ABSTRACT

A review of modern copper smelting processes with the advantages and disadvantages of each, taking into consideration fuel efficiency, metal losses, waste heat recovery, ease of computer control, utilization of oxygen, and environmental control. Materials handling problems are discussed, as are handling and cleaning of flue gases and drying of concentrates, control of impurities in the smelting process, increase in the size of conventional converter and emergence of the continuous converter, stack fluxing and charging of copper scrap through the hood, oxygen enrichment of blowing air and general acceptance of mechanical punching, gaseous oxidizing and poling in the anode furnace and use of automatic pouring and automatic anode takeoff, and continuous casting of anodes.

The tendency in modern copper refinery tankhouse design is to mechanize all electrode handling operations for savings in labor requirements. The pretreatment of electrodes to ensure vertical hanging in cells, the elimination of starting sheets by use of rigid stainless steel cathodes, short-circuit detection by use of infrared scanning, and cell voltage monitoring are studied. Modern tankhouse design, including building materials and ventilation quality control to ensure production of highest quality cathodes, advances in bleed solutions treatment, and continuous melting and casting with special reference to continuous casting of rod and the different systems available, are reviewed.

SMELTING

The copper smelting industry has been confronted during the past 10 years by the escalation of fuel oil prices and the cost of labor, increasingly stringent environmental regulations, and a decreasing selling price for its product. This has resulted in increased pressure on the smelter operator to reduce costs and achieve higher throughput in his smelting units. Many improvements can be made to existing equipment, but other changes can only be made when designing a new plant.

Two separate types of flash smelting furnaces were developed in the late 1940s - the Outokumpu furnace and the INCO oxygen flash smelting furnace. The development
of the former was vigorously pursued by its inventors, and many improvements have been made during the past 30 years by licensors, particularly in Japan. These include oxygen enrichment of the combustion air, high-temperature preheating of this air, and installation of electrodes in the furnace for slag cleaning. Operation of the furnace can be controlled by a computer, and concentrate tonnages of over 2,000 tpd can be smelted.

In contrast, the INCO oxygen flash furnace for a period was not promoted commercially by its developers, and the furnace at Copper Cliff has remained the only one in operation. The furnace was commissioned in 1953 and extended in 1968 to a rated capacity of 1,500 tpd. A second installation at ASARCO's Hayden Smelter is in the construction stage, and others are planned. One of the main advantages of this furnace, in which dry concentrate is burned autogenously in a stream of 95% oxygen, is that gas volumes are so small that installation of a waste-heat boiler is not justified.

The innovative Noranda reactor was developed during the 1960s, and considerable work was done on the pilot plant version and the commercial reactor, which was built in 1974. Initially, the commercial reactor was operated to produce blister copper, but it was found that the unit operated better when producing high-grade (72%-74% copper) matte. A high-copper-content slag is produced and treated by milling. Three Noranda reactors were installed at Kennecott's Utah smelter, and they are operating satisfactorily. The reactor uses oxygen, both on the concentrate burner and through the tuyeres. The process is extremely flexible and simple to control, and it can handle zinc and lead-bearing concentrates without affecting the composition of the matte.

The Mitsubishi continuous smelting process was introduced in the early 1970s after more than 10 years of laboratory-scale and pilot-plant work. It is a most ambitious and successful attempt at developing a truly continuous smelting and converting process. The process is highly sophisticated and is, of necessity, computer controlled. One plant is in operation at Naoshima, Japan, and another at Timmins, Ontario, Canada. Manpower and energy requirements are low, and the smelting and converting furnaces produce flue gases high in sulfur dioxide and ideal for sulfuric acid production.

Several other proposed continuous smelting processes have emerged during the past 2 decades, but none has reached the stage of commercial adoption. Their failures have been for a variety of reasons, chief of which was the inability to consistently produce a throwaway slag.
Materials handling was adequate when handling green charge by belt conveyors, or when handling calcines or dry charge by drag conveyors. The new flash smelting processes require extremely dry concentrate, flux, and feed; this has necessitated the use of pneumatic conveying. The use of flash and fluid bed dryers was successfully introduced for producing dry concentrates.

For dust collection, the Cottrell electrostatic precipitator continues to be the most commonly used, but with dry charge being so prominent, the baghouse collector has experienced renewed interest. This is partly due to the use of synthetics for bag construction; these materials can withstand higher temperatures than the natural cloth bags formerly used. Cyclones are frequently used ahead of baghouses to remove the coarser sizes and reduce the load on the collecting bags.

Many operators believe that the waste-heat boiler has been the weak point of the copper smelting furnace. Certainly, its record of reliability has not been good. One of the principal factors contributing to this situation is the high dust loading of the furnace gases, which results from the charging of extremely dry concentrates to the flash smelter. Despite the provision of large radiation cooling chambers in modern waste-heat boilers for cooling the offgases below the point where the entrained dust will adhere to the boiler tubes, operating and maintenance problems persist. It has been suggested that boilers be replaced by spray cooling chambers, but obviously this would not be acceptable in the present period of energy conservation.

Smelting furnaces can be fired with fuel oil, natural gas, or pulverized coal. However, with the large increases in the cost of oil and gas, the tendency today is toward the use of coal.

For many years, the 13-ft by 30-ft converter was standard throughout the industry. In recent years, however, converters have been built with a diameter of 15 ft and a length of 35 ft. There is no reason why even larger units could not be used.

Codelco-Chile introduced in 1977 the Teniente Modified Converter (TMC) at the Caletones smelter. A seed matte from the reverberatory furnace and copper concentrate is smelted and converted to white metal with oxygen enriched air. The continuous tapped white metal from the TMC vessel is charged to two Peirce-Smith converters for final blowing. The construction of a second facility is in progress at the Los Ventanas smelter of ENAMI.
In most smelters today, labor-intensive converter punching is replaced by mechanical tuyere punching. Addition of silica flux and reverts to the converters is generally by conveyor belt to a chute located in the side of the stack. Also, some smelters charge copper scrap from the top by a second chute. Radiation pyrometers are almost universally used to record converter gas temperatures.

Much has been written about the design of primary and secondary hoods; however, it is generally agreed that Japanese design is preeminent. The recovery of fugitive gases in their plants is outstanding, and they have little trouble meeting the stringent air pollution standards in Japan.

Waste-heat boilers are successfully installed behind the converter in a number of plants. It must be stressed that the purpose of these boilers is primarily to reduce the converter gas temperatures and not to recover energy. The length of the flues between the converter and electrostatic precipitator can be reduced when waste-heat boilers are installed.

Smelter layout has changed little over the years. However, the layout of two Japanese smelters, in which the flash smelting furnace is located on the same side of the aisle as the converters and anode furnaces, has much to commend it. It allows all gas-handling equipment to be located on one side of the aisle and permits shorter runs of flues. In addition, the design of the converter aisle crane is simplified by the fact that it only requires one auxiliary hoist.

With a few notable exceptions, all anode refining furnaces are of the rotary type, generally 13 ft in diameter by 30 ft long and holding a molten copper charge of up to 250 short tons. Airing and poling is performed through two tuyeres located in the front of the furnace. Poling can be done with any hydrocarbon gas (natural, propane, butane) or ammonia gas.

In most plants today, pouring of the anode copper into the molds of the casting wheel is done automatically. There are a number of designs, but they are all based on the use of load cells weighing out a predetermined amount of copper in the pouring ladle. A much closer tolerance in the weight of the individual anodes is achieved with this system, and when combined with other labor-saving operations such as automatic mold wash spraying and automatic anode takeoff, the labor required for the anode casting can be reduced to as few as three men. In several plants, anode casting is computer controlled.
In addition to the conventional casting of anodes on a circular casting wheel, several plants are now using Hazelett casters to cast a continuous strip of copper which is cut into the required length of anode. There are two systems in use. They differ in the thickness of the cast strip and the method of cutting the strip. In the Mitsubishi system, the strip is 3/8 in. thick, and the anode lengths are cut out by a press. In the Metallurgie Hoboken-Overpelt system, the strip is 1 in. thick and the anode lengths are cut out by a plasma torch. Both systems are operating satisfactorily. In a new plant, a decision as to which of the three casting systems should be used would be dependent on a number of factors and considerations.

This completes the review of modern copper smelting processes and techniques.

REFINING

In the past, the main sources of labor requirements in copper refining were electrode handling, starter sheet stripping, and cell inspection. Mechanized electrode-handling systems were initiated to replace a large part of the labor with machinery. The semiautomatic starter sheet assembling machine, introduced in the late 1950s, was later improved to be fully automatic, including a sheet-straightening device. Following this development, different models of cathode and anode washing machines and cathode and anode spacing machines were developed in Finland, Japan, and Sweden. However, this machinery was installed in existing tankhouses, normally in overcrowded working aisles on the ground floor, 4 to 5 m below cell level. The electrodes had to be hoisted or lowered by overhead cranes to the operating cell level.

The first refineries specifically designed for mechanized electrode handling started up in Japan beginning in 1965. Typical examples were the tankhouses in Onahama (Mitsubishi, 1965 and 1970), Naoshima (Mitsubishi, 1970 and 1975), Tamano (Mitsui, 1972), and Toyo (Sumitomo, 1973).

These four refineries have the following common features:

1. Anodes and cathodes are separately handled at the opposite end of the tankhouse aisle.

2. The handling equipment for starter sheets, anodes, cathodes, and scrap anodes is located in two levels. The electrodes are delivered or
picked up by forklift trucks at ground level. The spacing conveyors and the receiving conveyors of the washing machines are located at cell level, facilitating crane operation, coordination of electrode handling in sequence with cell changing cycles, and overall supervision. Lifting or lowering devices transport the electrodes between the two levels. When two tankhouse aisles are arranged in parallel, the spacing and receiving conveyors on the cell level are extended in the second aisle. The machines are automatically operated and each machine is controlled by one operator.

(3) The starter sheet assembly machines are located at ground level. The assembled starter sheets are directly transported to the storage conveyor of the starter sheet spacing machine.

With the exception of the Toyo refinery, which receives the starter sheets from Sumitomo's Niihama refinery, the starter sheet section of each tankhouse is equipped with an automatic stripping machine to avoid the labor-intensive manual stripping operation.

The Onahama No. 3 tankhouse, started up early in 1973, is distinctive in many important respects from any other tankhouse. The major differences are the electrode-handling system, cell design, and anode type. Lightweight strip-cast anodes weighing 120 kg and having a life of 9 days are used. The tankhouse is arranged in two aisles with 36 jumbo-type tanks. Each tank consists of 20 cell compartments without separation walls. In the cell compartments, the electrodes are supported on distribution beams which are in turn supported by pillars inside the tank. The tanks are manufactured from mild steel plates and lined with rigid PVC plates welded together in the tank. The basement is abolished and the cells are located 30 cm above the ground floor. The anode spacer, starter sheet assembly machines, and cathode and anode washing machine are arranged in parallel in a mechanical equipment bay, which is served by two automatic overhead hoists. The hoists transport the electrodes between the stationary machinery and the end station of an electrode carrier car system, and vice versa. The carrier car system is located in the middle between the two tankhouse aisles. Four fully automatic carrier cars travel on a two-line rail system with one automatic car traverser on each end. The cars either transport a one-cell lot of new electrodes to a position directly below the charging bridge or, traveling on the second rail line, return a one-cell lot of spent
electrodes to the equipment bay. Instead of conventional overhead cranes, a charging bridge, which travels just above the cells, is used for electrode handling. The charging bridge is equipped with a second trolley, which carries a sucking device to recover the anode slimes from the cell bottom. Although the charging bridge is designed to operate automatically when serving one tank, one operator is assigned to the cabin for safety purposes.

A second tankhouse of this type was commissioned in Timmins, Canada, in late 1981 for Texas Gulf.

Onahama claims that investment cost was decreased by approximately 30%, mainly because of the inexpensive tank design, the abolition of the basement, the lowering of the tankhouse building, and the reduction of the center-to-center distance of the electrodes resulting in a larger active electrode surface per cell. The use of lightweight, short-life anodes reduces significantly the copper inventory in cells by approximately 60%. However, there are also quite substantial disadvantages. The thinner anodes increase the anode scrap ratio and the cost for anode casting and handling.

After extensive research and pilot testing, Copper Refineries Pty. Ltd., a subsidiary of Mount Isa Mines, Ltd., incorporated its new electrorefining process in an existing tankhouse at the Townsville refinery in 1978. The main points of the ISA process are the elimination of starter sheets; the introduction of the permanent, rigid stainless-steel blanks as commercial cathode; and the automatic stripping of the copper cathode deposit. The process eliminated the complete starter sheet section, starter sheet assembly machines, starter sheet spacing conveyors, and the cathode washing machine.

The blades of the permanent cathode blanks are of 316L stainless steel, 3.25 mm thick, with a 2B finish. Hanger bars of extruded 304L stainless steel are stitch welded to the blades and subsequently copper plated to a thickness of 1.3 mm. Side edge masking is achieved by the use of plastic edge strips.

The cathode stripping machine is operated automatically using a hydraulic, pneumatic, and electrical control system. The following operations are performed:

(1) Receiving and conveying of cathode blanks.

(2) Washing of cathode blanks by water sprays.

(3) Air hammering of cathode blanks.
(4) Stripping of copper deposits by compressed air jets.

(5) Stacking, weighing, and stripping of cathodes.

(6) Electrode rejection and injection.

(7) Side edge sealing by wax spray.

(8) Bottom wax application by dipping.

(9) Discharging of stripped cathode blanks.

The Townsville tankhouse is equipped with two cathode stripping machines, which are located on the two ends of the tankhouse at cell level. The cathode cycle is 7 days. The two stripping machines are able to handle an annual copper cathode production of 175,000 tons, requiring a two-shifts-per-day, 5-days-per-week operating schedule. Each machine is controlled by a single operator.

Two anode handling machines and an anode washing machine are located in parallel, in a working aisle that divides the older cell sections from the new ones. The machines are designed to operate over two levels, ground and cell levels, as described above. The handling machines are provided with a pressing device, where anode body and lugs are straightened in two steps.

The new White Pine refinery now under construction in Michigan will incorporate ISA process technology.

Cell inspection accounts for approximately 40% of the labor force in conventional tankhouse operations. Various methods have been introduced to improve the vertical position of the electrodes to be suspended in the electrolytic cell, which is most essential to producing cathodes of good quality without using labor-intensive and only partially successful operating steps such as shimming of anodes or wet flapping of cathodes. At Naoshima, distorted anodes are straightened at the smelter prior to delivery to the tankhouse. At Toyo, a machine mills the lower part of the anode shoulder in a semicircle at the location where the anode is suspended on the bus bar. Because of the use of high-accuracy strip-cast anodes, decrease of anode and cathode hanging time, the slight increase of electrode pitch, and the reduction in current density, the Onahama No. 3 tankhouse completely abolished cell inspection. However,
current density is only 200 A/m² and the current efficiency varies between 90% and 93%.

The introduction of the rigid cathode blank, the short cathode life, and the use of pretreated anodes have significantly improved the plating condition and minimized the occurrence of electrode shorts inside the cell at the Townsville refinery. Short detection is further aided by a computerized cell voltage monitoring system. A digital computer has been programmed for two systems. The inspection work schedule is available as a printout from the computer, which lists all sections in the tankhouse with respect to short status, indicating which section should be checked first. The cell voltage display system permits detailed investigation of each section. Cells with voltages less than normal are marked on the printout. However, final detection of shorting electrodes has to be completed manually by Gauss meters. With these improvements, an average current efficiency of over 95% has been achieved with minimal inspection labor. The 36 inspectors required previously were reduced to four, who have maintained an improved record of performance. The current density is normally kept at 250 A/m².

The manual operation with the Gauss meter can be practically eliminated by infrared scanning. This control method is successfully used at Carrolton (Southwire), Amarillo (Asarco), Montreal-East (Canadian Copper Refiners), and Olen (Metallurgie Hoboken-Overpelt). The location of hot shorting conduct is clearly visible on the photographic print, which also indicates failure of electrolyte circulation. Cells with insufficient electrolyte flow and lower temperature are shown in a lighter shade of gray.

The wet contact equalizer bus bar was developed at the Tamano refinery in Japan for periodic reverse current. This system was later adopted with some minor changes by the Townsville refinery. Because of the tendency to increase the current density in electrorefining, it was discovered that the conventional Walker arrangement, with its small cross-section triangular bar, was not sufficient to guarantee equal power distribution inside the cell. The Toyo refinery developed a bus bar of unique design - a flat copper bar with rivet-type round heads approximately 6-7 mm high for electrode contact. This type of contact can only be used with milled anode lugs.
Modern tankhouse buildings are constructed of lightweight concrete at the roof and the side walls, with large openings for windows in two levels. All surfaces of concrete and steel exposed to acid and mist are protected by acidproof paint. The walkways around the cell blocks consist of plastic grid plates. The cells are covered with plastic sheets to reduce mist and conserve heat. In moderate and colder climates, tankhouse ventilation consists of forced-air units with air filter, air blowers, heaters, and powered roof ventilators. Ventilation and heating of the cell area is based on 7-8 air changes per hour.

In the last decade, various solution purification methods were developed to replace the conventional process, specifically the liberator cell operation, which has a high power consumption and forms poisonous arsine gas. Canadian Copper Refiners improved the process using periodic reverse current in the liberator section. The arsine emission has been reduced by more than 95%. Two methods, developed by Metallurgie Hoboken-Overpelt and Noranda, extract arsenic from spent electrolyte by solvent extraction combined with decopperizing and solution concentration in various steps. The Boliden process prevents the formation of floating slimes by balancing specific quantities of arsenic, antimony, and bismuth in the electrolyte and maintaining trivalent arsenic in excess. The oxygen dissolved in the electrolyte, primarily oxidizes the arsenic compound, and crystalline arsenates of antimony and bismuth are precipitated, and appear in the anode slimes. Excess of formed arsenic pentoxide is regenerated to trivalent ions by reduction with sulfur dioxide.

In the past, wire bars were the only source of copper wire production. Today, the direct casting of continuous copper rod has generally replaced wire bar casting.

The first commercial installation was commissioned in the 1960s by Southwire at Carrollton, Georgia. Since then, a total of 43 continuous rod-casting facilities have been installed or are under construction throughout the world. The capacities vary between 10 mtph and 55 mtph. The following systems are available:

1. Southwire Continuous Rod System (SCR)
2. Contirod system developed by Metallurgie Hoboken-Overpelt and Krupp
3. Secor system developed by Secim (France) and Copper Refineries Pty. (Australia)
Most of the facilities are equipped with an Asarco shaft furnace for melting the cathodes. Southwire lately has developed their own melting furnace as an alternative and offers it with their SCR system. Both Southwire and Secor systems use a grooved wheel made from copper-chromium-zirconium alloy as the casting unit, but wheel rotation, pouring point, and exit of the cast bar are opposite. The Contirod system is equipped with a twin belt Hazelett caster. Copper is poured between two moving endless steel belts with lateral walls formed by two side dam chains consisting of small special bronze blocks.

The "no-twist" rolling mills manufactured separately for each system by Morgan, Krupp, or Secim are slightly different in size and numbers of stands and drive arrangements.

Finished rod from the rolling mill is delivered to a special pickling line to clean the surface of the rod, which is then coated with wax for preservation. Southwire and Secor use an alcoholic nonacid compound. Contirod recommends the more complex lay pickling line using dilute sulfuric acid specifically for large capacities above 40 mtpm.

The laying head and coil-forming chambers of all three systems are nearly identical. At the larger installations, coils with a maximum weight of 9,000 kg can be formed. All three systems produce copper rod of excellent quality. However, it should be mentioned that only two installations of the Secor system with medium capacity are installed, one in Australia and one in Spain.

Modern copper refining practice as described above has by no means reached the state of perfection. Innovative ideas will further improve the process in the future.
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