CHAPTER III

LITERATURE REVIEWS

In this chapter, reviews on the studies related to a copper smelting process and the simulation of this process are presented and discussed. The smelting process is focused on the Teniente converter technology. Modeling of the Teniente converter is also given. In addition, the applications of METSIM program for copper production are discussed.

3.1 El Teniente converter

Mackey and Campos (2001) investigated a modern continuous smelting and converting process by a bath smelting technology including a Teniente converter. They stated that its origin at the Caletones smelter of Codelco, Chile in the early 1970s. As a result of autogeneous process and increasing smelting capacity, the Teniente converters were installed to replace reverberatory furnaces. To better understand the converter, the influence of independent operating variables on the dry concentrate smelting throughput and other requirements such as matte addition is studied. The theoretical results shows the effect of varying the blowing rate, the oxygen enrichment level and the grade of matte charged to the reactor. The important result indicates that oxygen has improved the thermal balance in the converter, reaching down to an autogeneous region with no matte addition is required. Based on 40%Cu grade in a copper concentrate, the autogeneous region is reached by smelting the concentrate feed for more than 2,000 ton per day and oxygen enrichment more than 36%.

Reviews on a copper pyrometallurgical practice were reported by Moskalyk and Alfantazi (2003). It is stated that a continuous smelting and converting process involves the pneumatic injection of copper concentrate through tuyeres into the reactor's molten bath (Gonzalez and Vargas, 1995). Copper concentrate is dried to a 0.2% moisture level prior to tuyere injection into the molten bath of the Teniente reactor. The exothermic reaction caused by oxygenated air reacting with iron sulfides in the green charge allows smelting without external heat application. Availability of technical oxygen has enhanced converter operations. An important feature of the Teniente unit is its ability to process both wet and dried concentrates. Concentrates with residual H_2O content require the addition of seed matte as produced in a standard reverb furnace (Rentz *et al.*, 1999). The resulting high-grade matte typically contains 74–76% Cu, plus a slag containing 4–6% Cu and 16–18% magnetite (Fe_3O_4). The white metal is converted to blister in a traditional P–S converter. Off-gases contain an average of 25–35% SO_2 at the reactor mouth while air leakage creates dilution in the flue exhaust system. The dirty slags containing 6–8% copper require additional treatment in a batch slag cleaning furnace to recover metal values before discarding the material to a dump site. Final discard slags contain less than 0.85% copper. On a general basis, slag is either discarded in its molten state at dumps or water granulated then pumped to an impoundment area. The exhaust gases are cooled, treated in conventional dust cleaning equipment then directed to an acid plant. Advantages of Teniente converter units are low capital investment, low operating costs, and low energy consumption (Morales and Mac-Kay, 1999). Apart from South American applications, the Teniente converter is employed at the Rayong smelter in Thailand.

3.2 Simulation of copper smelting process

Since Teniente converters are used worldwide, many studies about the mechanism of furnace such as phase equilibrium, the thermodynamic data and computational fluid dynamics are provided to understand the behavior of such a smelting reactor.

The oxygen efficiency calculation was studied by Rosales *et al.* (2003). In general, the metallurgical efficiency of the Teniente converter depends strongly on the utilization of oxygen feed within the reactor during the smelting and converting reactions of the iron and copper sulfide minerals of copper concentrates that lead to the production of white metal. The developed model showed that the oxygen efficiency is independent of air enrichment, and that it depends only on the total gas flow and it is diminished with increasing air flow and increases with increasing number of tuyeres. From their study, it was found that the variables that have an effect on the oxygen efficiency are blowing air and oxygen flow rates.

It is noted that there are many database of thermochemical properties and thermodynamic data of materials such as slags, mattes, metals and gases are studied. Davies *et al.* (1999) provided the use of MTDATA software package for calculating phase equilibrium; the MTDATA is incorporated into the METSIM model by using the FORTRAN programming interface. They also noted that most significant insights have been gained not only from the use of MTDATA but also from its use as part of an overall process model, such as provided by METSIM. An important task for the future is the development of tools for the integration of thermochemical software packages into process modeling software.

3.3 Model of Teniente converting process

Luraschi and Cañas (1997) presented three main topics on the smelting-converting process in the Teniente converter which are examined from the thermodynamic point of view: a) the mass and heat balance of the reactor which determines its capacity, b) the equilibrium of the matte-slag-gas phases with special reference to the magnetite contents of the slags, and c) the distribution of minor elements in the converter and in the smelter.

The mass and heat balances in the Teniente converter are first described by explicit equations which serve to exemplify a variety of situations and to analyze the effects of different process parameters, such as blowing rate, oxygen enrichment, and concentrate moisture, on the smelting capacity. The same mass and heat balances may be performed with higher flexibility and with integration of the Teniente converter to the whole smelter flowsheet by the use of process software such as METSIM. The results of such calculations for autogenous operation of the CT were shown as an example.

Equilibrium models of smelting reactors are of interest but tend to be too involved and demanding of computation resources. In the case of the Teniente converter, models have been developed based on previous efforts by other investigators, mainly with the objective of building impurity distribution models. However, so far it has not been possible to integrate general equilibrium models to plant simulators, due to their complexity. For this reason, a particular equilibrium calculation procedure for a copper smelting matte-fayalite slag-gas system has been developed, using the main equilibrium reaction and specially derived activity correlations of slag components. This algorithm is fast converging and lends itself to be integrated into plant simulation models. In the present case, it has been inserted in a METSIM model of the Teniente converter process, and was run to simulate some recent operations of the converter at Caletones. The results were compared with plant data and the results showed that the model prediction is reliable. The actual magnetite content of the slag is 20% higher than the equilibrium value determined by the model, which is to be expected, given the intensity of the process. Interesting conclusions may be drawn by comparing the effect of temperature on equilibrium and saturation magnetite contents in the slag.

The distribution of impurities in a smelter is a rather complex subject, and all the processes included until the production of the final copper must be considered to make a meaningful analysis of impurity behavior. A brief review is made of the models that have been developed and are available to analyze impurity distributions in the Teniente converter (and other processes) such as DIMPROF and CTIMP, and the use of METSIM to model impurity behavior in the complete smelter. Also, some results of a survey on the eliminations of impurities such as Pb, As, Sb, and Bi in different smelting and converting processes are presented. In particular, the Teniente Converter is characterized by high eliminations of volatile impurities.

3.4 Applications of METSIM

At the Kennecott smelter and refinery which employs the flash smelting technology, there is an effort to combine a total of eight process models for this plant due to the complexity. Siraa *et al.* (1999) examined the models and discussed their results and applications. The three major areas of the METSIM applications are as follows.

3.4.1 Strategic studies

The example for this topic was a Flash smelting furnace model. The use of METSIM in strategic studies illustrates the generation of system data that forms the input to thermochemical calculations by additional software. The window of thermochemical operation can then be defined and look-up tables generated to speed the sensitivity calculations. Ultimately links will be established between the two types of software to enable true interaction for complex equilibriums.

3.4.2 Metallurgical investigations

The METSIM models have been useful to predict stream data that are difficult to measure in real time. For example, concentrate blending was examined while keeping a constant feed rate. This was designed to optimize the heat balance while dealing with different ratios of recycled converter slag to wet concentrate or looking at the input of concentrates from different mine sources. The result outlined the conditions of using different feed materials on the heat balance.

3.4.3 On-line process control

The above examples are used to simulate one process area. In these cases, there are examples which illustrated an on-line process control.

The flash smelting and converting furnace are prone to numerous disturbances and inherent process attributes which make them troublesome to control. These disturbances relate primarily to feed grade changes, measurement error and unmeasured disturbances. In most smelters, it has been a complex task for a control room operator to take account of the constantly changing systems and take comprehensive action. As a result, the furnaces can exhibit considerable oscillations in temperature and product grades.

In response to those problems, there are two process control strategies that are being implemented, one for the flash smelting furnace and the second for flash converting furnace. The overall scheme consists of a feedforward and feedback component. The steady state heat and mass balance METSIM models of these two furnaces essentially make up the feedforward component of these control schemes. They calculate changes necessary to the plant based on feed changes (either of a composition or flow rate). The feedback component of the control scheme takes into account changes necessary based on the output information of the plant (assays, temperatures, etc.).

The controller parameters for the proportional-integral feedback equation were derived by comparing the METSIM model with plant data. By examining this data using time series analysis, the process lags and gains were determined.

In conclusion, it was found from literature survey that METSIM is a widely used program to model a metallurgical process. However, there is limitation in that thermochemical data is not included in METSIM. This can be solved by integrating data that can be calculated from other programs such as MTDATA.