DIAGNOSIS AND CONTROL STRATEGY FOR A TENIENTE CONVERTER

L.G. Bergh[§], P. Chacana[†] and C. Carrasco[†]

[§]*Chemical Engineering Department, Santa Maria University*
Valparaiso, Chile, luis.bergh@ usm.cl
[†]*Caletones Smelter, El Teniente Division, Codelco-Chile*

Abstract: A diagnosis of the actual distributed control and measurements system for a Teniente Converter, processing copper concentrates is presented. Besides the importance of this converter in Caletones Smelter, there are a number of unsolved problems related to lack of instrumentation, lack of process knowledge, odd operating practices, and in general lack of use of procedures to process data to aid management and operating decisions. In general, process control of some local objectives are frequently achieved, however, application of supervisory control techniques, has been rather slowly included. The second part of this work describes a proposal to implement a supervisory control strategy for Teniente Converters, in harmony with other process units in the smelter.

Keywords: automation, supervisory control, control diagnosis, converters

1. INTRODUCTION

First a diagnosis of the instrumentation and control system of a copper concentrate converter (Caletones Smelter, 1977) at Caletones Smelter, Chile, is presented. Large variations in copper content of white metal and slug have motivated a study to investigate the origin of such variations, in order to improve product quality, decrease recycling of material, and allow an increment in copper production. The study, at first considers the quality of key measurements, the achievement of local control objectives, and the operating practice. After the diagnosis was complete, a control strategy was developed, in order to organize and coordinate the use of converter supplies to improve products quality while considering the interaction with other process units (converters, slag cleaning, and gas treatment) and production goals. Similar works have not been discussed in the literature (Jamsa-Jounela, 2000).

2. CALETONES SMELTER

Caletones Smelter is located at the Andes Cordillera, 42 km from Rancagua, at 1556 m over sea level, in Chile. In 2004 the smelter produced two products: anodic copper (99.6 % copper) and fired raffinated copper (99.92 % copper), which in total represents a production of over 380,000 tons of copper per year. To obtain this tonnage about 1,250,000 tons of dried concentrate are smelted. The general diagram of the actual process is presented in Figure 1.

Following Figure 1, 3,800 tones of dried copper concentrate, with a mean moisture of 8%, are fed to the Caletones Smelter. 89 % of this tonnage is dried to 0.2 % moisture in three fluidised bed dryers and smelted in two Teniente Converters (TC), processing each one 1,900 tpd. In the TC two products are obtained: white metal (75 % copper as sulphur compounds) and slag (less than 8 % copper).

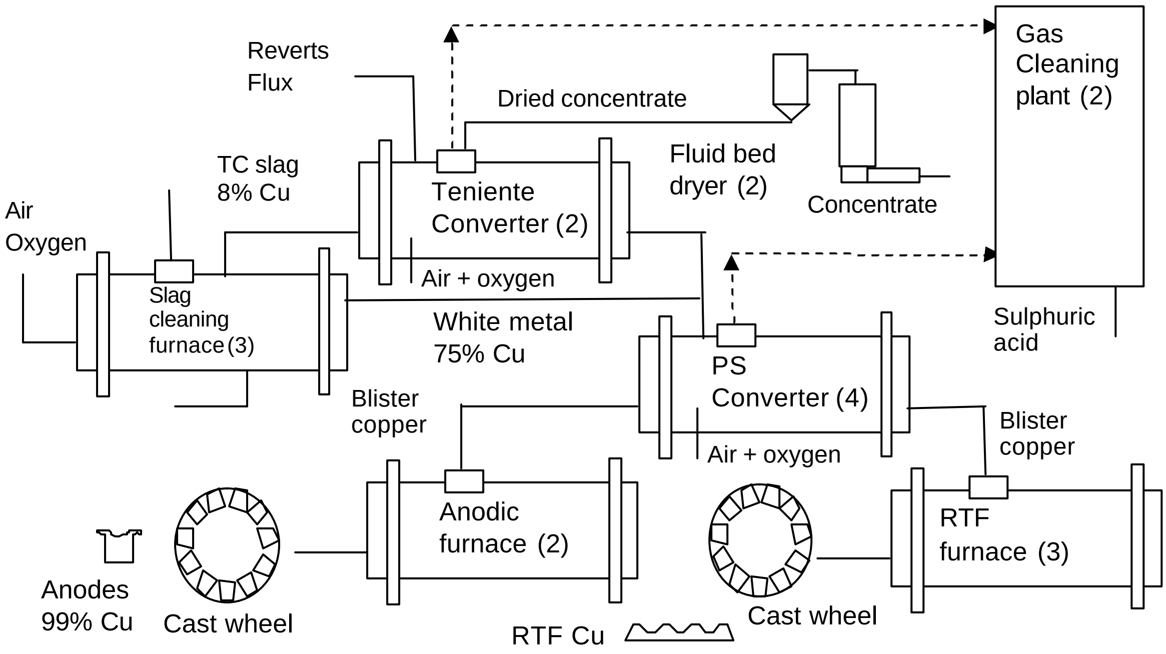

Fig. 1. Caletones Smelter diagram

The white metal is then processed in four Peirce Smith Converters (PSC), obtaining blister copper (99.3 %) which is transformed into anodes in one Anode Furnace and into fired raffinated copper in one FRF furnace. The slag from TCs is processed in four Slag Cleaning Furnaces (SCF) (Caletones Smelter, 1988). In the SCF two products are obtained: the matte (70 % copper) that is returned to the CTs or PSCs, and the final slag (0.85 % copper) that is dumped in the slag deposit.

2.1 Teniente Converters

Two Teniente converters process concentrate from an upstream drying process. Dried concentrate is stored in a 300-ton feed bin and is pneumatically conveyed through two concentrate injection tuyeres to the TC. Annular air is supplied around the concentrate injection tuyeres to aid in the distribution of concentrate as it enters the converter. Reverts and flux are fed from separate 100-ton feed bins. Each is fed independently to a main, 91 weigh belt feeder system and into the converter through a small bin. Air, blown from a 'garr gun', is used to convey the material into the converter. Air and oxygen are combined to produce an enriched air stream. The enriched air stream is blown into the TC through 40 air tuyeres. The calculation of the oxygen flow rate is based on the combined blown air, injection air, annular air, and garr-gun air flow rates. A flow diagram is shown in Figure 2.

The TC process is semi-continuous. The slag and white metal taps are removed from opposite ends of the converter and the slag and white metal are collected in ladles for further processing. At least three manual level measurements are taken each shift to monitor the level of the converter contents and determine when slag and white metal are to be removed. A white metal phase approximately 95 cm deep and a slag phase approximately 95 cm deep on top of the white metal are to be maintained. Approximately 17 ladles of slag and 7 ladles of white metal are removed from the TC each shift. The converter may also be rotated to two different positions to remove the either the slag (1st position) or the entire contents (2nd position).

Hot gases exit the TC through an open port at the top of the converter. Gases are cooled, passed through an electrostatic precipitator and sent to a gas handling plant for processing. Two machines, called MAPUCAs, are used for clearing the blown enriched air tuyeres. One of the machines is automatic and controlled based on the percentage opening of the blown air valve. The other machine is operated manually.

The copper quality targets for the white metal and slag are 75 percent and 9 percent respectively. Approximately 3 samples per shift of the white metal are taken and analyzed for copper concentration. Slag samples are taken and analyzed each time slag is removed from the converter. A composite concentrate sample is taken each shift from an automatic sampler, which extracts a sample every 20 minutes. The sample is moisture and chemically analyzed.

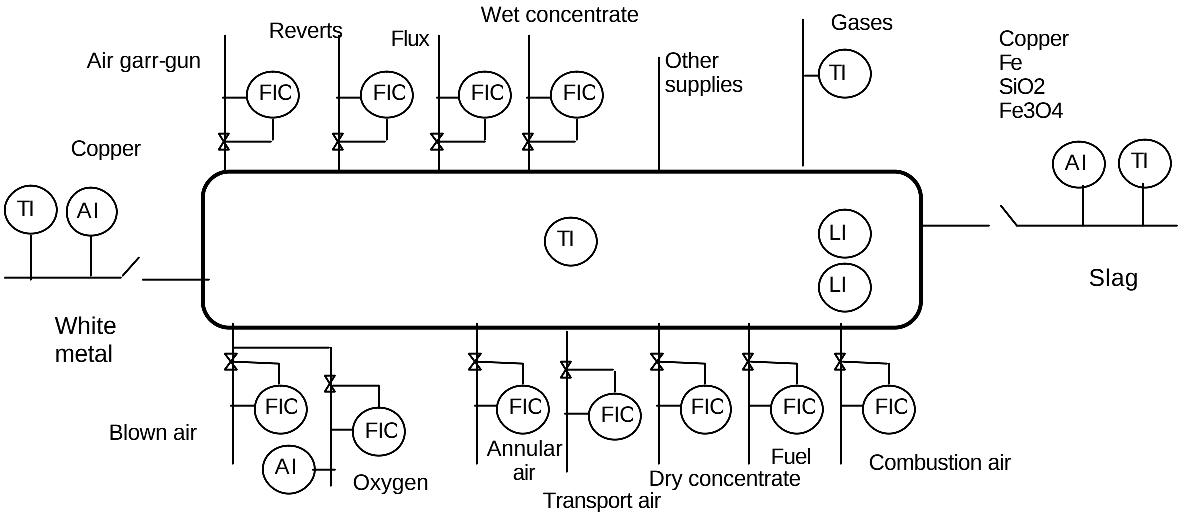

Fig.2 Simplified TC flow and instrumentation diagram

The current control system is comprised of a number of single loop controllers. Set points of the converter manipulated variables are determined by operators based on the current state of operations.

The scheme for controlling the white metal and slag copper content is quite complex. A number of manipulated variables influence the copper content in both the white metal and slag. Operators can manipulate several variables to affect the copper content in both the white metal and slag, including: air flow rate, oxygen enrichment, concentrate flow rate, revert flow rate and flux flow rate.

3. DIAGNOSIS

The current control scheme contains no coordination of concentrate flow, air flow and oxygen flow rates. The flux flow controller set point is determined by operators based on results of the slag chemical analysis, in particular the Fe and SiO_2 contents. A target Fe/SiO_2 ratio of approximately 1.6 is desirable in order to decrease slag viscosity and improve downstream copper recovery. The reverts controller set point is determined by operators based primarily on the slag temperature measurement. Reverts are used to cool the internal converter load. There is no automatic strategy in the current control system to maximize concentrate flow rate or reverts flow rate to maintain the copper concentrate in the white metal and slag.

In order to show the effect of operator decisions, two sets of operating data for some months ago are shown in Figure 3. The first set on the left was for an abnormal operation with large variability on the final objective variables, while the second set, on the right, corresponded to a better operation. Each period is two days long.

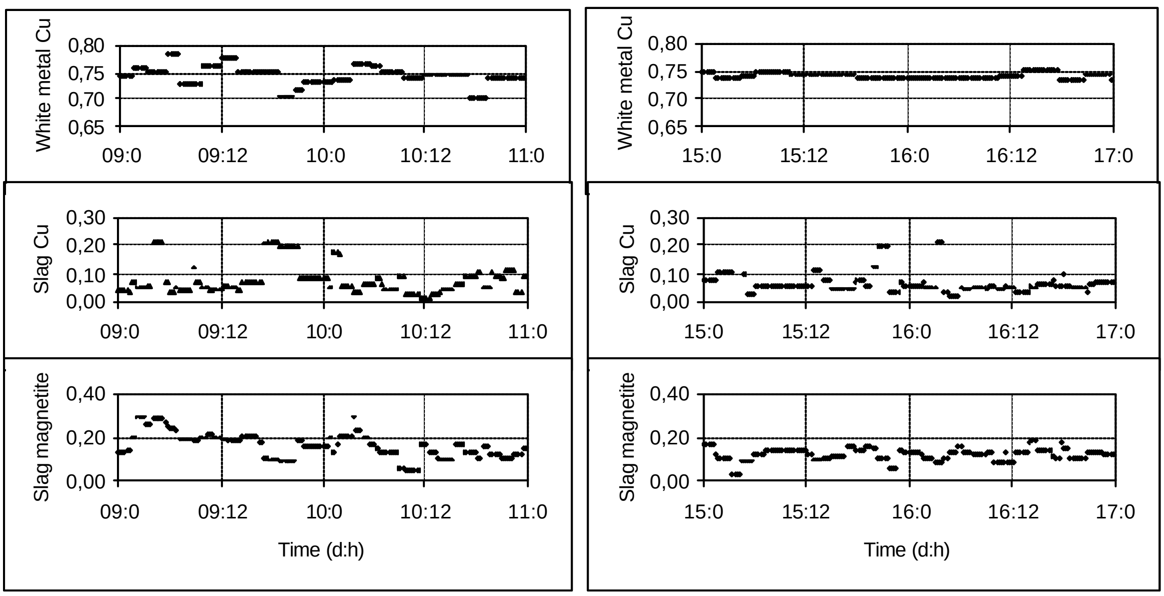

Fig. 3. Main output data for two different operating conditions

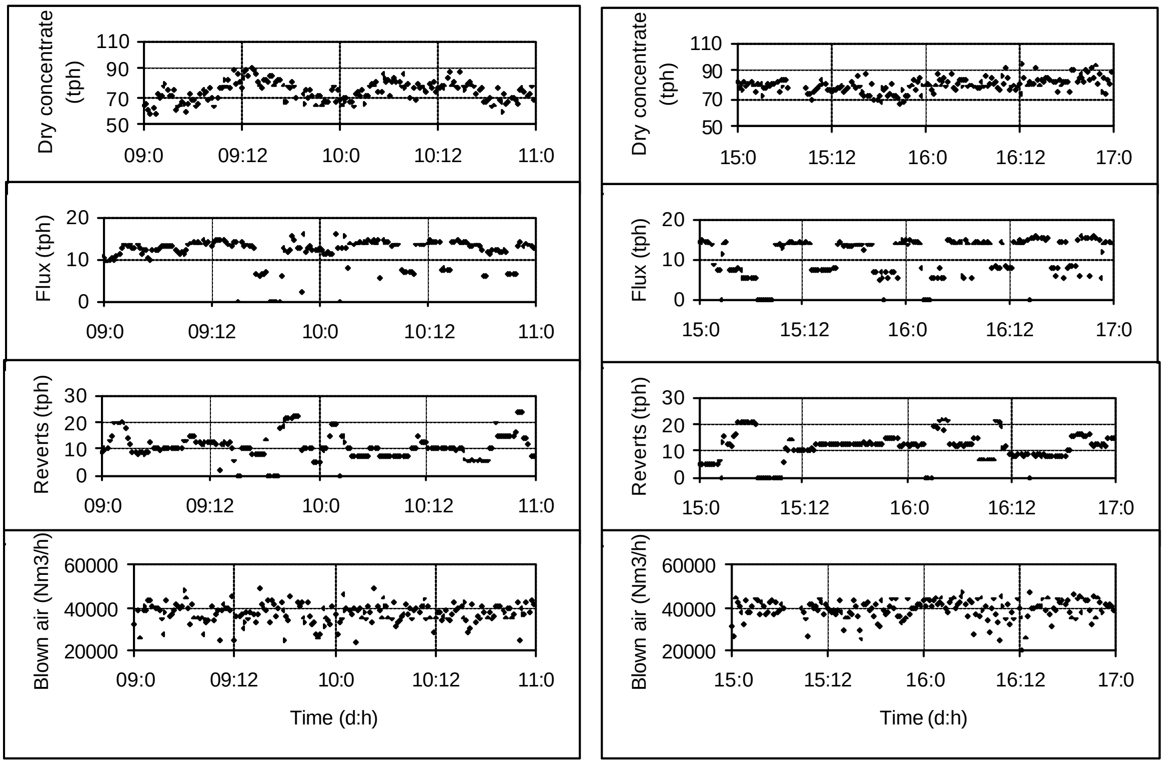

Fig. 4. Set of main input data for two different operating conditions

The main process input variables are shown in Figure 4, for the same periods. The data show the potential to improve the operation through a better control. Some of the variability can be attributed to odd decisions from personnel with a heterogeneous preparation and to local control problems of the main supplies. In general, it was found large product variability and a considerable recycle of products. The nature of the process propagates disturbances created in one process operation to others, increasing unnecessarily the recycling of intermediate products off specifications.

To improve the product quality and to decrease material recycling a better administration of local control set points of input variables must be achieved. There are two kind of constraining problems: the quality of some measurements and the lack of coordination of local control loops. In this paper a supervisory control strategy is proposed to address the later problem.

4. SUPERVISORY CONTROL STRATEGY

To develop a supervisory control strategy the model shown in Figure 5 was considered (Bergh et al., 1998). The variables that represent final objectives are to keep inside a narrow band, by regulating those representing intermediate objectives in a broader but limited band. To obtain these results, the input variables considered basic resources are changed accordingly.

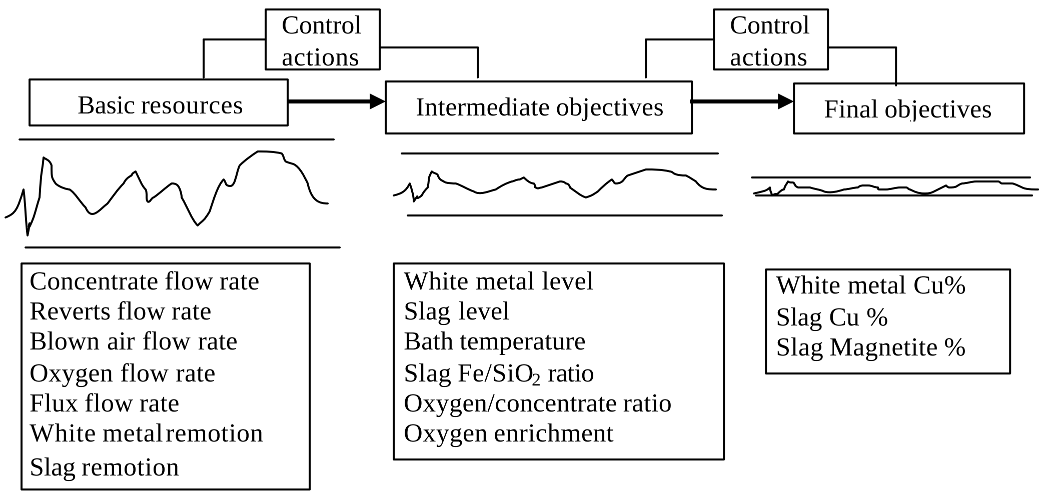

Fig. 5. Supervisory control model proposed

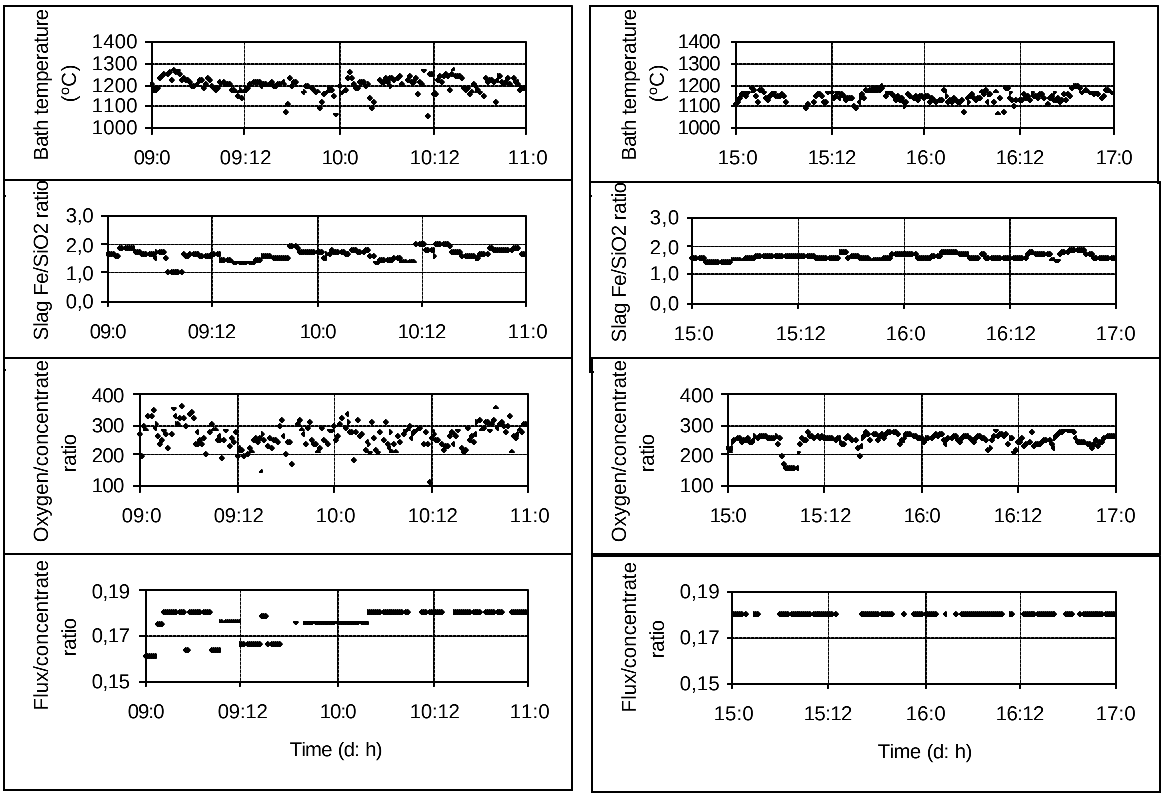

Fig. 6. Intermediate objective variables for two different operating conditions

This proposal is experimentally sustained on the behaviour of the calculated variables that represent intermediate objectives, for the same previous periods, shown in Figure 6. Better control of oxygen/concentrate ratio, bath temperature and slag Fe/SiO_2 ratio, shown on the right hand plots, lead to higher quality products. Oxygen enrichment was not included because at that time severe limitations in oxygen supply occurred. In these days a third oxygen plant and a new pneumatic system for delivering and injecting the concentrate are in service.

The supervisory control strategy is based on an expert system structure, where the inputs to each procedure come from DCS internal alarms and external alarms. The output of each procedure determines the set points values of the DCS basic control loops. The control scheme considers the processing capacity of other operating units, such as Pierce Smith converters, Slag Cleaning Furnitures, Gas and Effluent Treatment Plants and Production and Maintenance Programs. These constraints capacities are in fact the external alarms. The principal objective of the expert system is to find at any time the maximum concentrate flow rate that can be processed considering all the operating internal and external constraints. Once this variable is chosen then the rest of the basic set points are determined to obtain a white metal in a narrow band, usually around 75% Cu and a slag with a content of magnetite inside a band. The later is important not only for the process phenomena inside the TC but also in the efficiency of treatment the slag in other units. Afterwards, the air and oxygen flow rates are calculated from the previous data.

Since some variables are measured in a continuous basis and others are sampled at different frequencies, the organization of different procedures is more complex. One form to address this problem is illustrated in Figure 7. There are two groups of variables: those internals coming from the TC process and those externals restricting the production of white metal, slag and gases.

The internal group can also be divided in two according to the nature of the sampling frequency. The first group of continuously measured variables are the inputs to a set of procedures to find the optimal set for concentrate flow rate accordingly to the air and oxygen availability, and to keep the bath temperature inside a band by setting the reverts flow rate and the oxygen enrichment. These procedures are executed using average conditions over a period of time. The second group is measured at different frequencies and then each procedure can only be executed when the information became available. Since the final objectives are in this group, there are procedures to maintain the Cu content of the white metal and the magnetite content in the slag in narrow bands. This is achieved by finding the settings of the oxygen/concentrate ratio and the flux/concentrate ratio. In this group are also procedures to keep the white metal and slag levels.

The external group mainly defines the maximum concentrate flow rate that can be processed according

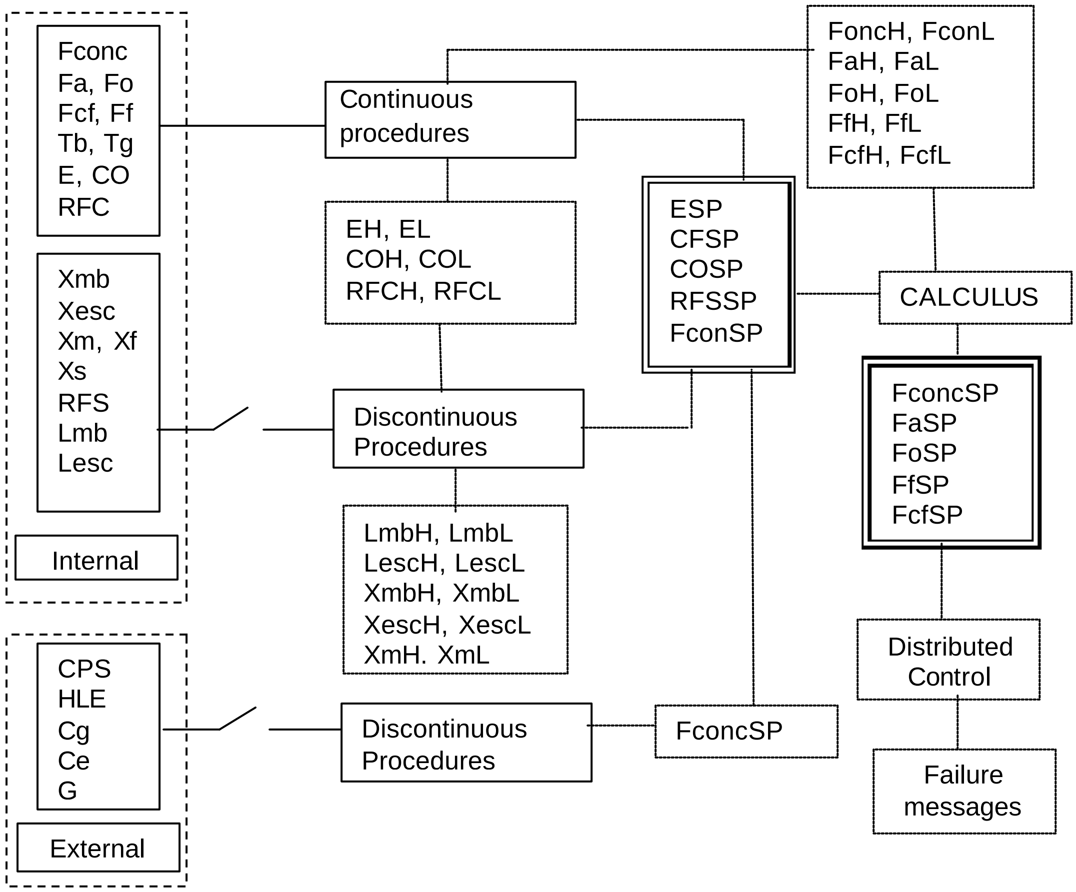

Fig. 7 Supervisory control procedures

to the external restrictions, as discussed before. Afterwards, a routine find the optimum concentrate flow rate using the suggestions of internal and external procedures. At this point the air and oxygen flow rates can be calculated from the previously determined variables. In this way all set points of basic controllers under DCS are determined.

In the next months this strategy will be commissioned and new results will become available.

5. CONCLUSIONS

The Teniente Converter is a very complex process where the key variables are measured infrequently and sometimes with considerable errors. The input variables are all under DSC control. However, operating decisions usually lead to large variability of product quality and hence to unnecessary recycling of material between the units in the smelter.

A supervisory control strategy has been proposed based on experimental studies in the form of an expert system. Complex procedures has been developed to consider internal abnormal situations and to consider external constraints. These procedures provide a consistent methodology to administrate the local control loops in harmony with the temporal capacity of the other units in the smelter. In a next future the results of implementing this control strategy will be discussed.

ACKNOWLEDGEMENTS

The authors would like to thanks Conicyt (Project Fondecyt 1020215) and Santa Maria University (Project 270522) for their financial support and to El Teniente for allowing the presentation of this work.

REFERENCES

Bergh L.G., Yianatos J., Acuña C., Pérez H. and F. López (1999). Supervisory Control at Salvador Flotation Columns. *Minerals Engineering*, **12**, N° 7, pp. 733-744.

Fundicion Caletones, Division El Teniente, Codelco-Chile, Patent 35164, Improvements in the continuous fusion and conversion of copper concentrates, March 1986.

Fundicion Caletones, Division El Teniente, Codelco-Chile, Patent 30226, A device for continuous fusion and conversion of copper concentrates, October 1977.

Jämsä-Jounela S-L., Current status and future trends in the automation of Mineral and Metal Processing, 2001, *Control Eng. Practice*, **9**, (9), pp 1019-1024.