boiler chunks are reverted. This has very important practical benefits since reverts storage, handling, and crushing systems are eliminated, greatly improving metal recoveries and housekeeping.

Since materials of 3 mm particle diameter or less are fed through the lances, three systems for handling lumpy materials were developed. Spent anodes recycled from the tank house are fed, as is, through a drop chute on the converting furnace roof. Copper scrap purchased from outside the smelter is pressed into 450 kg rectangular blocks, then fed to either the smelting or converting furnace depending on their copper grade. Intermediate size materials, such as 5 ~ 50 mm shredded copper scrap or boiler chunks, are fed directly through a drop chute that is located on the smelting furnace roof.

OVERSEAS PROJECTS

In addition to the existing and successful smelting operations at Naoshima and in Canada, the Mitsubishi process has been selected for some new and retrofit projects (Table 1). The Gresik project in Indonesia is featured as a greenfield smelter, which will treat the copper concentrates supplied exclusively from the Grasberg mine owned by Freeport Indonesia. PT Smelting Company is owned by Mitsubishi and Freeport, and the smelter is scheduled to be commissioned in December 1998.[6]

The Onsan project in South Korea is an addition to the existing 140,000 t/y flash smelting operation that was commissioned in 1979. LG Metal selected the Mitsubishi process for their new 160,000 t/y smelter, which started production in January. LG Metal's decision to expand their capacity at Onsan was made in order to meet the soaring demand for copper that is occurring in Korea.

The Port Kembla project in Australia will replace the existing Pierce-Smith converters with a single Mitsubishi continuous converting furnace. The operation was shut down some years ago because of high emissions; however, with the implementation of Mitsubishi converting, they have secured environmental approval to resume production. It is now at the detailed engineering stage, and operations are scheduled to start in the first quarter of 1999.

Figure A shows the schematic concept for the Port Kembla project. The existing Noranda reactor produces high grade matte of around 72% copper. The matte will be transferred by ladle to a new matte holding furnace. Since the ladle movement is always the same, sealed enclosures are designed to contain any gas emissions during transfer. Matte is fed to the converting furnace through a sloping launder at a constant rate. Blister copper then siphons from the converting furnace and continuously flows by launder into one of two anode furnaces.

Table 1. Overseas Copper Smelter Projects

Project	Country	Owner	Copper Production (t/y)	Project Type
Gresik	Indonesia	PT Smelting	200,000	Green field, copper concentrate from Grasberg Mine
Onsan	South Korea	LG Metals	160,000	Capacity expansion by the addition of a complete Mitsubishi furnace line
Port Kembla	Australia	Port Kembla Copper	120,000	Replacing Pierce-Smith converters with one Mitsubishi continuous converter

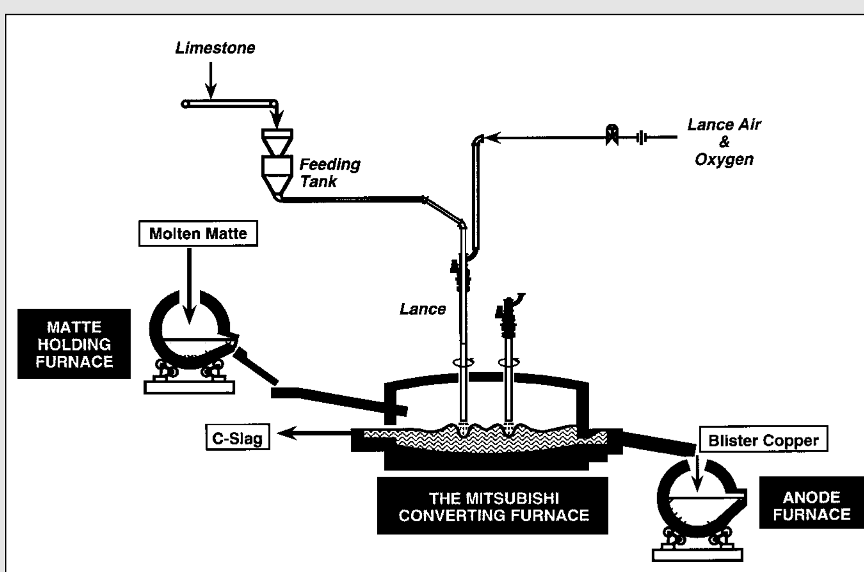

Figure A. The conceptual flow of the Port Kemba project.

THE DEVELOPMENT OF SENSORS FOR MELT-TEMPERATURE MEASUREMENT

Among several operational control strategies, the first priority is keeping furnace melt temperatures constant and at appropriate levels. This is essential in order to achieve good slag fluidity and longer furnace campaign life. To realize this, two methods designed to accurately monitor melt temperatures were developed.

Smelting Furnace Melt

Melt temperatures in the copper industry are usually measured by pyrometers, which can give poor readings because the source radiation is affected by the melt surface condition and by transmittance through the gases evolving from the melt. Therefore, a direct temperature measurement system utilizing a submerged type of thermocouple was developed and applied to plant operations in order to monitor temperatures more accurately. The thermocouple assembly is shown in Figure 4. The protection tube is made of a high chromium steel alloy, which is placed at the outlet of the smelting furnace, where the molten matte and slag mixture directly contacts the tube. The protection tube can be used for more than 30 days.

Figure 5 shows a histogram of the actual hourly furnace melt temperatures measured by this thermocouple over four years. The temperature control has been greatly improved. It has become possible to raise the average temperature slightly and keep the peak temperature at almost the same or a lower level. Temperature fluctuations have been significantly reduced, as can be seen from the year-by-year standard deviations. Resulting benefits from this tighter temperature control are reduced refractory wear and improved melt fluidity.

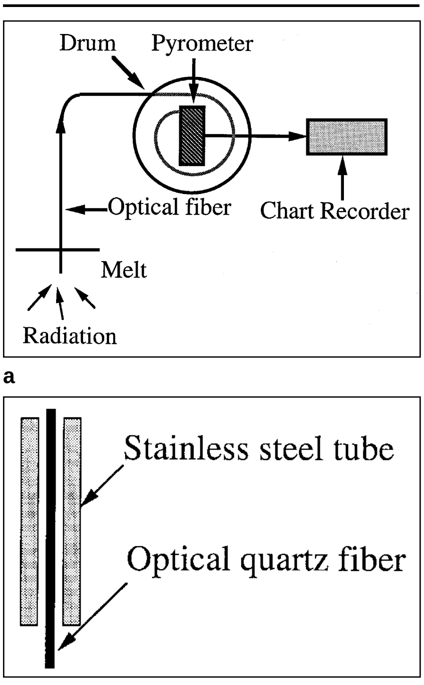

Figure 6. (a) An expendable immersion optical fiber thermometer and (b) the structure of the optical fiber.

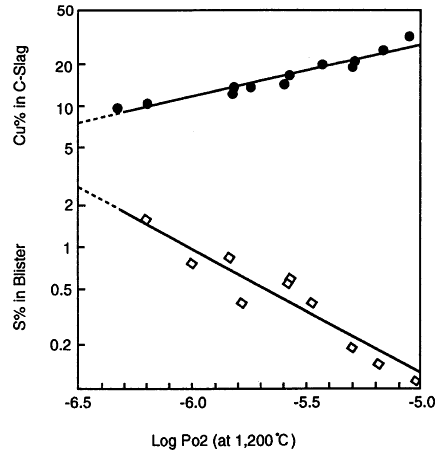

Figure 7. The relation among Po_2 and S% in blister, and Cu% in converter slag.

Converting Furnace Melt

Direct measurement by the thermocouple was difficult to apply to the converting furnace melts because both slag and blister copper are corrosive to most stainless steels. Therefore, the expendable immersion optical-fiber thermometer was developed and applied to the routine and regular measurement of blister copper (Figure 6). The optical quartz fiber of 125 μm diameter is sheathed in a stainless steel tube of 1.2 mm outer diameter, as shown in Figure 6b.[10]

Excess optical fiber is wound around the drum. One end is immersed in the melt, and the other end is connected to a pyrometer installed inside the drum. Thus, the radiation is transmitted along the fiber to the pyrometer and converted to a direct current analog output, which represents the temperature of the melt. The immersion depth is around 50 mm, and the immersion time is approximately five seconds, after which the fiber is immediately pulled up from the melt. Approximately 50 mm of the fiber tip is mechanically cut off after several dips, because the tip surface becomes cloudy. Measurements are taken at two minute intervals or less frequently as required.

CONTROLLING COMPOSITION

The next priority focuses on controlling the composition of each molten product as closely as wanted, especially matte grade copper content in the converting furnace slag and the content of the flux materials in the converting furnace slag and the discard slag. On-line x-ray analyses of matte, discard slag, and converting furnace slag are taken every hour, showing the operator all deviations from the set points. This steady-state aspect of the continuous process makes it easy to maintain all operational parameters at their optimum value; this is not possible with batch processes.

The statistical compilation of actual hourly plant data in 1996 for matte grade, slag loss, and copper content in the converting slag is given in Table I. The average matte grade was held tightly at 68.5%. Copper loss in slag was around 0.7%. The copper content in the converting furnace slag is exponentially related to the oxygen potential in the furnace and the sulfur content in the blister copper (Figure 7).[11] There are only two phases in the converting furnace, and no white metal phase exists, because the sulfur content in the blister copper is lower than the saturation point of 1.3–1.5% S. Therefore, changes in the matte feed rate or the oxygen-blowing rate are reflected directly and sensitively on the oxygen partial pressure and the copper content in the converting slag. These changes are more rapid than matte-grade change in the smelting furnace, because unit oxygen requirements and melt volume are much smaller in the converting furnace. For example, the oxygen requirement to increase copper content in the converting furnace slag by one percent as compared to that required to increase the matte grade by one percent in the smelting furnace is summarized in Table II.

In order to shift the matte grade from 68% to 69% in the smelting furnace, 5.62 Nm^3 of oxygen is required per tonne of matte. Since the amount of matte held in the smelting furnace is 440 tonnes, the total oxygen requirement for the whole matte phase is calculated as 2,473 Nm^3. On the other hand, 1.07 Nm^3 of oxygen is required in the converting furnace to increase the copper-oxide content in the slag, and an additional 0.72 Nm^3 of oxygen per tonne of blister copper is required to decrease sulfur and increase oxygen in the blister-copper phase to balance with a 1% increase of copper in the slag or maintain a higher oxygen potential. Thus, the total oxygen requirement for the whole melt phase in the converting furnace will be 248 Nm^3, which is around one tenth of the amount required to change the matte grade by one percent. This is why the converting furnace operation is so sensitive, and the standard deviation of the copper content in the converting slag in Table I is larger than that of the matte grade.

THE EXPERT SYSTEM

In the steel industries in Japan, expert systems were developed for blast furnace operation, where most operational parameters are constant. Similarly, operational parameters in the Mitsubishi

(Continued on page 65.)

Goto *(Continued from page 63.)*
process are also held as constant as possible, thus making it an ideal candidate for the implementation of an expert system.

The system is called the Mitsubishi process operation support system (MIOSS). It is not a direct computer control system, but is intended to standardize operational procedures, compile operational knowledge, stabilize operations, and simplify operational control. The MIOSS system gathers information, such as melt temperatures, x-ray data on melt samples, and concentrate and flux feed rates, into a central process controller (DCS) every minute. Then, the necessary corrective actions are determined to stabilize important operational parameters such as melt temperature and composition. The system incorporates the combined knowledge of engineers and operators at Naoshima as well as metallurgical fundamentals and stores this information as a knowledge base in the computer. In the control room, corrective actions are displayed on the computer screen and vocalized by a speaker system.

References

1. T. Nagano and T. Suzuki, "Commercial Operation of Mitsubishi Continuous Copper Smelting and Converting Process" (paper presented at the 105th AIME Annual Meeting, Las Vegas, NV, February 1976).
2. T. Nagano and T. Suzuki, "Process Development of Continuous Copper Smelting and Converting" (paper presented at the 15th Annual Conference of CIM, Ottawa, Canada, August 1976).
3. T. Shibasaki, M. Hayashi, and Y. Nishiyama, "Recent Operation at Naoshima with a Larger Mitsubishi Furnace Line" (paper presented at the 1993 TMS Annual Meeting, Denver, Colorado, February 1993).
4. S. Ajima, M. Hayashi, and Y. Nishiyama, "The Mitsubishi Continuous Process—Present and Future"(paper presented at Second International Symposium on Metallurgical Processes for Early 21st Century, Santiago, California, September 1994).
5. M.P. Amsden, R.M. Sweetin, and D.G. Treilhard, "Selection and Design of Texas Gulf Canada's Copper Smelter and Refinery," *J. Metals*, 30 (7) (1978).
6. O. Iida, M. Hayashi, and M. Goto, "Process Designs on New Smelter Projects of the Mitsubishi Continuous Copper Smelting and Converting Process" (paper presented at the 36th Annual Conference of Metallurgists of CIM, Sudbury, Canada, August 1997).
7. M. Goto and T. Echigoya, "Effect of Injection Smelting Jet Characteristics on Refractory Wear in the Mitsubishi Process," *J. Metals*, 32 (11) (1980).
8. R. Sridhar, J.M. Toguri, and S. Simeonou, "Thermodynamic Considerations in the Pyrometallurgical Production of Copper" (paper presented at the 35th Annual Conference of Metallurgist of CIM, Toronto, Canada, August 1996).
9. M. Goto and K. Kanamori, "Converting Furnace Operation of Mitsubishi Process" (paper presented at the 108th AIME Annual Meeting, New Orleans, Louisiana, February 1997).
10. F. Ogino et al., *Material Transactions of JIM*, 37 (4) (1996), p. 912.
11. S. Ajima et al., "Converting and Anode Furnace Operation of Mitsubishi Process at Naoshima" (paper presented at the 1994 TMS Annual Meeting, San Francisco, California, February 1994).

ABOUT THE AUTHORS

Moto Goto earned his Dr. Eng. in metallurgical engineering at Tokyo University in 1984. He is currently senior managing director at Mitsubishi Materials Corporation. Dr. Goto is also a member of TMS.

Eiki Oshima earned his M.S. in metallurgical engineering at Tohoku University in 1968. He is currently general manager of the Naoshima smelter at Mitsubishi Materials Corporation. Mr. Oshima is also a member of TMS.

Mineo Hayashi earned his M.S. in metallurgical engineering at Tohoku University in 1971. He is currently general manager of the process and technology department, International Copper Project Division, Mitsubishi Materials Corporation. Mr. Hayashi is also a member of TMS.

For more information, contact M. Goto, Mitsubishi Materials Corporation, 1-5-1, Ohtemachi, Chiyoda-ku, Tokyo, 100-0004, Japan.