RAPID REDESIGN AND RESTART OF THE VALE ONÇA PUMA NICKEL SMELTER

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ABSTRACT

Approximately 13 months into a challenging plant ramp-up, a series of furnace failures halted production at Vale's Onça-Puma ferronickel smelter in Pará State, Brazil. Rather than re-build the equipment 'in-kind' with the original furnace supplier, Vale chose to adopt a strategy of technologically upgrading the problem areas in the smelter. Significant step-change improvement was thereby achieved in furnace integrity (structural binding and cooling systems), slag tapping and the calcine transfer systems.

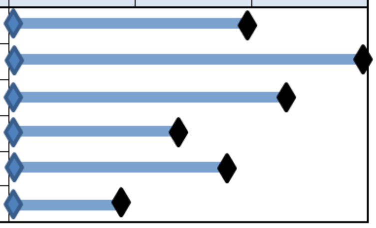
An integrated Vale-Hatch project team was established to execute the Furnace No. 1, Calcine Transfer System and Metal and Slag Tapping area upgrades, which were achieved in less than 1 year from start of detailed engineering to first slag tap. Key 'lessons-learned' from the original operating period were combined with design 'best practices' in order to address the main problem areas of the plant. During the project the close cooperation between Vale and Hatch, including rapid engineering development and timely decision making, led to a highly robust and well integrated design that enabled rapid project execution. As a result, the No. 1 Line was able to achieve >100% of its nominal capacity within 12 months of the first metal tap. Further, with the planned restart of the second kiln and electrical system upgrades, the Onça-Puma furnace will be capable of sustained operation above 100 MW. Key problem areas addressed by the rebuild project and the corresponding technical improvements are summarized in this paper.

1. INTRODUCTION

Vale's Onça Puma facility is a 2-line RKEF plant with nominal capacity of 50ktpy of Ni in FeNi which was started up in 2011. Approximately 13months into a challenging plant ramp-up, a series of furnace failures totally halted production at the smelter. Subsequent investigations uncovered significant issues in the installed equipment, particularly in the furnace, crucible, calcine transfer system, and the slag handling system. Thus, rather than re-build the equipment 'in-kind' with the original supplier, and risk a similar outcome, Vale chose to adopt a strategy of utilizing a suite of Hatch technologies to upgrade the problem areas in the smelter before re-starting. Significant step-change improvement was thereby achieved in furnace integrity (structural binding and cooling systems), slag handling and calcine transfer systems.

An integrated Vale-Hatch project team was established to execute the Furnace No. 1, Calcine Transfer System and Metal and Slag Tapping area upgrades, which were achieved in less than 1 year from start of detailed engineering to first metal tap. Figure 1 demonstrates the remarkable project turnaround time that could only be accomplished through close cooperation between Vale and Hatch.

Recent FeNi Furnace Installations			Tonnes Installed			Schedule Duration - Years		
Startup	Furnace Location	Size	Steel	Refractory	Coolers	Year 1	Year 2	Year 3
2008	Korea	350 m^2	450	2700	125			
2010	Onca Puma Original	400 m^2	1200	2900	50			
2010	Colombia	350 m^2	450	2700	80			
2011	Ukraine	240 m^2	1000	1650	65			
2013	Guatemala	225 m^2	350	1600	120			
2013	Onca Puma Rebuild	400 m^2	1200	2900	270			



Contract Award
First Metal
Greenfield
Brownfield

Figure 1: FeNi Furnace Construction - Onça Puma Versus Others

Key ‘lessons-learned’ from the original operating period were combined with Hatch best practices and technologies in order to address the main problem areas of the plant. During the project, the close cooperation between Vale and Hatch, including rapid engineering development and timely decision-making, led to a highly robust and well integrated design that enabled rapid project execution. As a result, the No. 1 Line was able to achieve >100% of its nominal capacity within 12 months of the first metal tap. Other installations in Brazil, which have suffered similar circumstances with the original suppliers’ equipment, are presently undergoing similar upgrades with Hatch and which will produce similar excellent results.

Further, Onça Puma is in the planning stages to restart the second kiln and CTS, after which the furnace will be capable of more than 100 MW sustained operation. Key problem areas addressed by the rebuild project and the corresponding technical improvements are summarized in this paper.

2. FURNACE

Both furnaces at Onça Puma suffered catastrophic failures at 6 months and 13 months into their initial campaigns. The furnaces were started up approximately six months apart from each other, so the failures occurred at roughly the same time 13 months into the plant start up. These failures resulted in total furnace run-outs and ultimately halted production entirely at the plant.

Upon detailed review by Vale, Hatch and others, it was determined that the furnaces failed due to a) significant design/installation issues and b) thermal cycling caused by equipment in other areas (e.g. calcine transfer) causing regular and lengthy stoppages.

The identified issues, and their solutions, are summarized in the following table. Each area is further detailed below.

Table 1: Identified Issues at Onça Puma

Area	Problem	Improvement
Hearth / Refractory	• Hydration due to: • Water-bearing castables used in curvature ram • Falling film cooling along with water infiltration points (instruments, etc.) • Minimal frozen build-up	• No use of water-bearing castables in the hearth • Weep holes for moisture escape • No falling film water cooling – replaced by air cooling • Hearth conductivity increased creating a thick protective frozen heal
Tapblock	• Differential movement between refractory wall and taphole bricks opening leak paths	• Tapping block that is allowed to move with the refractory wall but resists axial forces such as mudgun/drill loads
Cooling Systems	• Shallow copper coolers	• Deep cooled thicker plate coolers in high heat flux zone. • Re-use of shallow cooled thin copper coolers (original supplier) in low heat flux zones to optimize project costs
Bindings	• Binding system which allowed bath infiltration between hearth bricks	Binding system upgrades: • Spring loaded sidewall waler beams • Upgraded endwall binding loads • Upgraded sidewall hold down load • Addition of endwall hold down springs • Addition of corner springs

3. COOLING SYSTEMS

3.1 Copper Coolers

With both furnaces at Onça Puma damaged and inoperable it was imperative to reduce the overall design and fabrication time in order to return the furnace to operation as quickly as possible. As fabrication of a complete set of new deep cooled plate coolers would have extended the overall rebuild project, a design was developed which uniquely utilized a combination of new and existing coolers. This combination was employed to increase slag bath depth (from 400mm to 1000mm) as well as minimize construction time by re-using the original coolers in less intense areas of the furnace.

The existing coolers from both furnaces were carefully removed and inspected for reuse. One third of the coolers were found to have excessive corrosion, pitting, flaking of the chrome coating, and penciling which ruled them as unsalvageable, as shown in Figure 2. The poor condition of many of the coolers was unexpected due to their short operation duration. The reduced number of acceptable coolers required the cooler layout, and in turn the associated shell panels, to be quickly redesigned. The final design utilized new Hatch plate coolers in the high heat flux metal zone and a combination of new and reused coolers in the lower duty reserve slag capacity area.

Figure 2: Damaged Coolers Removed from the Furnaces (Original Design by Others)

3.2 Film Cooled Sidewall Plates

The existing sidewall utilized a water film cooled lower shell plate to prevent overheating of the furnace shell steel. Water was sprayed onto the lower shell allowing a thin film of water to cascade down the shell collecting in a large trough at the base of the shell. Water is one of the most significant risks in the vicinity of a metallurgical furnace. If water is able to enter the furnace, it can lead to total degradation of the furnace refractory through hydration. Additionally, if water comes into contact with the molten bath, a steam explosion can occur. Both scenarios have previously led to catastrophic furnace failures at other facilities.

The existing shell design contained numerous paste injection ports, thermocouples, and skew measurements points which amounted to approximately 130 locations where water could enter the furnace, and when used in combination with falling film technology, there is a possibility where only one is required to ruin the furnace. Visible signs of hydration were found during the demolition of both furnaces at Onça Puma.

The furnace shell was redesigned with an integrated air cooled cooper fin system on the lower shell around the full perimeter of the furnace. The forced air cooling system is able to maintain the shell well below the design temperature while greatly reducing the chance of refractory hydration or steam explosion.

3.3 Metal Tapblock Design

The original furnace design locked the metal tapblock to the fixed shell while allowing the refractory within the tapblock to expand and contract both laterally and vertically with the wall refractory. The differential movement between the copper cooled block and the refractory opened up gaps within the refractory and provided a leak path for the bath which the furnaces at Onça Puma, and others of near identical design.

The new Hatch tapblocks were redesigned to float with the refractory to ensure uniform movement between the refractory and the block, thereby removing any risk of differential brick movement leak paths.

4. HEARTH DESIGN

The previous design was only able to maintain a thin frozen heal at the center of the furnace. A large frozen heal is advantageous as it forms a protective barrier between the liquid bath and the hearth refractory reducing the likelihood of bath infiltration and ratcheting.

Hatch and Vale decided to decrease the infill thickness to create a more conductive hearth. The revised hearth is able to maintain a frozen heal which is well over three times the thickness at the center of the furnace and extends outwards protecting the entire hearth to the walls.

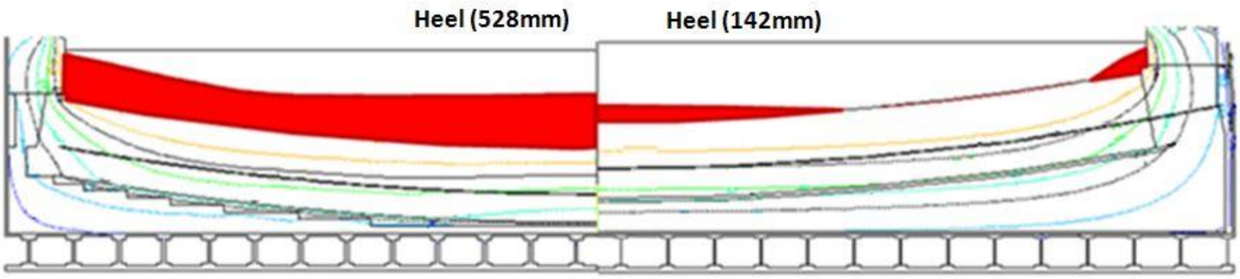


Figure 3: Thermal Comparison of Hearth Designs – Hatch/Vale (Left) and Other's (Right)

5. BINDING SYSTEM

A successful furnace binding system provides a compressive force in all three dimensions in order to maintain tight brick joints, minimize bath infiltration, and greatly reduce the likelihood of leaks. The binding system is particularly important during a cool-down phase when the refractory is cooling, and therefore contracting, thereby opening up gaps between the bricks.

The original furnace design utilized a combination of a fixed frame design in the transverse direction and a more conventional sprung bound system in the longitudinal direction. A fixed frame design has the same limitations as a traditional round furnace; the system is unable to maintain tight brick joints during a cooling phase. The longitudinal binding system was not capable of maintaining brick joint tightness during cooldown which led to bath infiltration between the refractory bricks. The result was a highly infiltrated hearth as shown in Figure 4.

Figure 4: Onça Puma Hearth During Demolition

The redesigned binding frame was on the rebuilt project critical path and therefore it was imperative to maintain as much of the fixed frame as possible to minimize the fabrication and construction time and ultimately bring the furnace back to operation faster. The innovative sidewall binding system developed required rapid basic engineering with constant input from Vale in order to maintain the fast tracked engineering program.

To be able to preserve the existing fixed frame, the shell plates were replaced allowing for a gap between the furnace and the fixed frame to permit the furnace to properly expand and contract as the furnace is heated and cooled. A novel system of waler beams with internal spring sets were installed between the sidewall fixed frames to load the hearth with a known load during all phases of furnace operations, including heat-up, cool-down, and steady state operations. The waler beams more evenly distributed the load along the length of the furnace sidewall to further maintain tight brick joints at all locations within the furnace hearth.

The entire endwall binding system was replaced. The longitudinal binding load was increased by over three times from the original load in order to provide the necessary forces to maintain bath containment integrity.

Further improvements, such as the inclusion of corner springs and increased capacity of the hold-down system, were combined to make a much tighter furnace and greatly reduce the chance of bath leaks, ratcheting, or a run-out.

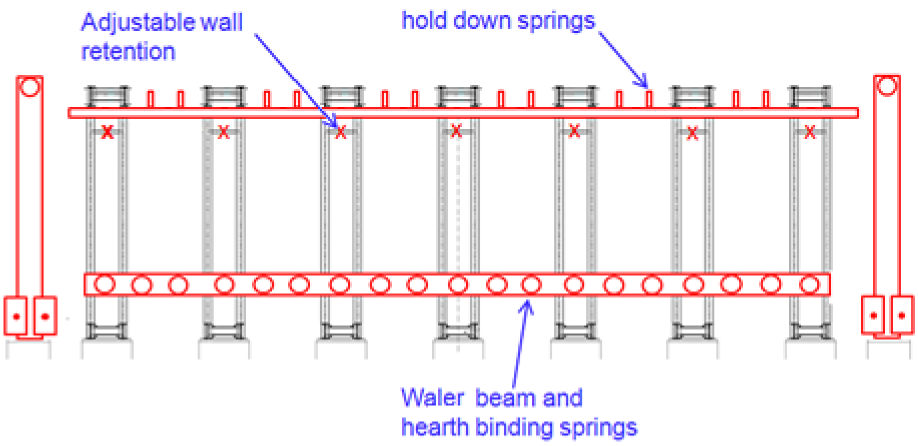


Figure 5: Upgraded Binding Design

6. CALCINE TRANSFER SYSTEM

6.1 Background

During the earlier furnace campaign, problems in the Calcine Transfer System (CTS) resulted in frequent stoppages of the RKEF lines, resulting in lost production and reduced process stability. When taken together, problems in the CTS (including container filling, transfer cars and cranes) were the single largest contributor to lost nickel production (before the furnace run-outs). Further, the constant stop-start-stop nature of operation put stress on the kilns and furnaces.

As part of the Furnace Rebuild Project, a decision was made to implement a comprehensive solution involving the replacement of most of the calcine transfer system with proven heavy-duty equipment.

The changes to the system are documented below.

Table 2: Calcine Transfer System Changes

Area	Problem	Improvement
Container Filling	• Inconsistent container feed rate • Valve blockage and failures • Calcine discharge spills and container over-filling	• Improved silo geometry according to Jenike & Johansen design • Replacement of container filling valves and chutes (new swing valve by Hatch and new slide gate valves by Nicro)
Transfer Car and Containers	• Hot calcine (~1000°C) spills damaging electronic components of the transfer cars and power supply system • Calcine blocking rails due to rail location (at grade) • Poor positioning control at interfaces points • Poor stability of containers	• New transfer cars with robust components located strategically away from track. • Elevated rails for transfer car • Hardwired communication with plant control system via festoon • Improved positioning instruments and control system • Containers supported above their center of mass to improve stability. • New lighter Hatch containers with higher capacity (+20%).
Transfer Cranes	• Structural integrity concerns • Crane positioning and automation issues • Container guiding system issues – high friction and poor positioning accuracy • Brake alignment issues • Poor positioning due to excessive dust from calcine transport	• New heavy duty calcine transfer cranes with automation and positioning improvements • Multi-axis constrained guide system for higher accuracy positioning and increased reliability of vertical movements • New redundant motors and on-board equipment for improved operating factor

6.2 Container Filling

One of the first problems to be addressed with the original Onça-Puma CTS design was the unreliable filling of containers at the discharge of the Calcine Surge Bin due to the unpredictable flow from the bin as well as frequent valve problems/blockages. Improvements to this area included replacing the original flat-bottomed bin with a modified J&J mass-flow design, replacing the existing pendular-type valve with a robust valve custom-designed by Hatch, replacing the discharge chute with a more uniform cross-section for smoother calcine discharge flow, and installing a new independent hydraulic circuit for the Nicro valves so that they can close independently of the Hatch pendular valve in case of primary hydraulic failure. With these modifications, the calcine feed to containers became more predictable and downtime associated with blocked and failed valves was essentially eliminated.

6.3 Transfer Cars

Another key issue with the original Onça-Puma CTS was the transfer car arrangement. In the original design, the transfer cars were located on narrow gauge rails placed at grade running between the surge bin and the transfer crane hoist wells. While the rails at grade simplified access to the cars, it made them vulnerable to hot calcine spills (~1000°C) as well as inevitable slow leaks of material that would accumulate and block the tracks.

Although the surge bin and valve improvements discussed above would help to reduce the frequency of spills, it was recognized that calcine spills cannot be completely eliminated by valve improvements alone and that it was necessary to reduce the vulnerability of the system to the spills that could occur.

Hatch and Vale revised the arrangement such that the transfer car rail elevation was revised from grade to approximately 3m above grade on new reinforced concrete walls. Material from spills and leaks would now fall between the rails into a pit without blocking the tracks or damaging the car. Further, a new car design, to accommodate the rail relocation, had improved mechanical and electronic component locations (relocated away from areas vulnerable to spills) and improved container supports. The revised car was custom-designed by Hatch to fit the Onça-Puma plant layout. A new set of Hatch transfer containers were installed which provided a>20% increase in capacity, while staying within the original container envelope. The increased capacity combined with a lighter container design resulted in more operating flexibility and throughput for the CTS.

7. SLAG HANDLING

One of the most important features of FeNi furnaces is the ability to remove large volumes of slag generated in the process. About 90% of the material fed into the smelting furnace is removed as slag, thus a robust slag tapping system with high availability is key to successful operation. The Vale and Hatch teams recognized this fact and assembled a joint design team consisting of Hatch project team members along with Vale operations and maintenance staff to develop the improved design.

7.1 Background and Operational Issues

The original design of the Onça Puma furnaces included 6 slag tapholes along the west sidewall of the furnace. Slag generated in the furnace was tapped via one of the six tapholes into one of four possible slag pot locations for hauling to the slag dump. There were several issues related to the original slag launder configuration that led to operational and availability issues.

The location of the slag pots relative to the furnace required a relatively long flat launders to be installed. Additionally, the profile of the slag launders included a flat bottom with a poor cooling channel arrangement which resulted in increased contract between the cooled launder surface and the molten slag, and high adhesion of the slag in the bottom of the launder. When combined, these features resulted in significant build-up issues occurring requiring considerable operator intervention for cleaning.

The challenges faced by operators was worsen by the poor access provided along the entire length of the launders from the main slag tapping floor. The tip of the slag launders was located well below floor level resulting in very poor ergonomics for cleaning. A second floor level was available; however, insufficient clearance was provided to allow personnel to routinely work in the space for launder cleaning.

7.2 Operational Improvements

In order to provide more reliable and robust slag tapping systems, the following key improvements were made to the slag tapping area:

- Reduced launder length and steeper slope
- Improved launder profile including redesign of the cooling passage arrangement for more even cooling
- Reconfigured tapping floors for improved access

To reduce the launder length and increase the slope, the slag pot positions were changed and moved closer to the furnace. The number of tapholes was also reduced from 6 to 5 and reconfigured.

The launder profile was improved and a profile with a curved bottom and tapered sides implemented to minimize the wetted surface in contact with the molten slag flow. Implementation of these design changes has led to an observed reduction in formation of build-up on the launders. The build-up that does form, tends to be thinner and easier to break free of the launder surface when cleaning.

As a direct result of the design and operation improvements implemented, operators have reported that the launder cleaning operation now involves very little effort. This is proven by the time to clean the launders which is now less than 2 minutes which is reduced significantly from the cycle time of more than 60 minutes on the original furnace.

8. INTEGRATED FURNACE CONTROLS

8.1 Furnace Monitoring

Hatch has developed an integrated suite of controls to help the furnace operator maximize performance from a furnace.

A more detailed description of the controls functionality is provided in a paper by F. Stober et al. [1].

The integrated suite of controls has been further refined to improve the furnace operations with a focus on alarming and alarm management, specifically on the Furnace Monitoring Application which consisted of a large number of instruments (approx. 1000).

The furnace monitoring controls are designed such that summary alarms are provided to the operator. For example if the furnace roof is experiencing high temperatures, instead of 16 roof thermocouples exhibiting a high temperature alarm, a single alarm comment is provided indicating that the furnace roof is experiencing high temperatures. If the furnace operator wishes to analyze further, the HMI screens provide more detailed information to show the roof temperatures and variation over the roof area. Alternatively, now when the roof temperature is high, the furnace operator may select to charge more feed into the furnace or open the roof air ingress ports to mitigate the problem and then acknowledge the alarm. Concerning the operator, he only had to acknowledge 1 alarm instead of 16.

The result is fewer but more effective alarms focusing the operators' attention on the task and not on acknowledging alarms. Yet, the information provided to the operator is displayed more eefectively.

Hatch has further championed advancement in the furnace controls, with:

1. Radar-based feed level control – measuring the charge banks in the furnace to ensure sufficient cover and smelting. The radars are installed in the most critical and high production area of the furnace to provide the control system and the operator with the level feedback to manage the feed bank profile. To accurately control the feed bank level it is necessary to know the furnace slag level.
2. The slag level can be inferred from the electrode position. The electrode position can be based on an assumption of constant electrode length, which is regularly updated. Alternatively, the electrode tip position can be measured using radar electrode trip instrumentation (patent pending).
3. Furnace level measurement – Hatch has designed a robust level measurement delivery system to address crusting of the feed cover in the furnace. This robust level measurement delivery system provides consistent, operator independent, level data for the furnace operator to improve furnace taping predictability and so scheduling of the rest of the refining operation.
4. Fibre-optic tap hole monitoring instrumentation and software – providing a high resolution temperature profile for the face of the taphole and the refractory in that area – summarized in a manner to keep the furnace operator informed.

8.2 Calcine Transfer System

The controls for the Calcine Transfer System were also improved. Advanced controls and equipment is required to provide maximum throughput of material. Controlled movement of the calcine transfer car, calcine transfer crane hoist control and calcine transfer crane trolley control ensures that the calcine transfer container is moved at the highest safe movement speed while providing accurate positioning of the container. The result is a high material throughput with minimal spillage of material. The reduction in spillage of material increase the operation efficiency (no need to have an operator to clean up spills and maintenance to repair damaged equipment) while improving the system efficiency.

9. FUTURE DEVELOPMENT – HIGHEST THROUGHPUT FENI FURNACE IN THE WORLD

In order to further increase production, Vale is in the planning stages for a resumption in production from Kiln No. 2 to feed additional calcine into Furnace No.1. This includes a partial rebuild of the No. 2 CTS (including advanced self-learning control around the kiln discharge valve and cross-feeding control) leveraging the proven Line 1 design, see Figure 6.

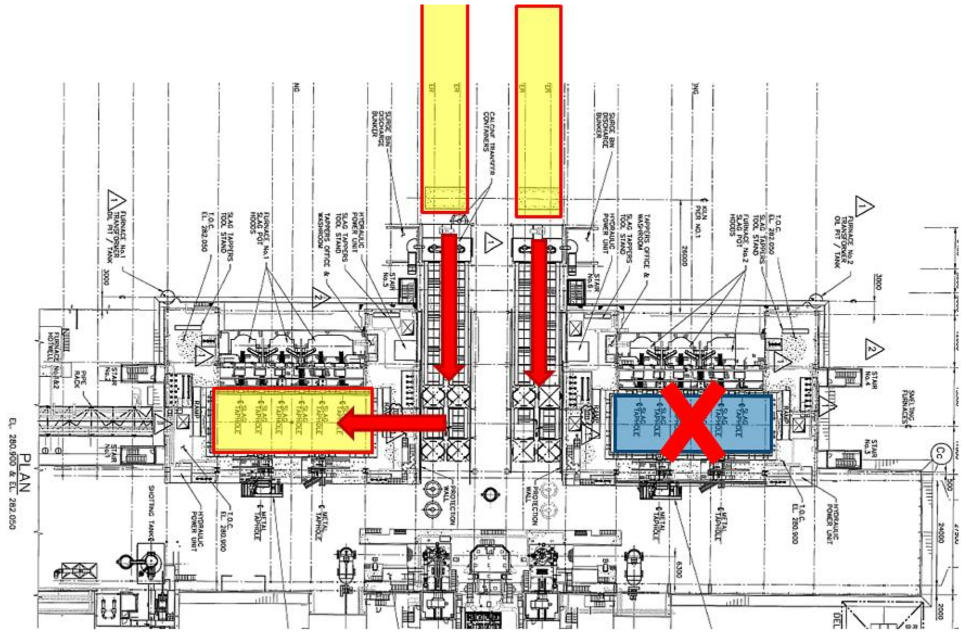


Figure 6: Future Plans for Onça Puma Production

With an operational Kiln No. 2 & CTS Line 2, Onça Puma will be able to produce more calcine resulting in a higher feed rate to the #1 Furnace, and removing calcine availability as the plant bottleneck. Analysis indicates that with both kiln and CTS lines in operation and with good calcine quality, the #1 Furnace will be able to operate sustainably at 100 MW and achieve a throughput of >190tph calcine. The furnace crucible itself is capable of>120MW provided other bottlenecks (such as secondary voltage) are eliminated.

10. REFERENCES

[1] F.A. Stober , T. Gerritsen, J. Janzen, A. Kepes, "Developments in Integrated Furnace Controls to Enhance Furnace Operation and Crucible Integrity in Shielded-Arc Laterite Smelting", TMS International Laterite Nickel Symposium – 2004, Pp. 545-562.