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DIAGNOSIS AND MODIFICATIONS OF THE COPPER CONCENTRATE INJECTION CONTROL IN A TENIENTE CONVERTER

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

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

Abstract: A study to develop a fault diagnosis system in the pneumatic injection of copper concentrate into a Teniente Converter at Caletones Smelter, Chile, is presented. The availability of the injection system must be improved at least in 2% to satisfy the actual production demands. The most frequent operating failure were pump pressurization and pump overcharge. However, most of the problems were due to disturbances propagation either from the reactor or silo operation. A research to identify and remedy the main causes of operating failures leaded to modify the control and supervising system and to introduce changes in the plant layout.

Keywords: automation, process control, data processing, pneumatic injection

1. INTRODUCTION

Fault diagnosis systems (Himmelblau, 1978) have been particularly useful in avoiding process to be operated under abnormal conditions with the consequent quality degradation. When process constraints are about to be met, a procedure can be initiated to relax these constraints, recovering process controllability. Most of the diagnosis and isolation fault systems are building upon process models (Isermann and Bale, 1997). These models are difficult to obtain for complex processes, such as those in the mineral processing area. In this case the process and systems knowledge is frequently encapsulated in expert type systems (Jämsä-Jounela, 2001). In this paper the first part to develop a supervisory system in the pneumatic injection of copper concentrate into a Teniente Converter (Fundicion Caletones, 1977) at Caletones Smelter, from Teniente Division of Codelco-Chile, is presented.

2. CALETONES SMELTER

Caletones Smelter is located at the Andes Cordillera, 42 km from Rancagua, at 1556 m over sea level, in Chile. In Caletones two products are produced: anodic copper (99.6 % copper) and fired raffinated copper (99.92 % copper), which in total represents a production of 380,000 tons of copper per year. To obtain this tonnage about 1,250,000 tons of dried concentrate is smelted. Most of the concentrate is coming from the Colon Concentrator from the same Division and about 10% from Andina Concentrator, also from Codelco-Chile. The general diagram of the actual process is presented in Figure 1.

Following Figure 1, 3,700 tones of dried copper concentrate, with mean moisture of 8%, are fed to the Caletones Smelter. This tonnage is dried to 0.2 % moisture in two fluidised bed dryers and smelted in two Teniente Converters (TC), processing each one 1,850 tpd. In the TC two products are obtained: white metal

(75 % copper as sulphur compounds) and slag (8 % copper). The white metal is then processed in four Pierce 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). 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 Injection of copper concentrate into CT

All the concentrate is pneumatically injected through nozzles into each TC, being the smelter production extremely sensitive to any malfunction or failure in that system. These reactors operate in autogenously regime. The dried concentrate is stored in two 150 m^3 silos, one for each drier. Each silo has a battery of bag filters to separate the concentrate from the air, used to transports the solid from the drier.

A schematic of one injection system (Caletones, 1986) is illustrated in Figure 2. It can be observed that the level of solid in the silo is measured and that the nitrogen pressure used to fluidize the silo is under control. The discharge from the silo is dossified to a Fuller pump by measuring the concentrate tonnage with an impact weight meter and regulating the speed of a rotator valve. A screw-type pump to the air stream transports the solid. The pressure and the flow rate of the injection air are measured and controlled. As both control valves are installed in the same pipe, the airflow rate controlled is tight tuned while the air pressure controller is rather loose. Pressure and temperature in different parts of the system are measured. Electric current consumption in motor pumps is measured. All controllers are implemented in a Foxboro Distributed Control System, and then operators have remote access to all the operating variables and its trends. Here, basic PID controllers and more complex control algorithms are implemented. A database is fed from field and processed measurements. This database is shared with a PC computer network operating under Plant Information (PI) System from OSI Systems. The PI system is mainly used to monitor the complete past operation and to collect experimental data for further analysis.

2.2 Objectives, resources and constraints

The main objective is to satisfy the specific demand of concentrate to be fed at each CT at any time. There are a number of resources available as well as limiting constraints to achieve that. Then a failure to provide the right tonnage of concentrate may be due, among others, to:

- The selection of a combination of set points associated to the control of the main operating variables
- Inadequate design or specification of system parts, such as silo geometry, rotatories feeding devices, weight meters, pump characteristics, circuit layout
- Inadequate process supervision leading to odd operating decisions, implemented either by the DCS or operators
- Software and hardware misuse

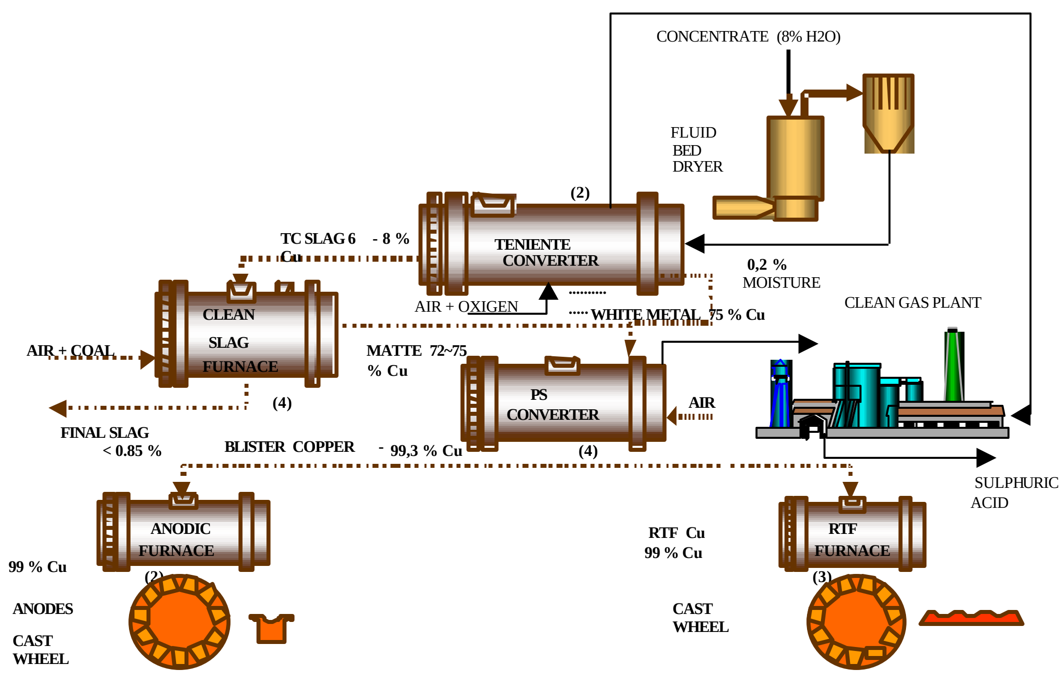

Fig. 1. Caletones Smelter diagram

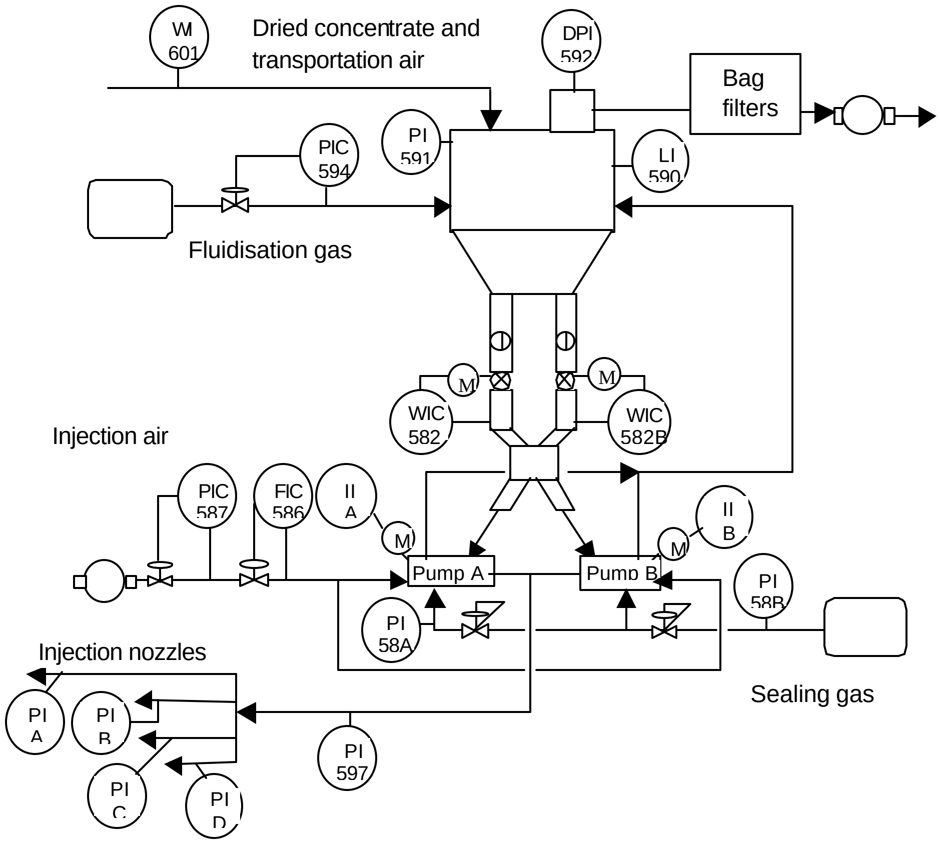

Fig. 2. Schematic of copper concentrate injection system and its instrumentation and control system

The most common failures are due to silo and pump pressurization and pump overcharge, but the origin of the problem is usually a combination of events. Mechanical, electric and external type of failures are usually rapidly identified and remedied, mainly because of the availability of spare equipment.

The first part of this study is focused in increasing the system availability that means how to avoid the main problems, and then to improve the operation to reduce the variability of the concentrate supply. The main operating problems and the relationship among the operating variables are investigated in this work, to propose a supervisory control system with the architecture squematically shown in Figure 3.

3. OPERATING VARIABLES STUDY

Using data collected either from historical records that satisfied some given criterion or from specific experiences designed to provide inside on a particular situation, the following studies were realized (Bergh, 2001a).

3.1 Tonnage control

Considering the large variability observed in the flow of concentrate, the fluidisation pressure and rpm of rotator valves were kept constant over a period of time. In Figure 4 the concentrate tonnage is displayed for three periods. In the first period the weight control is on and in the two others the weight control is off. The solid horizontal lines represented the tonnage average and the vertical lines the 95% confidence interval, as a measure of variability. The increment in tonnage average is explained because the weight control set point is automatically decreased when the injection air pressure is close to a certain limit to avoid pressurization. The control algorithm is overreacting in this case. The tonnage variability is still large, supporting the thesis that silo geometry and other operating variables are affecting significantly the tonnage variability and that the weight control acting on the rpm of the rotator valve are not able to compensate such deviations.

3.2 Fluidisation pressure

After studying some historical data, changes in fluidisation pressure leaded to changes in weight set

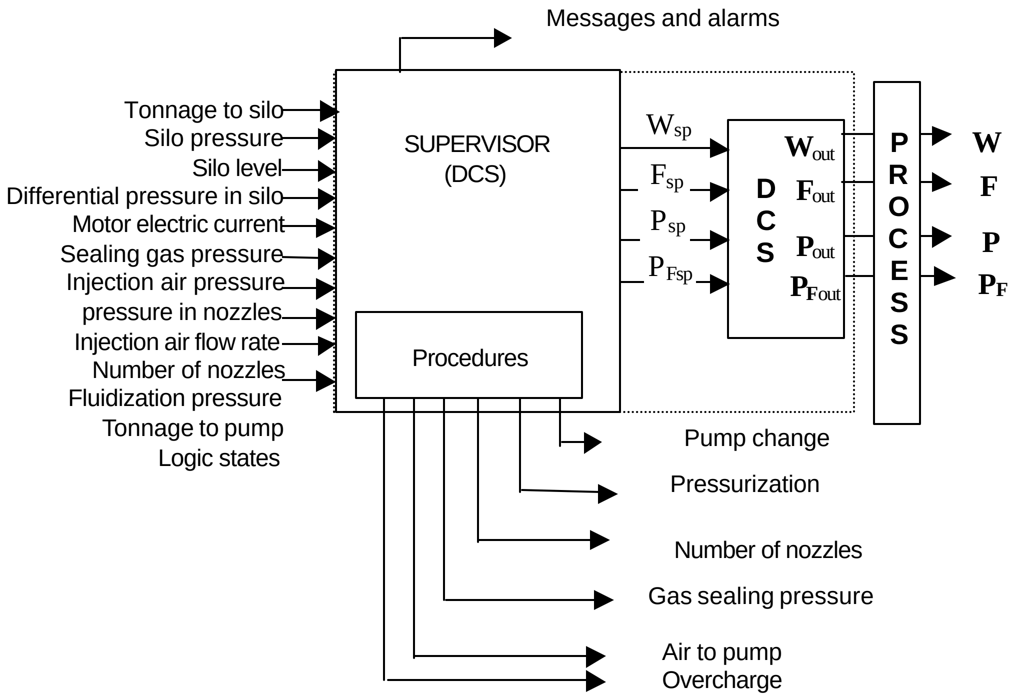

Fig. 3. Proposed supervisory control of concentrate injection system

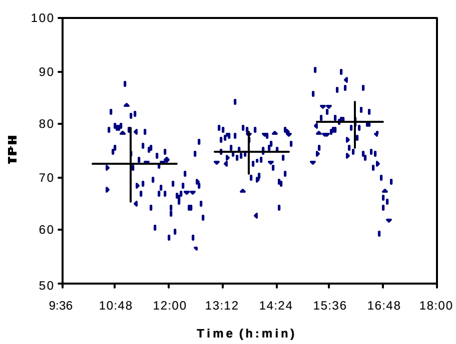

Fig. 4. Tonnage control

point control and usually to instable operating conditions. Data displayed in Table 1 were collected at different fluidization pressures, and shows how the variability of the tonnage increased with pressure, but also how the variability of the electric current consumption in the pump decreased with pressure.

Table 1. Statistics at different fluidisation pressures

	Pressure (KPa)		
	19	28	32
Weight (TPH)	78	75	75
Var(weight) (TPH^2)	26	44	67
Var(current) (A^2)	128	44	54

In plant it was observed that even when at low pressure the tonnage variability is significantly decreased over several minutes, suddenly a large peak is presented causing pump overcharge. However, variance is not a precise index in the sense that at equal variance a behavior with no important peaks will be preferred. Peaks in tonnage causes pump overcharge and can also trigger a pressurization process. Therefore the experiences were suspended until a complete study of the concentrate characteristics and silo geometry was performed.

3.3 Differential pressure across pump

Looking at historical data it was noticed that unstable operating periods were characterized by large pressure difference across the pump. On the contrary, when the difference was rather small the injection system operated more stable and the frequency of failure decreased, and consequently a larger injection of concentrate was achieved. The airflow rate was under control and with similar set points, and then the pressure lost in the pump is related to the compactness state of the concentrate in the pump and to the setting of the counterweight in the discharge dump.

3.4 Flow and pressure injection air control

As can be seen in Figure 2, the injection air flowrate and pressure are both controlled. The pressure control loop is loose tuned with a broad dead band, while the air flowrate control set point is mainly selected as a function of the number of injection nozzles operating at that time. Therefore the control system forces a given air flowrate irrespectivly of the air injection pressure. The system often became pressurized because of problems originated in the silo discharge or in the injection nozzles, and this process is aided by the flowrate control algorithm.

A different approach is to have a tight control on the injection pressure and to leave the air flowrate floating. Experiences were designed and implemented in plant. The collected data is shown in Figures 5 and 6. During the first 90 minutes the injection system is operating as usual under air flowrate control, and in the next 90 minutes under air pressure control. Part of this period was used to properly tune the PI pressure controller.

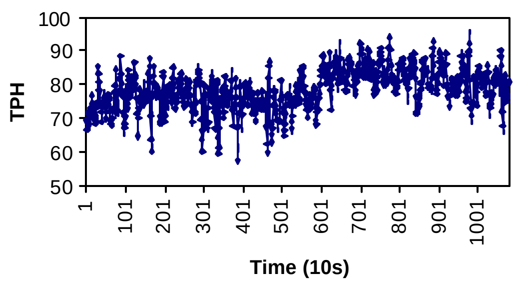

Fig. 5. Tonnage

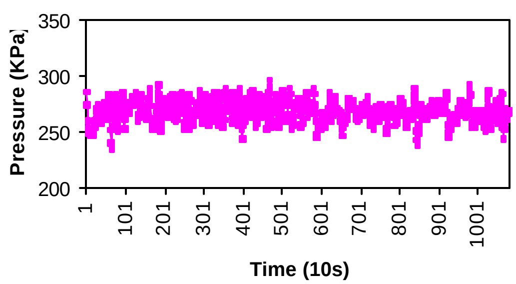

Fig. 6. Air injection pressure

The statistics for the main operating variables are displayed in Table 2, where the first row of data is for the first set of experiences where the CT is operating with only two injection nozzles. The most remarkable result is that the tonnage delivered has increased in almost 10% even when the weight set point is always 80 TPH. Again, this difference is due to the weight control algorithm that reduces automatically the set point when the injection pressure is over a limit. Furthermore, the tonnage variability was also decreased under pressure control. On the other hand, the average and variance of the electric current consumption at the pump motor slightly increased.

The improved operation was achieved working with a low airflow rate that also means a low injection air pressure instead of a larger tonnage delivered. This result is very important because it was obtained when the tuning of the control pressure may be still improved. A second set of data, shown in Table 2 as second rows, was obtained with a better-tuned pressure controller and operating with three injection nozzles. The aim of this experience was to evaluate the tonnage variance reduction, because smaller tonnage variability means either larger weight set points or better pump operating condition, reducing the failure frequency.

Table 2. Statistics for two control systems

Variable	Under flow control		Under pressure control	
	Average	Variance	Average	Variance
Tonnage (TPH)	75.2 73.6	25.6 85.9	81.7 75.3	23.8 32.4
Pressure (KPa)	269 252	102 501	266 257	76 88
Current (A)	151 104	305 136	159 103	487 95

3.4 Changes in layout

Encouraged for the previous better results, operating with lower air flow rates and tighter pressure control, a study to find out the range of operation for the air flow rate considering the pump system, the pneumatic transport from the pump to the CT, and the injection nozzles, was performed. The airflow demands were increasing from the pump to the CT, especially when the number of injection nozzles was three or four. Because the demand of concentrate is variable, to accommodate the operation synchronism between different furnaces and production programs, there is not a unique specification of ducts and fittings to solve the overall problem. In other words, to achieve more than one operating objective more than one resource must be available. Considering that the lower demand for air flow is in the pump, a change in layout has been proposed as the one displayed in Figure 7, where a by pass with a different control scheme are included.

A fraction of the total air is passing through the pump and taking the concentrate to the pneumatic conveyor. The rest of the air is conducted through the by pass. The sum of these two airflow rates is used for the pneumatic transport of the concentrate and to feed the injection nozzles in operation. The total airflow is only a function of the number of nozzles in operation, while the fraction passing through the pump is the result of maintaining a difference in pressure across the pump. This pressure difference is calculated considering several inputs, among them the actual tonnage. The total airflow is controlled using the control valve located at the by pass.

Some test using this approach has shown that the injection system operation has been improved, allowing the deliver of larger tonnage with lesser variability than before. As consequence the failure frequency of pump pressurization is considerable lower than before (Bergh, 2001b).

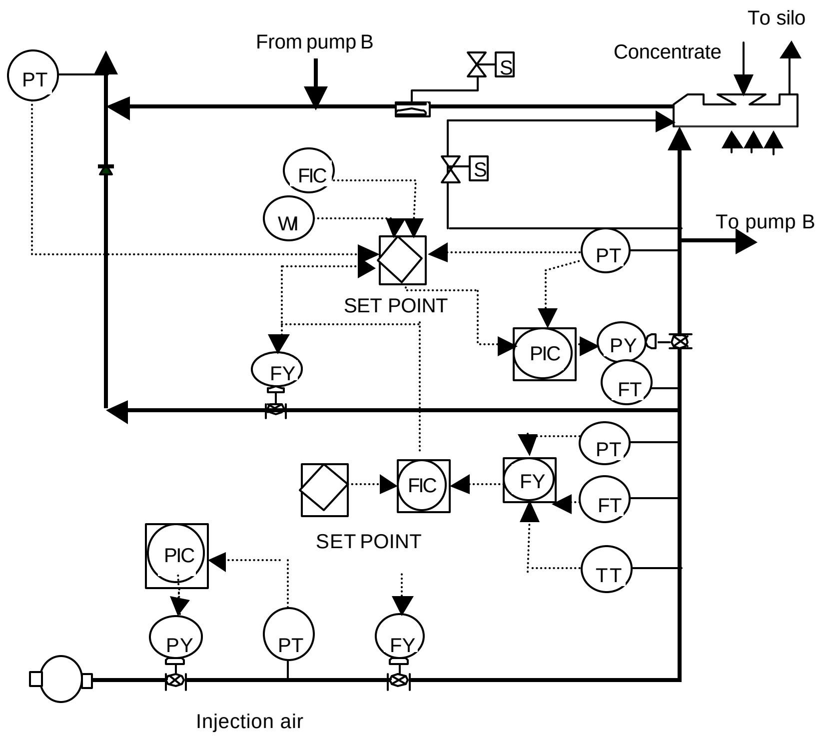

Fig. 7. Proposed new layout and control system

4. CONCLUSIONS

During the first part of this study the following conclusions can be arised:

- The injection air layout and control system have to be modified, introducing a by pass of the air around the pump and a new control philosophy
- A complete study of the concentrate characteristic has to be made to improve the design of the silo and the fluidization system
- The encripted control system should be opened, leading to an expert-type system and more on-line support should be provided to operators

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