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pH advanced process control solution for Impala BMR first stage high pressure acid-oxygen leach

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Synopsis

The CSense advanced process control (APC) solution's main objective was to improve the stability of the pH in the first stage leach process thereby improving nickel and iron extraction efficiencies and reducing the base metal (BM) content in the platinum group metals (PGM) concentrate. By improving the stability of the control of the pH on the first stage leach it had the corresponding effect of improving the Ni extraction efficiency by 0.5% and the Fe extraction efficiency by 3.3%. The system relieved the operators of many decisions that were virtually impossible to make given the complex, variable and real-time nature of the processes in their charge. On the operational side, the operators understand the APC system and they trust it. Another benefit is the reduction in pH peaks in the autoclave, which can oxidize certain elements whereby they become difficult, if not impossible, to leach. These elements go right through the process and end up contaminating the PGM solids, with the result that the entire batch has to be recycled through a lengthy and costly processing pipeline.

Introduction

Impala Platinum's Base Metals Refinery in Springs gets its raw material from the company's mining, concentrating, smelting and converting facilities in Rustenburg. The BMR then removes as much of the base metals as possible and sends the PGM (platinum group metals) concentrate to the PMR plant for further processing. The base metals are refined and sold separately to maximize the conversion of raw material into revenue (Figure 1).

A background to first stage leach

The aim of the first stage leach process is to maximize the dissolution of nickel, cobalt and impurities and to leave copper and PGMs in the solids for treatment in the second stage processes. The subsections that follow describe the first stage leach process together with process chemistry and the process challenges.

Process description

Figure 2 shows a flow diagram of the first stage leach process. The matte from the mineral processing plants is fed with demineralized water to the ball mill to increase the surface area of the particles for leaching. Tank TK2100 serves as a buffer tank for the milling operation and the feed tank to the first stage circuit. Pulp density is adjusted in tank TK2102 with spent electrolyte solution. The spent electrolyte solution is return solution from the copper electrowinning section.

The slurry from tank TK2102 is pumped to the first compartment of the autoclave. Currently two autoclaves operate in parallel. Steam is added to the first compartment to maintain the required temperature and oxygen is added to maintain pressure as well as to oxidize the sulphides to sulphates in the presence of sulphuric acid from the spent electrolyte. The spent electrolyte also serves to control pH in the autoclave.

The overall reaction mechanism could roughly be divided into three stages (as determined by batch leaching experiments by Rademan, 1995) where the major reactions occurring in each stage of the leaching process differ, i.e.:

- *Stage I* (10–40 minutes)—the cementation of copper and the leaching of nickel from the alloy phase and out of the Ni_3S_2 phase. Refer to reactions Equations [1]–[7] as determined by Rademan (1995) and Rademan, *et al.* (1999)

$$Ni + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Ni^{2+} + H_2O \quad [1]$$

$$Ni_3S_2 + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Ni^{2+} + 2NiS + H_2O \quad [2]$$

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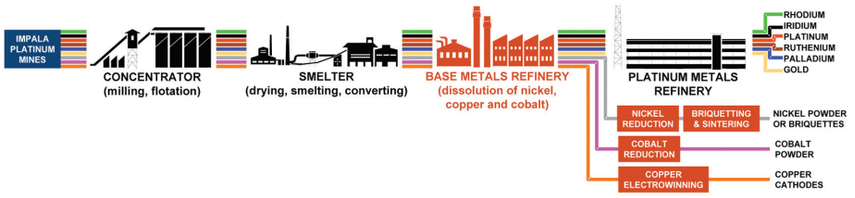

Figure 1—A simplified flow diagram of Impala's processes

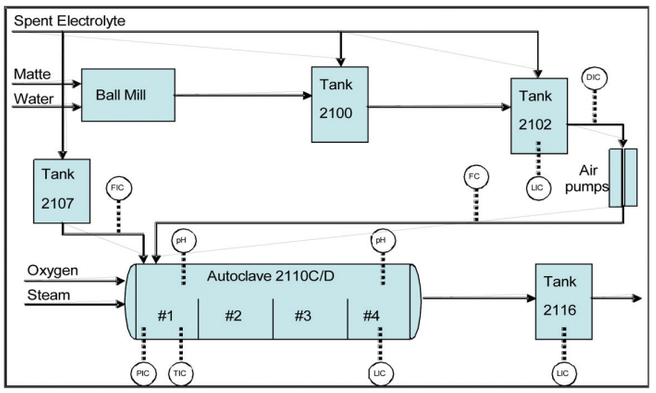

Figure 2—First stage leach process flow diagram

$$Ni + Ni_3S_2 + 4Cu^{2+} \rightarrow 4Ni^{2+} + 2Cu_2S \quad [3]$$

$$Ni_3S_2 + 2Cu^{2+} \rightarrow 2Ni^{2+} + NiS + Cu_2S \quad [4]$$

$$5Cu_2S + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Cu^{2+} + 5Cu_{1.8}S + H_2O \quad [5]$$

$$Ni_3S_2.FeS + 2H^+ + \tfrac{1}{2}O_2 \rightarrow 3NiS + Fe^{2+} + H_2O \quad [6]$$

$$Fe + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Fe^{2+} + H_2O \quad [7]$$

- *Stage II* (40–160 minutes)—the selective leaching of nickel to form various Ni-S mineral phases and the simultaneous leaching and cementation of copper to form the various Cu-S mineral phases. Refer to Equations [8]–[13] as determined by Rademan (1995) and Rademan, *et al.* (1999).

$$25Cu_{1.96}S + 8H^+ + 2O_2 \rightarrow 4Cu^{2+} + 25Cu_{1.8}S + 4H_2O \quad [8]$$

$$16Cu_2S + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Cu^{2+} + Cu_{31}S_{16} + H_2O \quad [9]$$

$$5Cu_{31}S_{16} + 22H^+ + 11\tfrac{1}{2}O_2 \rightarrow 11Cu^{2+} + 80Cu_{1.8}S + 11H_2O \quad [10]$$

$$3Ni_3S_2 + 4H^+ + O_2 \rightarrow 2Ni^{2+} + Ni_7S_6 + 2H_2O \quad [11]$$

$$Ni_7S_6 + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Ni^{2+} + 6NiS + H_2O \quad [12]$$

$$4NiS + 2H^+ + \tfrac{1}{2}O_2 \rightarrow Ni^{2+} + Ni_3S_4 + H_2O \quad [13]$$

- *Stage III* (160–300 minutes)—the simultaneous leaching of nickel (to form NiS and Ni_3S_4) and copper (to form and CuS). Refer to reactions Equations [14]–[18] as determined by Rademan (1995) and Rademan, *et al.* (1999).

$$5Cu_{1.8}S + 8H^+ + 2O_2 \rightarrow 4Cu^{2+} + 5CuS + 4H_2O \quad [14]$$

$$5Cu_{1.8}S + 8Fe^{3+} \rightarrow 4Cu^{2+} + 5CuS + 8Fe^{2+} \quad [15]$$

$$Ni_3S_4 + H_2O + 1\tfrac{1}{2}O_2 \rightarrow 3Ni^{2+} + 2H^+ + 4SO_4^{2-} \quad [16]$$

$$Ni_3S_4 + 3Cu^{2+} + H_2O + 3\tfrac{1}{2}O_2 \rightarrow 3Ni^{2+} + 3CuS + 2H^+ + 4SO_4^{2-} \quad [17]$$

CuS is oxidized by O_2 (Equation [18]) to form Cu^{2+} and SO_4^{2-}.

$$CuS + 2O_2 \rightarrow Cu^{2+} + SO_4^{2-} \quad [18]$$

The principal reactions occurring in the initial stages of the first stage leach are the reactions of nickel alloy (Ni) and heazlewoodite (Ni_3S_2) with sulphuric acid (H_2SO_4) and Cu^{2+} in solution in the presence of oxygen (O_2) to form copper sulphide and nickel sulphate.

For control purposes the process needs to be controlled as close to the end of Stage II as possible at all times.

Process challenges

The required iron (Fe), an impurity, in the matte is below 1%. However, matte batches delivered to the BMR sometimes have more than 1% Fe. The Fe needs to be leached in the first stage process and is then removed in the jarosite circuit. When this does not happen, the Fe finds its way to the PGM circuit where it is very difficult to leach out and therefore constrains the downstream processes.

The problem experienced in the first stage leach process is that the process controllers are not always able to cope efficiently with the apparently capricious behaviour of the process. This could be due to:

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- A lack of sufficient understanding of the critical control elements of the process
- Having to cope with plant emergencies and breakdowns and not being able to closely monitor the process (specifically pH), and
- The fact that they have, most of the time, two processes to monitor continuously, i.e. two autoclaves.

Most of the process controllers control the process by experience and feeling, which inherently means that different operators will control the process differently. Therefore, this causes an unstable process from the one shift to the next.

Nickel (Ni) in the matte is in the region of 47% and is primarily leached in the first stage process. Therefore it is crucial to have a high Fe and Ni extraction efficiency in the first stage leach process. It is known that pH in the region of 1.8 and 2.2 serves to offer good extraction efficiencies. pH was manually controlled by process operators with some shifts performing better than others. Considering the myriad reactions taking place in the first stage leach process as well as the other control variables, the challenge was to control pH within the specification limits in real time.

Samples are taken hourly from compartment nos. 1 and 4 of the autoclave for analysis of the metals content (Ni, Cu and Fe). pH samples are taken at shorter intervals to determine the pH of the pulp in these two compartments because it is the primary control variable. Depending on the pH, the operator will vary the spent electrolyte flow rate to the autoclave or adjust the pulp flow rate to the autoclave. In certain instances the operator will also increase the pulp density in the feed to try and make up for lost production to the detriment of the efficiency of the process.

The performance improvement design

A feasibility study was conducted to define the boundaries of the problem, assess current status and to present a solution design before starting with the implementation.

Feasibility study

The problem experienced in the first stage leach process is that the process controllers are not always able to cope efficiently with the apparently capricious behaviour of the process. To provide the context of the complex behaviour each parameter used as part of the solution and its effect on the process are briefly discussed below:

Process disturbance variables

- *Matte composition*—the variation in the composition (amounts of the different elements) in the feed matte will have an effect on the leaching process to a varying degree, depending on the actual increase or decrease of a specific element. For example, if the feed matte contains a higher concentration of iron (Fe) it will result in a higher concentration of iron, in either the leach discharge solution or in the solids (depending on the control efficiency of fist stage leach).
- *Spent electrolyte solution composition*—variations occur in the acid concentration of the spent electrolyte solution coming from the copper electrowinning section, as well as in the concentration of other ionic species (Ni, Cu, Fe, Co, etc.). The variation in the acid concentration will influence the rate of chemical reactions taking place in the autoclave. The variation in the ionic species will have the same effect on the leaching process as does the variation in the matte composition. Furthermore, it is possible that ammonium ions (NH_4^+) in the spent electrolyte solution will form jarosite precipitates under high pH conditions in the first stage leach, making it almost impossible to leach out in the latter stages of the process, and it will eventually result in high Fe in PGM (platinum group metals) concentrate product to PMR (platinum metals refinery).
- *Pulp feed rate*—the feed rate to the autoclave should be set at a setting that is believed to be the optimum for the maximum throughput while obtaining the desired degree of leaching. Currently the feed rate is sometimes varied by the operator, to help to get the pH within the required control range more quickly, but mostly when downstream bottleneck conditions occur.

Process state variables

- *Pulp density*—the pulp density is a very important factor in the reaction kinetics of the pulp, because for lower or higher pulp densities the leaching will either be more, or less efficient. More importantly, this will affect the pH in the autoclave. Ultimately the pulp density in the first compartment in the autoclave needs to be controlled. The design requirement was for a pulp density of minimum 1.35 kg/m^3 to a maximum of 1.50 kg/m^3 in the autoclave. A too high pulp density will result in high pH values and too low pulp density will result in too low pH values.
- *Cu in solution*—the Cu in leach solution is necessary for the cementation reaction with metallic Ni, but an oversupply of Cu in solution negatively affects downstream processes. The Cu in solution is primarily supplied via the spent electrolyte that can contain high concentrations of Cu.

Adjustable variable

- *Spent electrolyte flow rate*—the spent electrolyte flow rate to the autoclave is the primary variable to control the pulp density and indirectly the pH in the autoclave. The spent electrolyte flow rate is also adjusted by the operator to achieve the desired pH in the first compartment of the autoclave that ultimately influences the performance of the process.

Target variable

pH in 1st compartment of autoclave—the pH in the first compartment of the autoclave is controlled by the addition of spent electrolyte solution to the autoclave. Furthermore, it is assumed that if the pH (and pulp density) in the first compartment is correct and the standard process conditions exist, the pH in the fourth compartment will be correct.

Therefore, the primary parameters, from the above list, that lead to variation of the pH in the first stage leach are:

- Pulp density
- Spent electrolyte flow rate to the autoclave
- Pulp feed rate to the autoclave.

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PID control loops

Proportional-integral-derivative (PID) control loops are single-input single-output controllers based on first order Laplace transform calculations. PID loops are the norm for forming the base layer control of any industrial plant. Therefore, it is important to ensure that PID control is used as far as possible, and that the current PID control is maintained properly.

Sampling and measurement

A key requirement for implementation of automated advanced process control (APC) solution is that the target measurement is available online and timeously. An online pH sampling system has been developed by Impala in house, as shown in Figure 3.

pH sampling sequence:

- Sample and the drain valves open for 3 seconds
- The drain valve closes but the sample valve remains open for a further 4 seconds
- Sample valve closes
- All valves remain close for 50 seconds giving the solution in the pot time to settle and the pH transmitter opportunity to read the sample value
- The reading from the transmitter is stored into the correct PLC address location for the time of sample taken. (Each time interval sample for the 10 minute sequence has its own address allocated and displayed on Scada)
- The drain and flush valves open simultaneously for 6 seconds, flushing out the sapling pot
- Drain valve closes but the flush valve remains open for another second before closing
- The pot should now be filled with water waiting for the next sample to be taken.

The sampler sequence is triggered from the PLC clock every 10 minutes, starting on the hour.

Performance benchmark

The average pH and standard deviation values for the autoclaves 2110C and 2110D are shown in Table I. The average pH in the first compartment of both autoclaves is acceptable, but the problem is rather the high standard deviations, i.e. > 1. The high standard deviations are also an indication of the reactive control that operators have to use to bring the pH back to the target value, which is roughly around 2.0. The average pH in the fourth compartment of autoclave 2110D poses a problem as this average of 3.4 is excessively high and will lead to insufficient leaching (Rademan, 2005). This 'unleached' material is then propagated through the circuit to the final PGM concentrate that is sent to the PMR.

Figure 4 is an indication of the distribution of the pH values in the first compartment of autoclave 2110C (top) and 2110D (bottom). The objective of the proposed pH control system would be to reduce the tailing of the pH to the high side (as marked on graph). The reduced variation in pH in the first compartment should lead to reduced pH variation in the fourth compartment. The pH in the fourth compartment of the autoclave is a direct result of the pH in the first compartment.

If one analyses the average pH values with the daily extraction efficiencies for Ni, Cu and Fe, certain trends can be recognized:

- The lower the average pH value the higher the Ni extraction
- A large difference between the pH average on the #1 and #4 compartments result in a low Fe extraction
- A low Fe extraction gives rise to a high Cu cementation rate (high negative value).

The lower the average pH value, the higher the Ni extraction. This confirm the findings by Rademan (1995) that for higher acid concentrations, the higher the Ni extraction.

Table I

pH averages and standard deviations for autoclave 2110C and 2110D

	2210C	2210D
Average pH #1	2.2	2.4
Standard deviation pH #1	1.16	1.23
Average pH #4	2.3	3.4
Standard deviation pH #4	0.82	1.49

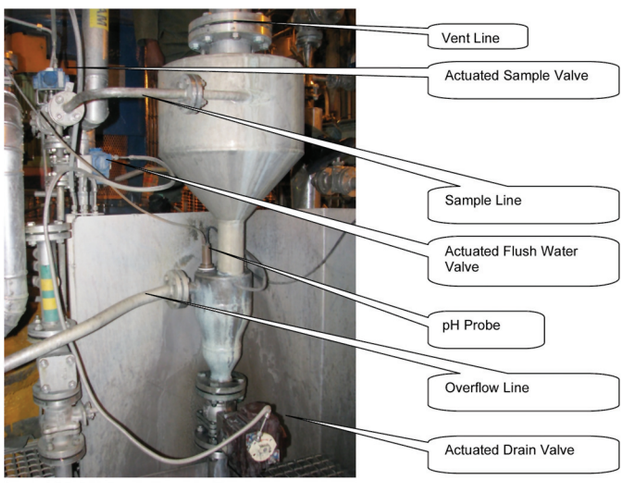

Figure 3—Picture of actual pH sample pot arrangement on the autoclave

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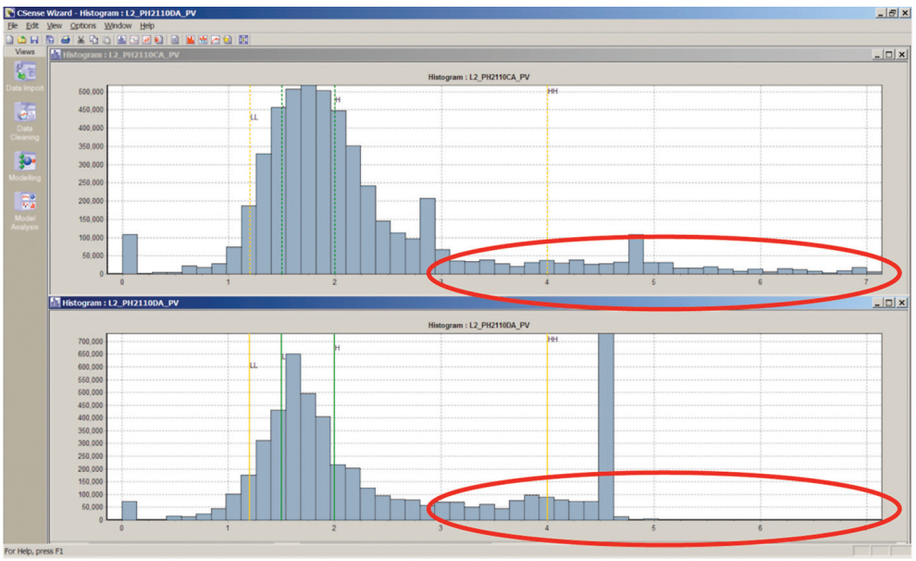

Figure 4—pH in #1 distribution histogram for autoclaves 2110C and 2110D

Therefore, Ni extraction is purely a function of acid concentration or pH. A negative outcome of too high acid concentration is that Cu might start leaching, i.e. the kinetics for Cu extraction will increase.

A large difference between the pH average on the #1 and #4 compartments result in a low Fe extraction. This is an effect caused by unstable pHs were the operator has to decrease the pH in the first compartment significantly to quickly get the pH in the fourth compartment under control. This leads to an excessive amount of spent electrolyte being added in the first compartment, where the Cu in solution has to be cemented first before any significant Fe leaching can occur. The end result is that only Cu cementation occurs with the associated Ni leaching, but not much Fe is leached in the process. This then results in the phenomenon where a low Fe extraction gives rise to a high Cu cementation rate (high negative value).

The objective is to improve the pH control on the first stage leach process. The first step is to stabilize the control as far as possible by trying to avoid significant pH variations. The second step is to optimize the process to increase throughput and improve quality.

Control philosophy

Based on the results and discussions above, a practical and low risk control solution can be developed. However, in certain areas it will also require a change in the current operating philosophy. In principle the philosophy is to automatically manipulate the spent electrolyte flow rate via the controller, leaving the pulp feed rate to the autoclave as a variable that the process controller can adjust.

The proposed control philosophy is to vary as few parameters as practically possible.

- The temperature and pressure in the autoclave should be set to 145°C and 450 kPa, respectively, and should not be changed
- The pulp density in tank 2102 should be kept constant as far as possible
- For increasing or slowing down production, the pulp feed rate to the autoclave should be adjusted
- The spent electrolyte flow rate should be used as the parameter for primarily controlling the pH in the autoclave.

In summary, change the feed rate setpoint for increasing or slowing down production and change spent electrolyte flow rate to control the pH. By varying any of the parameters unnecessarily it becomes exponentially more difficult for the process controller to maintain a constant pH in the first stage leach process.

The controller will be able to adapt for variations in the pulp feed rate to the autoclave. The controller will also be able to adapt for any change in the variables mentioned above, but it will result in less stable pH control. The control philosophy for the advanced controller is schematically shown in Figure 5. The controller will consist of two components, i.e. a feedback control component and a feed forward control component.

The feedback control component will make use of the latest available pH measurement and implement set point changes on the spent electrolyte flow rate through a fuzzy controller. The feed forward control component will calculate the required amount of spent electrolyte given the current pulp density in tank 2102 and the pulp feed rate to the autoclave. A rule based method will be followed to combine the feed forward and feedback suggested changes to the spent electrolyte flow rate to achieve optimal pH control in the first compartment of the autoclave.

Controller design and simulation

Process and instrumentation data were collected from the plant historian. The data were analysed to establish the following:

- Scope and opportunities for process control and automation improvements

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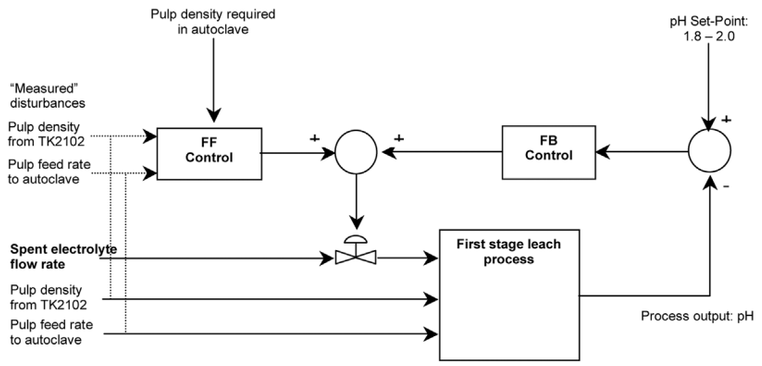

Figure 5—Proposed advanced pH process control solution for the first stage leach process

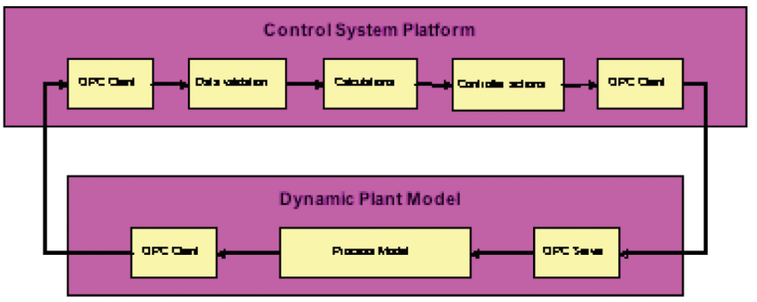

Figure 6—CSense simulation—structure layout

- Base layer control stability
- Equipment health and constraints
- Control element operating range
- Current operating and control philosophy
- Sufficient step test data to perform system identification.

Plant data analysis revealed that there was a real need for higher level automation of the autoclave since regular operator action was required to maintain plant stability. Due to regular process step changes by the operators, sufficient step test data were available to perform system identification. System identification was performed (Ogunnaike and Ray, 1994; Seborg *et al*. 1989) and dynamic process models for the process were obtained. This was used to construct a simulation of the process that in turn was used for control system design (Ogunnaike and Ray, 1994; Juuso, 2007).

The initial modelling and control system design was done in Matlab after which it was migrated to the implementation platform, CSense, where further simulation testing was performed before commissioning of the control system. Figure 6 shows the simulation configuration that was used in CSense. Commissioning of the control system was rapid since control system architecture and controller parameter optimization was done upfront.

Figure 7 describes the relationship between the pH setpoint, feed flow rate and copper concentration. For higher copper concentrations a higher pH is preferred with a maximum pH of 2.5. pH setpoint is adjusted based on autoclave throughput and discharge copper content according to Figure 7. Figure 7 was formalized based on operator experience.

The control system consists of the following elements:

- Feed forward control on spent electrolyte proportional to the autoclave feed rate
- Fuzzy controller feedback control (Reznik, *et al*. 2000) on the pH measurement by manipulating spent electrolyte flow rate
- Feed forward and feedback controller speed adjustment based on the spent electrolyte acid concentration
- pH setpoint selection based on feed rate and Cu concentration
- Logic for that caters for exception process conditions.

SCADA interface

The SCADA pages were modified to give the process controller feedback from the APC. The buttons on the top right-hand corner of the page indicate the status of the controller. From the first stage summary page one can navigate to the APC page by clicking on the header text for pH values.

Figure 8 shows the first stage summary page from which the APC pages can be accessed.

Figure 9 is an illustration of the SCADA mimics that the operator can view the samples, stop and start the pH controller and do some basic troubleshooting. On the APC page the various parameters used by the APC can be viewed. The pH values obtained for the previous hour can also be seen.

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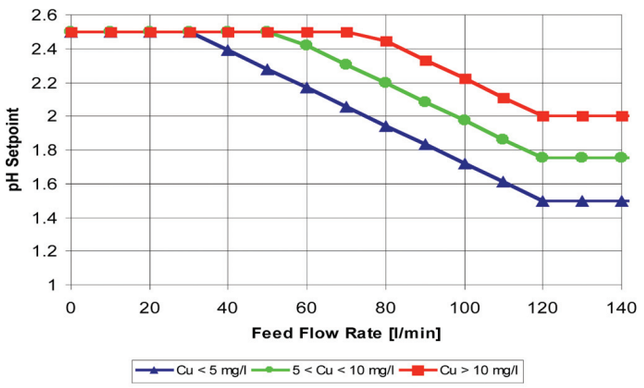
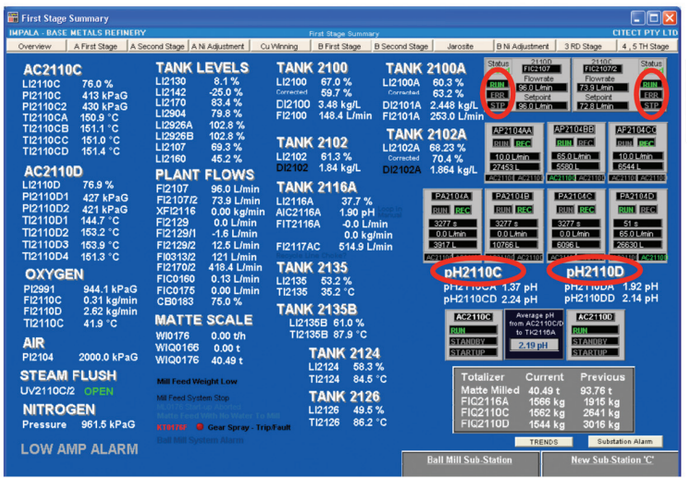


Figure 7—pH setpoint as function of feed flow rate and Cu concentration in first compartment



Communication status of the APC

Short cut to the APC page

Figure 8—First stage summary page on SCADA

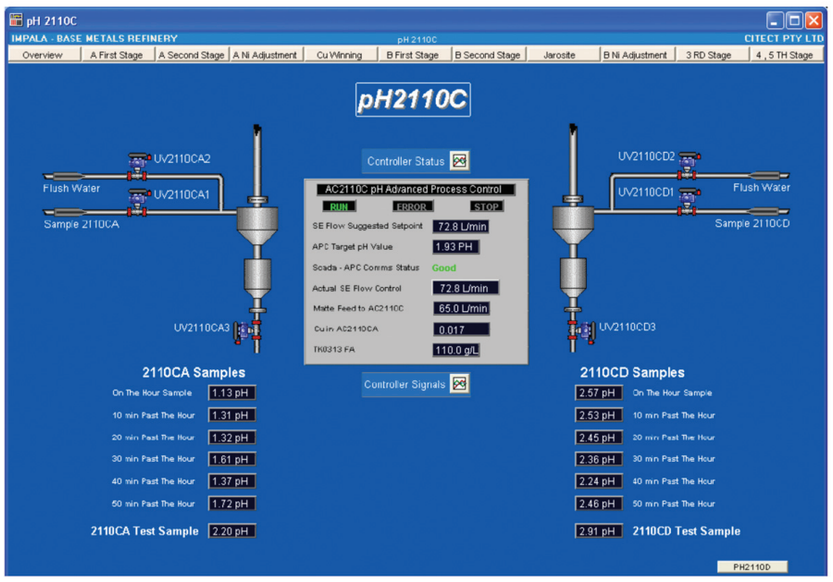


Figure 9—SCADA mimic of pH sampler and advanced process control (APC) solution

Commissioning of the APC began in mid-August and lasted four days. This reduced commissioning period was achieved through good simulation and presentation exercises. The commissioning did not interrupt the daily operation of the process. Minor changes were required for better performance of the control system. A value for the concentration of acid in the spent electrolyte (SE) was added as the concentration of the acid in the SE affects the leaching kinetics.

On these mimics a suggested setpoint value, target pH value, APC communications status, spent control faceplate, matte feed value and Cu value can be obtained.

- *SE flow suggested setpoint*—this setpoint value is fed back from the advanced controller and will replace the setpoint of the spent flow control should the APC controller be turned on. The value is determined by calculation in the APC controller
- APC target pH value—this value is determined by the APC controller taking into account the feed rate of matte into the autoclave and also the Cu value of solution in first compartment of the autoclave
- *SCADA-APC communications status*—this is also called the heartbeat of the APC controller. Should communication be lost between APC controller and the plant PLC, this status will indicate an error. If this error or error indication between RUN/STP buttons (Bad Data) activates, the controller will automatically be turned off and an audible alarm will activate to inform the process controller of this action. When this happens, the last known setpoint will remain active in normal auto mode and can be changed by the process controller if required
- *Actual SE flow control*—this is the loop faceplate to control the flow rate of spent into the autoclave. The setpoint will automatically be adjusted if the APC controller is turned on. The setpoint will then be the same as the suggested setpoint value from the APC controller. The process controller must enter the setpoint value for flow when the APC controller is turned off
- *Matte feed to autoclave*—this value is the total matte feed to the autoclave from the air pump feed settings
- *Cu value in first compartment*—this value represents the Cu as sampled in the first compartment of the autoclave. The value must be entered by the process controller to adjust spent setpoint accordingly. This value is used in the calculation of pH setpoint and needs to be updated when significant changes occur in copper values
- *TK0313 FA*—this value gives spent electrolyte acid concentration. It is to increase or decrease the response speed of the APC feedback controller. When spent acid concentration is high, the APC controller is slowed down and vice a versa
- *Trends*—trends are also added to view historical data of APC controller outputs. These trends can be viewed by selecting the pop-up trend buttons located on the mimic.

Controller limitations are its dependency on accurate measurements and on the operator to enter Cu assays as they become available.

Server infrastructure layout and OPC connection

A server is located in the process control server room and connected on the process control network is used as the CSense server. It communicates with the Citect SCADA servers via OPC to allow control via SCADA mimics (see Figure 10).

The server is supported by a Dell maintenance agreement providing 4 hours' turnaround time and a cold desktop standby is available in the event of failure. A backup copy of the control blue print is made every time an audit is conducted on the system. Although the CSense APC server has not failed since installation two years ago, Impala BMR is considering a hot server standby as more advanced process controllers are being installed in the plant to control critical process parameters.

Project management

The project was managed using the guidelines of the project management body of knowledge (PMBOK) by the PMI (Project Management Institute) and managed by a PMP (project management professional). A well developed capital application backed by a good feasibility study, choosing the best project team, having regular project meetings, managing change as the project progressed, involving stakeholders, good communication, and rewarding team efforts contributed towards a successful project that was completed on time and within budget.

Informal hands on training were provided for the first stage process operators and the supervisor during the commissioning period. The functioning and the operation of the APC were explained. Formal training was provided on CSense Architect for engineers and instrumentation technicians. Work procedures have been developed for the use of the advanced controller via the Citect SCADA. The work procedures are a quality document and registered on the SAP system. The work procedure is used by operational personnel in conjunction with the leach domain operational work procedures.

All stakeholders were involved in the project from the onset. The presence of a control engineer on site during the commissioning period also helped with change management. The success of the implementation of the controller could be seen immediately with improved pH values.

The plant manager—leach as well as the leach supervisor were kept fully abreast of the progress of the project and also participated in project progress meetings. Buy-in from the leach supervisor was instrumental in getting the process

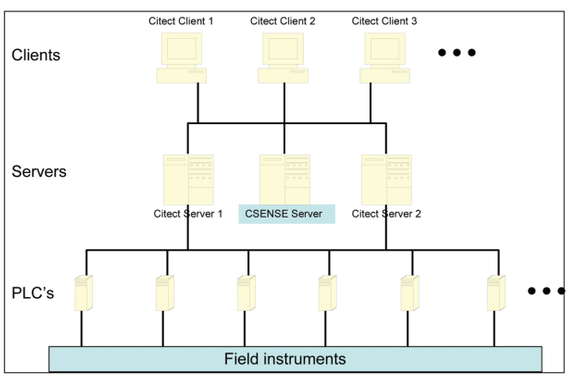


Figure 10—Typical control infrastructure for leaches domain

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controllers to accept the new controller. The immediate improvements in the pH values in both first stage autoclaves resulted in happy customers. The extent of the satisfaction of the end user is remarkable as they would not allow for the controller to be switched off when a request was made to conduct a before/after analysis.

Performance results

Data gathered during the scope study (termed 'old data') were used to compare with data obtained after controller implementation. The analysis focused on proving the following:

- Better pH values
- Improvement in Ni and Fe extraction efficiency
- Reduction of base metal (BM) content in the PGM concentrate.

The control solution's main objective was to improve the stability of the pH in the first stage leach process thereby improving nickel and iron extraction efficiencies and reducing the base metal (BM) content in the PGM concentrate.

All data refer to corresponding periods in October-November 2005 and October–November 2006. The standard deviation for pH decreased from 1.16 to 0.82 and 1.23 to 0.74 in Autoclaves AC2110C and AC2110D respectively. By improving the stability of the control of the pH on the first stage leach it had the corresponding effect of improving the Ni extraction efficiency by 0.5% and the Fe extraction efficiency by 3.3%, as shown in Table II (Rademan, 2007).

The BM content in the PGM concentrate was lower for the period examined. Nickel in the concentrate was reduced from 1.93% to 1.46% and iron from 5.58% to 3.75%. The standard deviation for BM in the PGM concentrate was lower for the period. A net improvement of 1.4% in the total PGM concentrate despatched to the PMR was achieved by better control of the pH in the first stage leach autoclaves.

These results indicate conclusively that the CSense pH controllers have improved the operation of the first stage leach significantly.

Controller performance monitoring

For support and ongoing monitoring an e-mailed report using the CSense platform is made available to key stakeholders of the first stage process. The report is emailed at 03:00 every morning and provides the graphical performance of the pH control on both first stage autoclaves for the previous day's 24 hours. The report offers assistance with detection of deviations and observance of good performance. Figure 11 shows an example of the daily report.

Real-time monitoring of the controller performance is done via SCADA.

The haphazard adjustment of spent electrolyte flow rate has been reduced. In the past, process controllers used to change the pH setpoint every 20 minutes, provided that they were present in the control room. Now, the pH setpoint is changed automatically, every 10 minutes, by the APC. Figure 12 shows an impressive trend of the pH in autoclave AC2110D. The green line represents the pH in the first compartment and the red line is the pH setpoint. The yellow line represents the pH in the fourth compartment. The blue line displays the changes made on the spent electrolyte flow rate.

Change management

The manner in which the project was implemented enhanced personnel confidence in the control system. A control engineer spent time on site, not only to gain an understanding of the process but also to explain the new control system to those who were directly involved. Any questions or uncertainty experienced by the operators were quickly resolved.

Before the controller was implemented, a setpoint for the spent electrolyte flow was suggested to the process controller. The process controller then manually adjusted the spent electrolyte flow. In this manner the process controller could assess the performance of the APC and also indicate it was

Table II

Extraction efficiencies for Ni and Fe in corresponding periods in 2005 and 2006

Extraction efficiency	2005		2006	
	Average	Std deviation	Average	Std deviation
Ni	91.2%	1.70	91.7%	1.35
Fe	85.2%	5.69	88.5%	6.97

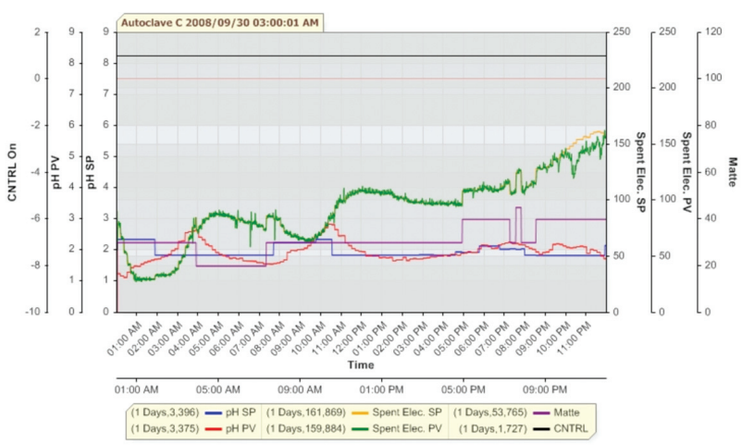

Figure 11—Daily controller performance report

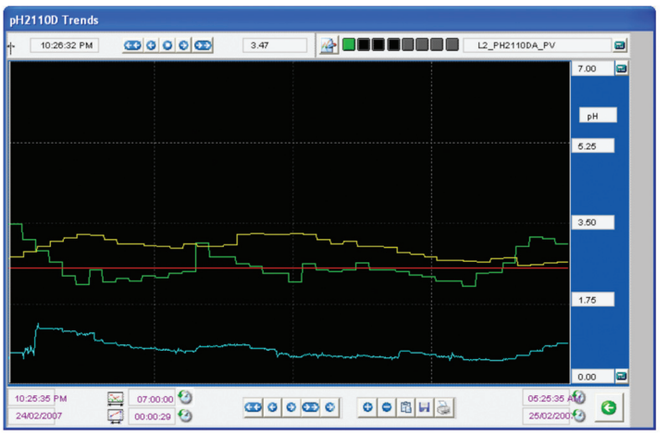

Figure 12—pH and spent electrolyte SCADA trend

achieving the correct result. On the success of this process the APC then assumed automatic control of the spent electrolyte flow rate.

The leach process supervisor and the first stage process controllers have verbally expressed confidence in the system. The project was also primarily motivated on the basis of improving the PGM concentrate quality and this was achieved, making the project a resounding success.

'For me, the CSense-based APC is like an extra process controller on that section of the plant. Previously, if a process controller was to leave the plant for any reason, there was no one left to control the pH. Today the APC takes care of that. From a manual system, this has evolved to a system where pH samples are evaluated in real time (instead of through a lab) and you can see the result of these evaluations changing the process as it happens.' Arnoldus (Vossie) Vosloo, Leach Plant Supervisor, Impala Base Metals Refineries (Khan, *et al.* 2008).

Conclusion

The system relieved the operators of many decisions that were virtually impossible to make given the complex, variable and real-time nature of the processes in their charge. On the operational side, the operators understand the process and the APC system. pH is the control parameter and the CSense-based APC currently in use has resulted in operators trusting it and using it to their advantage. Another benefit is that the system allows the operator time to look after the multitude of critical process variables and equipment.

Realized benefits:

- Through less iron and nickel content, the PGM concentrate grade is much improved
- From the performance analysis:
  - The pH variation has been reduced from 1.2 to 0.7 (an improvement of 40% in pH stability)
  - The nickel extraction efficiency has increased by 0.5%
  - The iron extraction efficiency has increased by 3.3%
  - The PGM grade has increased by 1.4%

These numbers may seem small, but they are extremely significant to the financial benefit of all our refining processes.

Other benefits include:

- A reduction in pH peaks in the autoclave, which can oxidize certain elements whereby they become difficult, if not impossible, to leach. These elements go right through the process and end up contaminating the PGM solids, with the result that the entire batch has to be recycled through a lengthy and costly processing pipeline
- Acceptance of the system by operating staff who now also trust it to do the right thing
- Stable process control in spite of variations caused by disturbance variables
- Indirectly limiting environmental emissions
- Real savings affecting Impala's business bottom line.

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