ROLE OF OPERATIONAL SUPPORT IN RAMP-UP OF THE FeNi-II FURNACE AT PT ANTAM IN POMALAA

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ABSTRACT

The role of dedicated operational support in the ramp-up and stabilisation of the FeNi-II furnace for ferronickel production at PT Antam's smelter located in Pomalaa, Indonesia is described. The furnace was uprated to 32MW capability in a rebuild performed in 2005. This primarily involved installing a larger transformer, coupled with adoption of HATCH water-cooled copper plate, waffle and flanker coolers with integrated metal and slag tapblocks, HATCH air-cooled copper fin lower sidewall cooling and HATCH vertical sidewall binding system – "holddowns".

Following a smooth commissioning period, the progress in attaining the preliminary ramp-up target load of 24MW is described. This initial target was set by Antam, subject to some prevailing smelter equipment constraints, particularly kiln capacity. Stabilisation of the furnace operation is discussed, together with some of the specific commissioning and operational challenges surmounted by the joint Antam-HATCH team. These included:

- *Mastering furnace integrity monitoring and operation with copper coolers, especially metal tapblock planned maintenance and repair strategies;*
- *Transition from traditional "immersed electrode" to "brush-arc" mode of operation approaching as closely as possible to the productive "shielded-arc" mode of operation within existing equipment constraints;*
- *Reductant selection and control issues;*
- *Utilising the sophisticated furnace monitoring to provide detailed indication and warning of potentially destructive furnace upset conditions such as Si reversion and CO boils.*

1. INTRODUCTION

The trend towards high-power, high-productivity electric furnaces utilising existing crucible equipment sizing for nickel laterite smelting continues, largely facilitated through the application of newer technologies to maintain furnace integrity and improve furnace control[1]- [3]. The major benefit of such high power furnaces is high single line capacity, resulting in lower CAPEX per annual tonne, and lower energy, electrode and labour costs per tonne. Critically, the process development of "shielded-arc" operation has driven the trend away from classical "immersed electrode" operation, largely to facilitate operation at acceptable process temperatures (especially metal temperature) and heat fluxes, despite increasingly higher power operation[1], [4]and [5].

As a first step towards improving productivities and increasing ferronickel production, PT Antam retained HATCH to upgrade the FeNi-II furnace in 2004/5. Details of the process and engineering design intents, as well as commissioning of the furnace, are described elsewhere[6]. This paper focuses on the role of a joint Antam and HATCH technical and operational support team in post-commissioning ramp-up to achieve the initial target load of 24MW set by Antam.

2. OPERATIONAL SUPPORT

Direct consequences of the increased drive to high-power, higher productivity furnaces, have been the increased needs to:

- better understand the subtleties of the underlying core process metallurgy, especially those associated with shifting away from traditional low-power "immersed electrode" operation
- enhance the level of furnace monitoring systems, and
- implement tighter furnace control.

Antam recognised these needs and, consistent with several operations elsewhere recently, requested HATCH to assist with a formal program of technical and operational support on FeNi-II. Such Operational Support delivered by HATCH can either form part of a broader Operational Readiness program, in which case it commences shortly after project initiation[7], or it can follow commissioning. The latter was the case with Antam and the first 6 months of HATCH Operational Support was focussed, with the express intents of:

- accelerating FeNi-II furnace ramp-up (initially to 24MW),
- more safely,
- while, maximising knowledge transfer to process and engineering staff, especially those newly recruited to operate both the FeNi-II furnace at a higher power and the recently added rotary kiln and FeNi-III furnace (42MW) smelter line.

Clearly a critical aspect to any such Operational Support is to entrench learnings with the operators. Therefore, the primary role of the on-site operational support team is to assist in identifying shortcomings and especially to try to anticipate operational difficulties before they manifest themselves. Keen familiarity with the process requirements, and intimate knowledge of the furnace design and operational requirements are critical to permit the team to deliver on this[7],[8] and [10]. These are then brought routinely (at least daily) to the attention of the operating team, who remain at all times responsible and accountable for the operation of their furnace. The operators are encouraged to present their solutions to address arising issues. The technical and operational merits of these approaches are then explored jointly. The operational support team finally engages in coaching, by presenting any alternative options that may be worthy of consideration, before the final onus falls back on the operators to select the most appropriate course of action.

Altogether in a period spanning some 218 days from furnace start-up, the Operational Support team provided over a hundred observations related to safety, health and risk; helped update or develop 23 operating procedures and was involved in reviewing over 200 core setpoint changes. Some of the more interesting technical and operational issues addressed by the joint Antam-HATCH team are now described in more detail, to illustrate how such a partnership effectively expedited the safe ramp-up of furnace FeNi-II to stable operation.

3. PROCESS BACKGROUND AND OPERATIONAL GOAL

Past operation at Antam was characterised by an "immersed electrode" mode of operation at low furnace power (18 MW and below). At such low operating power, a highly reducing operation was permissible, and conducive to tapping of alloy containing typically <17.5%Ni, 2-3%C and 2-3.5%Si (liquidus temperature as low as 1200°C), still at relatively low temperatures of 1450ºC. The resulting high alloy superheat, while detrimental to the furnace lining and metal taphole wear, was desirable to limit ladle skulling and for downstream refining of the crude furnace alloy.

Unfortunately, with operation at higher power levels application of "immersed-electrode" smelting leads to increased slag temperatures through an increased bath power ($P_{bath} = i^2R_{bath}$ heating). This results in increased transfer of energy from the overlying slag to the metal phase, which is exacerbated by more deeply immersed electrodes, leading directly to increased metal temperatures. Consequently, high-power smelting of nickel laterites is normally performed with a greater contribution of the total power input, $P_{total} = P_{arc} + P_{bath}$, being through arc power ($P_{arc} = P_{total} - i^2R_{bath}$).

In the latter mode of operation, the so-called "shielded-arc" mode of smelting[2],[4] and [5], the arc is typically "shielded" to capture a larger portion of the energy associated with P_{arc} for direct smelting of calcine rather than for heating of the slag. This is achieved in practice through a carefully sized rotary kiln calcine feed of relatively low carbon content, both to secure suitably low electrical conductivity and to secure adequate gaseous permeability to ensure that the integrity of the calcine "shield" is maintained through avoidance of excessive gas evolution, gas burners or arc flaring. The latter conditions are detrimental to effective capture of arc energy, leading to lower energy efficiencies and, in the extreme, can cause furnace roof and feed-chute damage.

A key objective of the joint Operational Support team was to define empirically, based on close scrutiny of the furnace smelting conditions, a suitable window of operation on FeNi-II that minimised process temperatures to maximise furnace lining integrity and campaign life at higher operating powers; specifically metal temperatures around 1450°C (below 1530°C) and slag temperatures below 1580°C. This was to be achieved through progressively raising the electrodes to a "brush-arc" (< 10% electrode immersion in slag), or even "shielded-arc" condition, to the maximum permitted by the prevailing furnace configuration (choke-fed calcine distribution around electrodes and small freeboard volume with roof height configuration). This was coupled with judicious adjustment (lowering) of the calcine reducing condition in the furnace, to minimise the extent of production of gaseous products of reduction (with the existing gas offtake being a known bottleneck), yet still securing acceptable recoveries of nickel to the alloy and adequate alloy superheat for downstream refining.

4. FURNACE INTEGRITY

To facilitate ugrade of the furnace FeNi-II from 18 to 32MW, the furnace crucible became a core element of furnace integrity requiring re-design to permit sustainable operation at the required increased hearth power density of up to 214kW/m^2[6]. Despite incorporating the capability for a change from Antam's traditional "immersed electrode" operation to "brush-arc" (and ultimately approaching a "shielded-arc") mode of operation, the process design basis still had to be adjusted upwards to permit operation with both higher slag and metal temperatures (as described above) and higher average sidewall heat flux of 40kW/m^2[6].

The specific improvements made by HATCH to the furnace cooling system and integrity included addition of:

- High-intensity, water-cooled copper Waffle coolers in the lower slag zone, from the top of the maximum slag-metal interface;
- Copper Plate coolers in the remainder of the slag and into the freeboard zone;
- Integrated water-cooled copper Slag Tapholes;
- Water-cooled copper, refractory-lined Metal Tapblocks (comprising skew, side and lintel copper cooling elements) and Flanker Coolers;
- Lower Sidewall Cooling through forced draft air-cooled copper-fins in the zone below the waffle coolers;
- Vertical wall Holddown springs to secure tight sidewall/hearth joints and to promote wall cooling.

In Operational Support, the team focussed on the monitoring needed to secure the integrity and effectiveness of these new design elements. Clearly, this was a requirement from a risk perspective, to secure the safest possible operation with water-cooled copper elements. However, as has been reported previously[10], a further objective was to alert the operators to the valuable additional insight into process conditions prevailing in the furnace afforded by an advanced furnace monitoring system.

Operational Support re-inforced to the operators the need for routine monitoring of furnace conditions (and especially cooler integrity) throughout their shift. Key furnace growth and temperature trends were re-assessed on a daily basis, with detailed analysis performed in conjunction with Antam shift engineers every week.

4.1. Copper Coolers

While alarms were occasionally encountered during the period of power ramp-up, the only thermal events of significance involving copper coolers were:

- Metal tapblock copper faceplate failure (damaged through a combination of undetected refractory insert damage, skew drilling and lancing), and
- Slag tapblock insert damage (through skew lancing and a practice of drilling the hole fully open before each tap).

The value of carefully monitoring furnace plate cooler temperatures was readily demonstrated through the early diagnosis of several feedchute blockages (Figure 1: and Figure 2:). Increased separation of the hotter average waffle cooler thermocouple A temperature located in closest proximity to the metal-slag interface, relative to the averages of the B, C and D average thermocouples located higher in the waffle coolers was helpful in diagnosing rising metal level (Figure 3:). In addition, as the original brick in front of the waffle coolers is progressively eroded and replaced by a thinner true slag accretion freeze lining, careful monitoring of waffle cooler temperatures alerts the operators to process instabilities in the furnace (e.g., impact of Si reversion and CO boil - see Section 5.6).

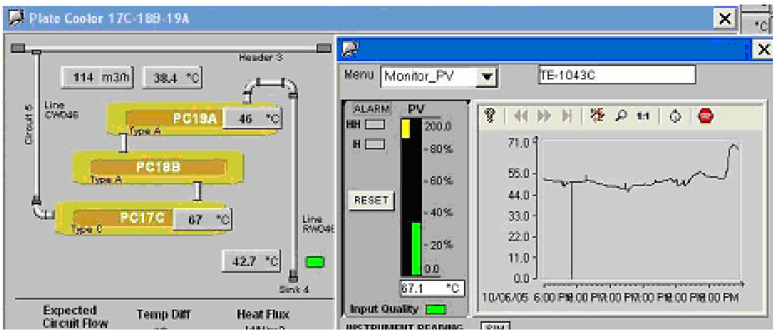

Figure 1: Plate cooler PC17C to a temperature of 67℃, indicating a feedchute blockage

4.2 Metal-slag Refractory and Sidewall Temperatures

Metal-slag interface refractory thermocouples were added into the furnace monitoring system (positioned in the refractory brick close to the inner shell surface) with the furnace upgrade, to supplement sidewall shell thermocouples located in the region of the lower sidewall cooling system. These metal-slag interface refractory thermocouples proved essential in:

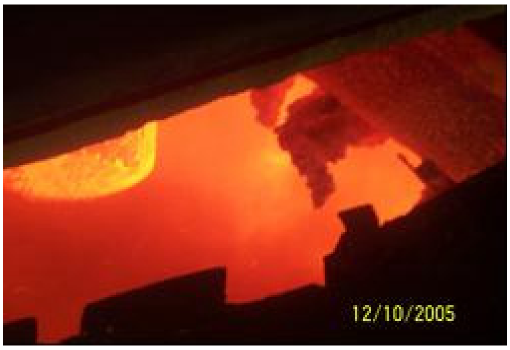

Figure 2: Unblocking of Feedchute 9A – so hot, glowing yellow

- Alerting to conditions of low metal level, through higher temperatures (Figure 4:), which are detrimental to erosion and under-cutting of the refractory located just below the waffle coolers (Figure 5: versus Figure 6:);
- First indication of the development of severe thermal events through alarms, and then protecting the furnace against further damage through tripping the furnace once the HiHi alarm (180°C) had been attained

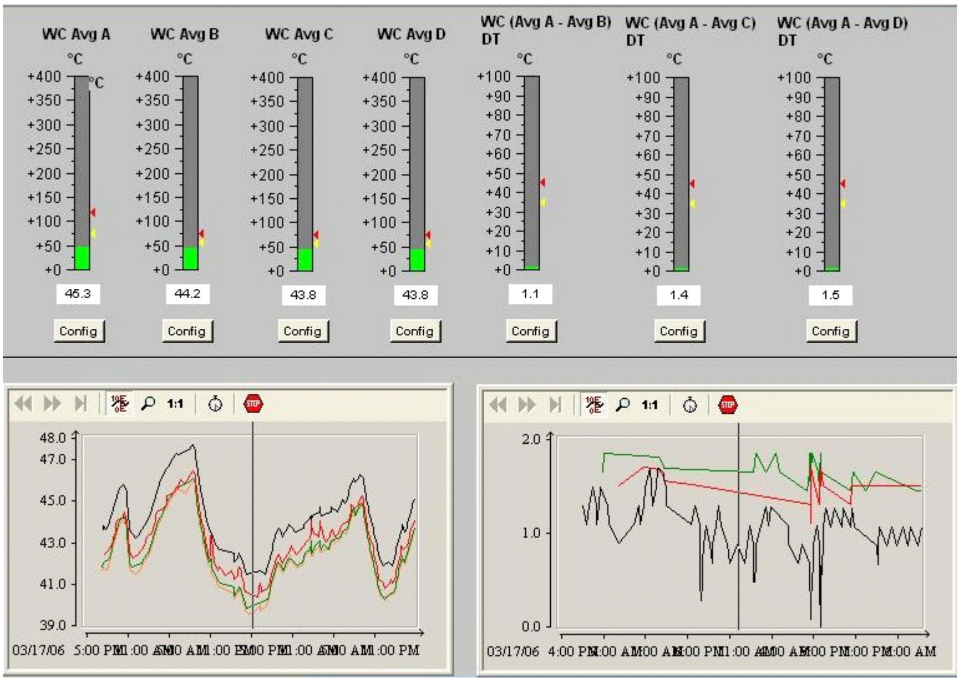

Figure 3: A period of rising metal level, indicated by an increased temperature difference between the average A-thermocouple (nearest to metal-slag interface at the waffle cooler base – black line), and the average B-, C- and D-thermocouples located higher up in the waffle coolers

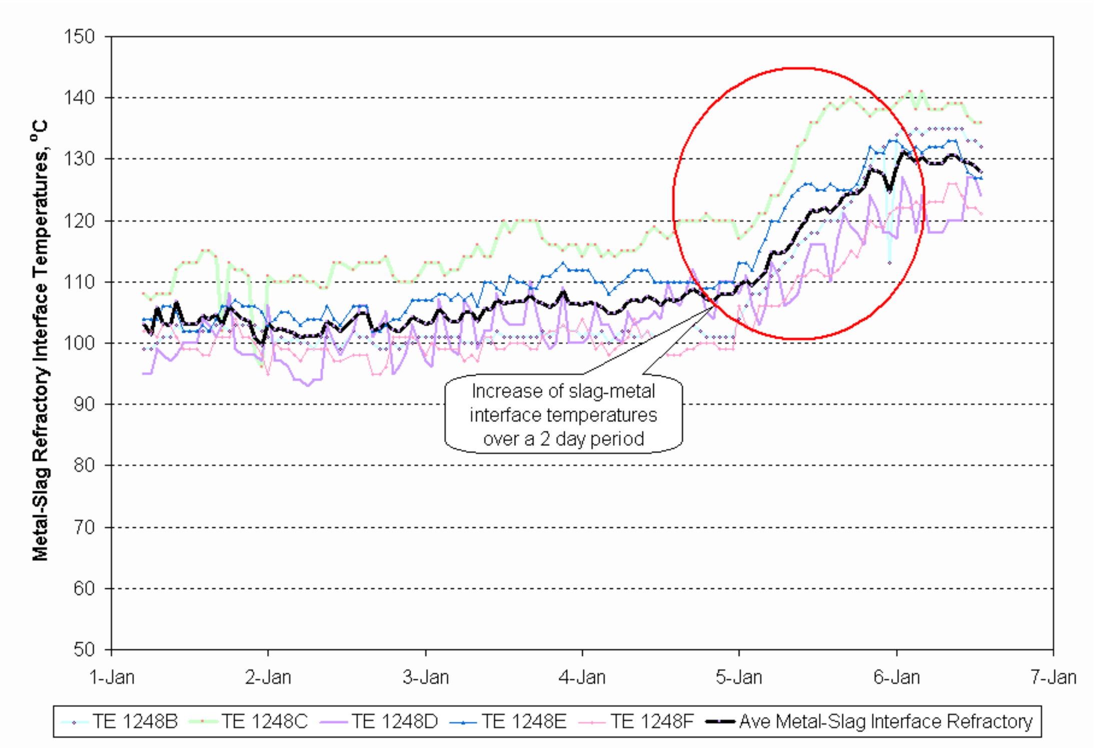

Figure 4: Response of slag-metal interface refractory temperatures over a 6-day period, which increased almost 30°C in a period when metal levels dropped significantly below 160mm level

(Figure 21:). With temperatures in excess of 180°C, incident sidewall heat fluxes over 150kW/m^2 are calculated by the furnace finite element analysis (FEA) model (Figure 6:). Excessive sidewall erosion and waffle cooler basal corner copper tip temperatures exceeding 450ºC were predicted by the FEA model for such conditions, which emphasise the magnitude of the thermal event that a full Si reversion and CO boil can create (see Section 5.6).

4.3 Metal Tapblock (MTB) Maintenance

The two metal tapblocks (MTB) each comprise a separate basal water-cooled skew copper cooler, two side copper coolers and a lintel copper cooler. The tapping channel formed by the coolers is lined internally with pitch-impregnated magnesia surround bricks, containing the pitch-impregnated magnesia tapping module bricks. The arrangement is intended to permit ready maintenance of the MTBs, effected through routine replacement of the tapping module bricks.

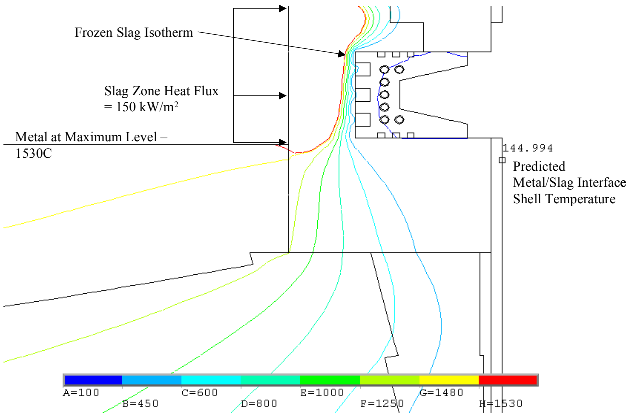

Figure 5: Refractory erosion predicted for a combination of high metal level at base of Waffle cooler and high incident heat flux of 150 kW/m^2

Upon completion of 9 faceplate insert and first-brick tapping module repair campaigns on FeNi-II, MTB1 was generally performing better than MTB2 (Figure 7: and Figure 8:), with:

- 5.2% longer mean tap time; 3.8% lower total tapping rate (mean of 0.55 t/min.) and 13% deeper drill depth (mean of 630 versus 530mm)

and despite:

- 1.1% higher mean tapping temperature (1495 versus 1480°C); tapping 10.7% more total metal (6587 versus 5948t) and higher resulting corrosion and corrosion-erosion indices by 11.4 and 2.7%, respectively (Figure 9:).

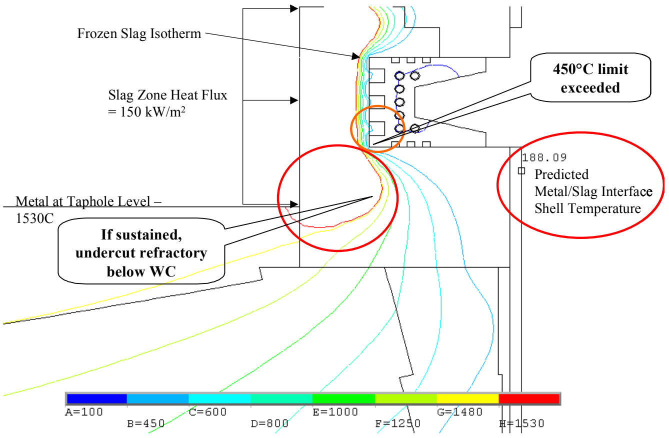

Figure 6: Severe "tidal-zone" refractory erosion predicted for a combination of low metal level and high incident heat flux of 150 kW/m^2

Causes for the poorer performance of MTB2 than MTB1 included:

- The shorter drill depth on MTB2 indicated a problem with its mudgun (low cylinder pressure diagnosed).
- 31.1% less incidence of slagging on MTB1 than MTB2 (10.9 versus 15.8% of total taps).

MTB1 in particular (Figure 7:), showed good performance up to the end of campaign 4, with drill depths maintained at almost 700mm and low tapping rates (< 0.5t/min.). However, in MTB1 campaign 5, excessive metal tapping temperatures (mean of 1538°C) and metal superheats (estimated maximum of 323°C) were experienced, associated with a period of Si reversion and CO boil. This appears directly to have caused some damage to MTB1 (high corrosion-erosion index - Figure 9:), in conjunction with more normal progressive MTB wear with time of the deeper tapping module bricks 4-6.

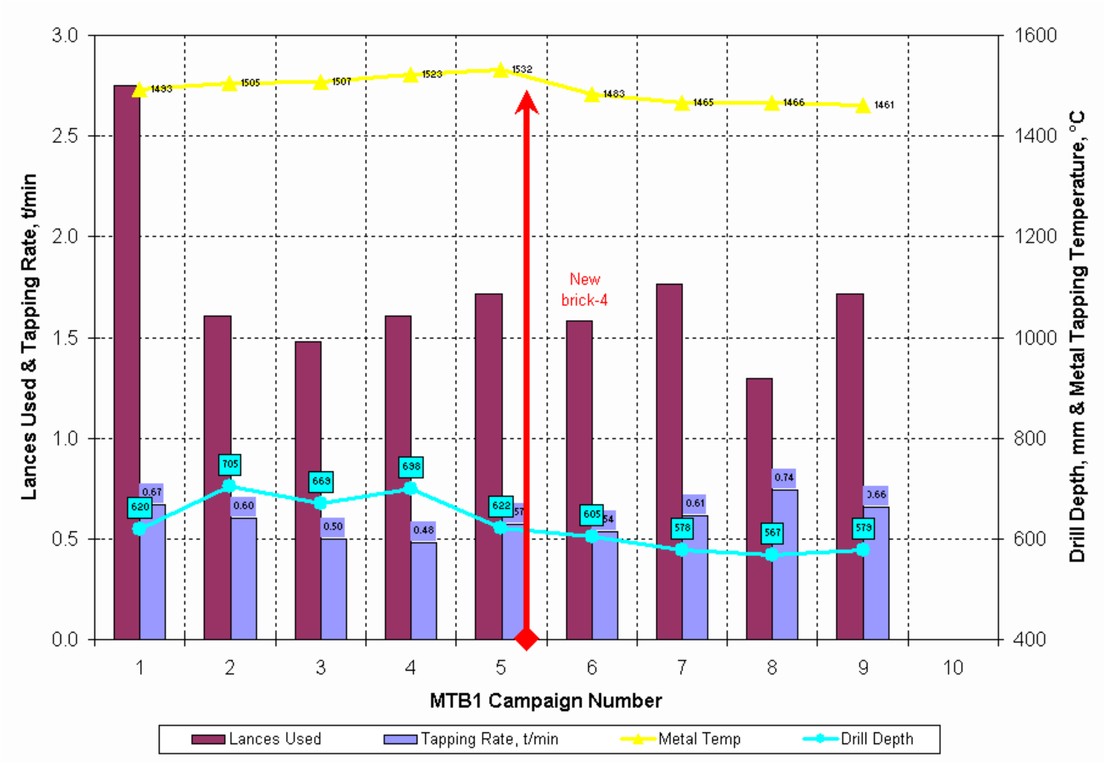

Figure 7: Tapping performance of MTB1 in first 9 Brick-1 repair campaigns

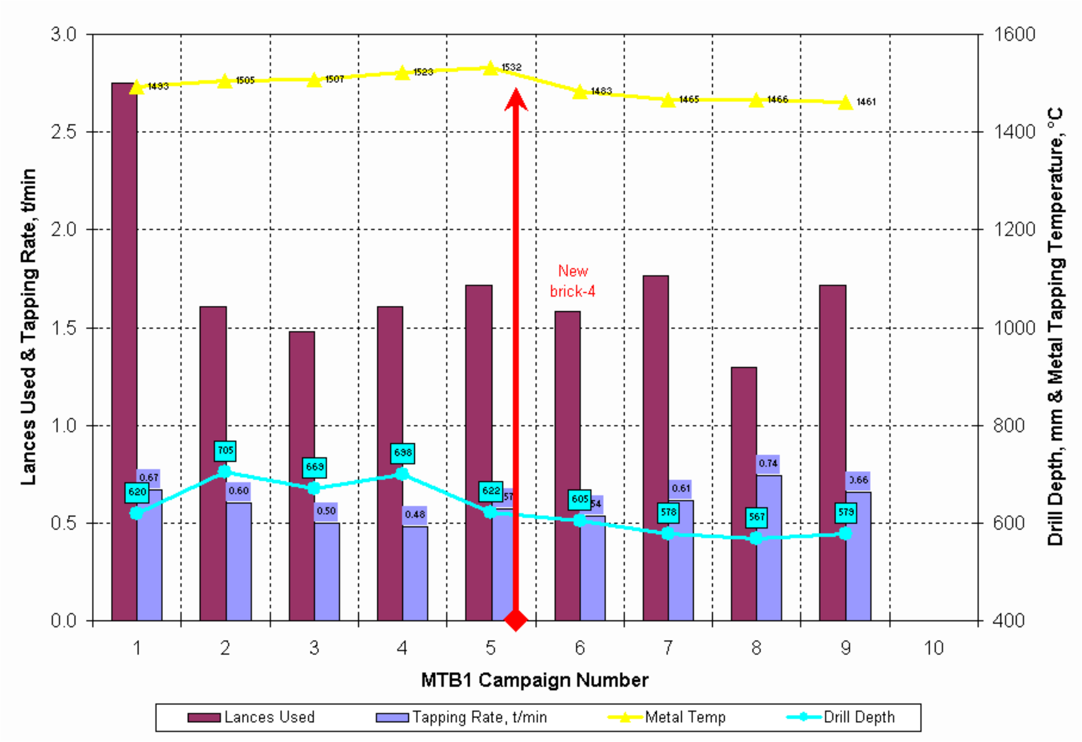

Figure 8: Tapping performance of MTB2 in first 9 Brick-1 repair campaigns

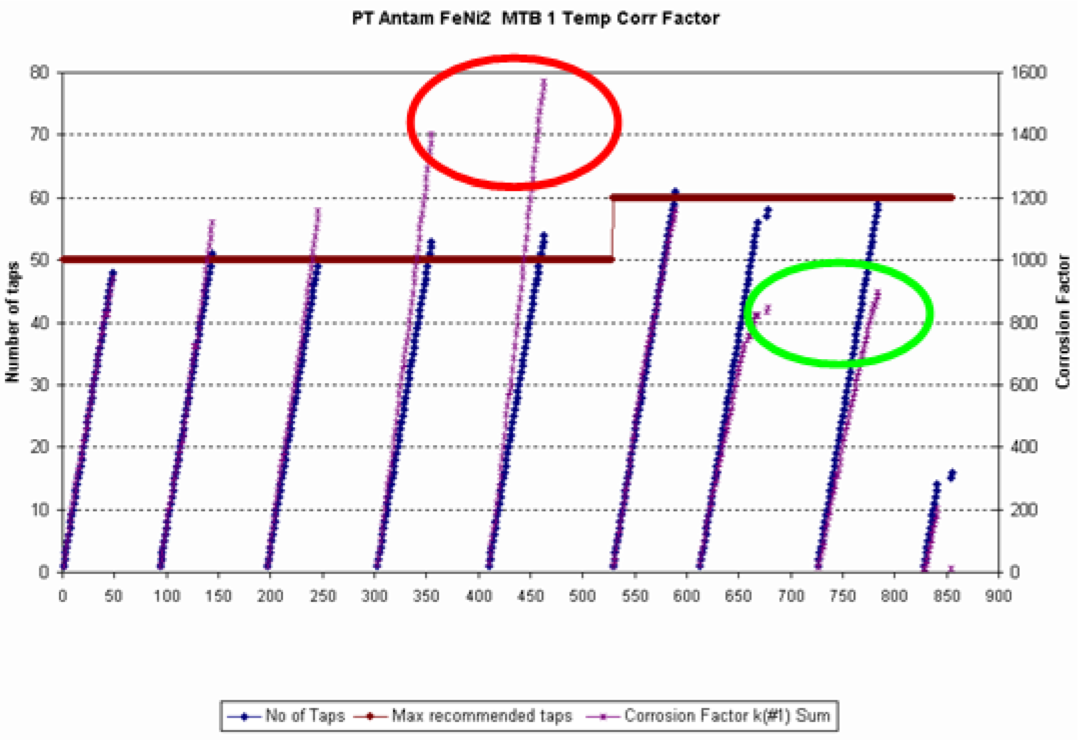

Figure 9: Corrosion factor predicted for MTB1 in first 9 Brick-1 repair campaigns; an Arrhenius function of metal tapping temperature is assumed. Excessive metal tapping temperatures in Campaign 5 are due to the effects of Si reversion and CO boil. Notice also the change to 60 taps between brick-1 repairs after campaign 5. The low corrosion index predicted in campaigns 7 and 8 are due to stabilisation of the process at less reducing conditions and higher electrode resistance

Replacement of brick-4 at the end of campaign 5 (Figure 7:) appeared, somewhat unexpectedly, to have had little effect on improving MTB1 conditions. Coupled with known instances of skew drilling and lancing, the MTB1 condition worsened progressively, with mean drill depths shallower than 580mm and higher tapping rates between 0.61 – 0.74 t/min. A greater incidence of drill and lance damage was also recorded in recent MTB2 repairs.

4.3.1 MTB repair trends - interpretation and recommendations

Overall MTB trends suggest that manageable issues, such as the incidence of furnace slagging and skew drilling and lancing damage of MTBs contributed more to their wear than conventional refractory corrosion (tapping temperature, and exposure time to a quantity of tapped metal) and erosion (primarily tapping channel velocities – tapping rate t/min. adopted as a proxy for this, and promoted typically by higher tapping temperatures) effects. Especially, as in the recent period improved furnace control led to an impressive 2.9% lowering of the mean tapping temperature (from 1505 to 1463°C) and, more importantly, the metal superheat dropped an impressive 31.7% (from 240 to 164°C). This resulted in a lower tapping channel heat flux determined by $q = h\Delta T$, where ΔT is the metal superheat (and h is the convective heat transfer coefficient), which should have been favourable to improved MTB performance.

The following remedial actions were thus identified:

- Focus on avoiding slagging the MTBs unnecessarily (more rigorous attention to control of metal and slag levels - Figure 5: and Figure 6:)

Figure 10: MTB1 – Brick-1 sacrificial replacement after 5 taps. Characteristic "+" shape cracks. Minor crack in surround brick

Figure 11: MTB1 – Brick-4 after 219 taps. Multiple drilling of taphole off-centre, coupled with skew lancing

- Avoid skew drilling of the taphole – PT Antam need to implement a "fixed drill" arrangement (Figure 11:).
- Rigorously check after every drill event, the depth of drilling and that the taphole is not drilled skew – use the drill-T made specifically for this purpose after each and every drilling.
- Focus on not continuing to lance (and tap through) any taphole, which is known to be skew or damaged. First replace and repair any tapping module bricks with any signs of drill damage – even if brand new.
- Use a lance guide to minimise any risk of skew lancing.
- Ensure both mudguns are always functioning properly – (diagnose rapidly any evidence of inadequate cylinder pressure, such as on MTB2 mudgun recently).
- Trial alumina-chrome brick as an alternative to pitch-impregnated magnesia brick, initially as lower risk brick-1. Ensure that any bricks installed are not oversize (230 +0mm top size), grinding such bricks to ≤ 230mm if necessary before installation. Oversize tapping module bricks coupled with high thermal shock both promote cracking of bricks in a "+" shape (Figure 10:).
- Consider shortening the insert and brick-1 life back from 60 to 50 taps. It may be coincidental, but MTB performance deteriorated in the past 3 months with the longer brick-1 repair cycle.

5. OPERATIONAL DEVELOPMENTS

5.1 Initial Furnace Power Target (24MW)

A stable "brush-arc" operation at 25MW power (21-25 mΩ impedance operation) below a target 530 kWh/t dry ore was achieved within 5 months of start-up. Over a two month period, the mean slag temperature was 1550°C, analyzing: 0.1%Ni, 10%Fe, <1%Cr, 55%SiO_2, 30%MgO, 3%CaO and 2%Al_2O_3. The corresponding crude ferronickel metal was tapped at 1450°C (an acceptable superheat of between 135-150°C) and analysed: 26%Ni, 0.3%Co, 1.5%C, 2.8%Si, 0.6%Cr, 0.03%Mn, 0.03%P and 0.3%S.

This performance can be improved upon by progressing more towards "shielded-arc" operation to realise even greater smelting efficiencies, but some inherent latent limitations for attainment of the final design 32MW operation persist that must first be de-bottlenecked, mainly related to: current rotary dryer and rotary kiln capacity and calcine quality deficiencies; suboptimal choke-fed feed distribution within the furnace; electrode and power controller shortcomings; under-sized offgas system; downstream metal refining, and slag skimming and granulation pond water-cooling capacity deficiencies.

5.2 Entrenched Lime/Limestone-Free Operation

Lime-free operation requires a lower smelting energy requirement (eliminates endothermic calcination of limestone), without deleterious impact on alloy recovery or process metallurgy. It is permitted specifically through application of freeze-lined coolers provided that the slag-metal interface is maintained near the base of the waffle coolers, which limits refractory brick attack in this "tidal zone".

5.3 Metal Tapping Frequency and Level Control

One of the principles that took some time to entrench was full appreciation that you "cannot tap alloy that has not been smelted, even if the refinery wants it". Persistently lowering the metal-slag interface and "slagging" the MTH is extremely bad for furnace refractory lining integrity below the waffle coolers (Figure 6:). A procedure was developed to control the metal level between 160-210mm (just encroaching base of waffle coolers - provided it does not trigger undue heat flux on copper coolers). After several attempts at an in-house level control program, a HATCH version based on the nickel mass balance was finally implemented to guide both metal (and slag) level tapping cycles, in conjunction with daily furnace soundings (Figure 12:).

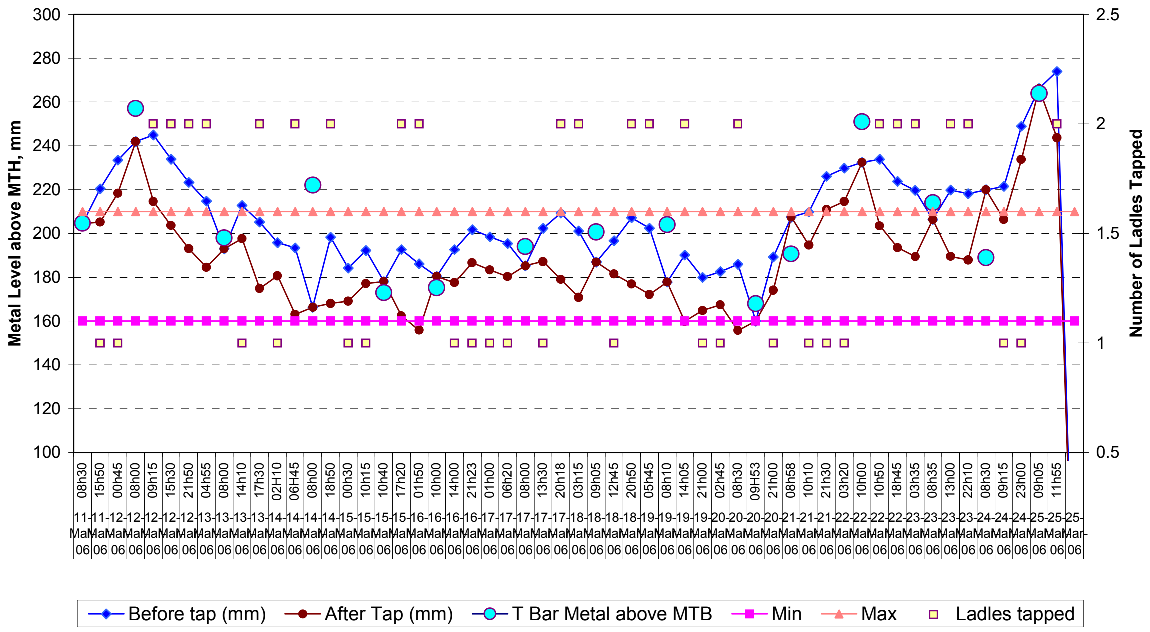

Figure 12: Predicted metal level before and after tapping, compared to T-Bar metal soundings. Metal levels kept above minimum, limiting metal-slag interface refractory erosion below waffle coolers

5.4 Slag Level Control

A minimum slag level above the STH of 250mm was defined initially. The maximum slag level of up to 900mm above the STH is dictated by the upper plate cooler position. Future "shielded-arc" mode of operation may dictate a "thin" slag for optimum results[4], depending on any influence of a "thick" slag on transitory metal droplet refining reactions.

An empirical HATCH slag level prediction was finally adopted to effect improved control over the slag skimming cycle (Figure 13:). Although the aim was to progress towards more continuous slag skimming, especially with increasing furnace power, limitations on the capacity of the slag granulation system (especially on the sea-side launder initially) limited this to a batch process. The travel of the electrode holder positions downwards during tapping was used to guide the duration of each event (Figure 14:).

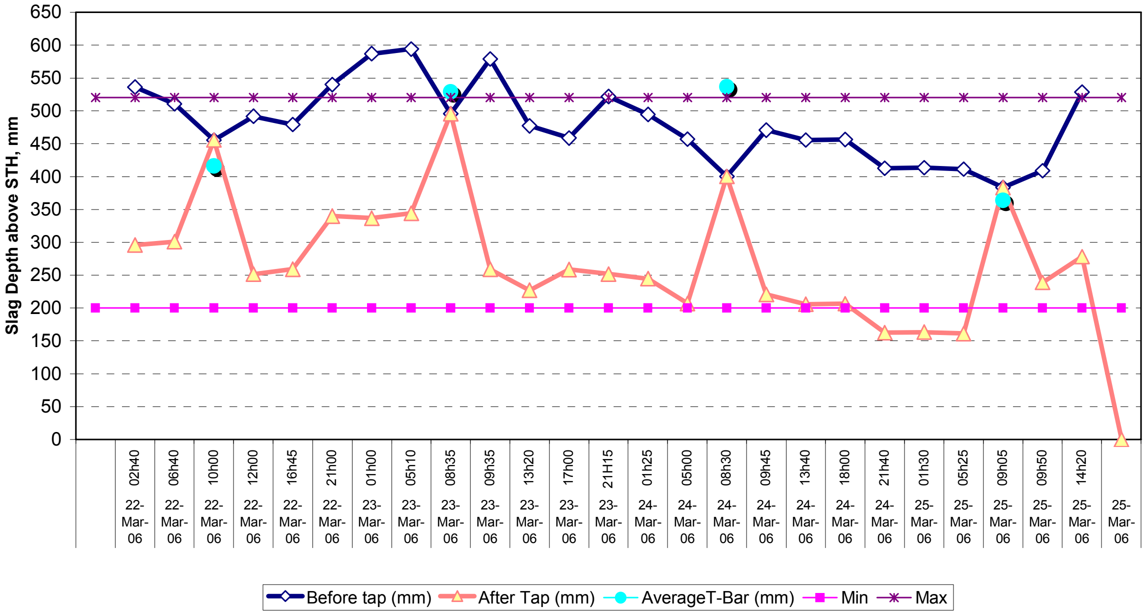

Figure 13: Predicted slag level before and after tapping, compared to T-Bar slag soundings

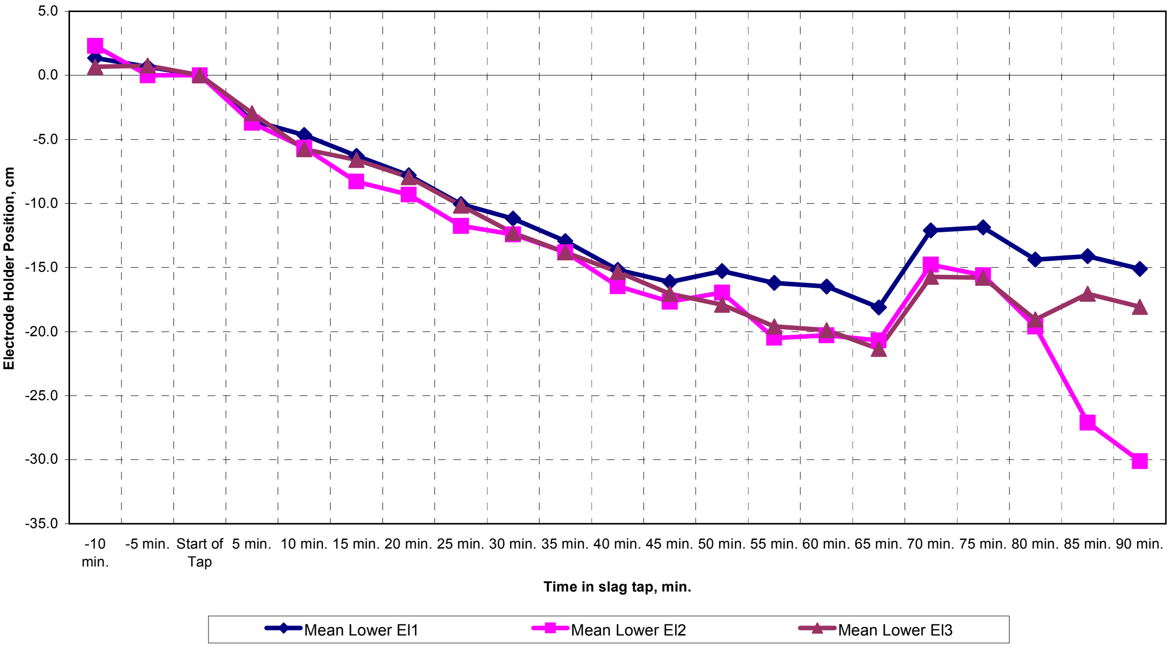

Figure 14: Typical movement of the electrode holders during slag skimming on the mountain-side taphole (closest to Electrode 3 – Electrode 2 opposite metal tapholes). Used to determine tap duration

5.5 Reductant Selection

Fluctuating reductant types and compositions affected rotary kiln and then in-furnace smelting performances. Probably the most dramatic event followed a change from a Chinese to a Vietnamese anthracite in the coal and anthracite reductant blend. The latter Vietnamese reductant was clearly less "gaseous" reactive in the rotary kiln than the Chinese anthracite, and especially the coal (shiny unreacted anthracite being observed in the rotary kiln discharge - Figure 15:).

However, this poor "gaseous" reactivity in the rotary kiln translated to a higher "liquid" reactivity in the furnace (as has frequently been found to be the case elsewhere for dissolution of carbon into alloy and smelting of higher rank reductants[10], [11] and [12]. This resulted in significant reduction (alloy in excess of 3.8% Si and 2.8% C) and copious generation of gaseous reduction products. Especially with the deep valleys that exist between choke-fed calcine piles that extend to the electrodes (Figure 16:). Preferential downwards flow with segregation and channelling of lighter reductants to the electrode tips was frequently observed to develop. This fuelled reduction at the hot electrode tips that caused blowing or surging of product gases (Figure 17:), gas blowers capable of ejecting feed and slag from around the electrode tips (Figure 18:) and, in the extreme, arc flaring (especially at higher furnace power level and operating impedances above 20 mΩ - Figure 19:). Conditions became so over-reducing at times, that copious fumes and deposits of the white magnesia and silica oxidation products of fumed Mg(v) and SiO(v) were observed in the offgas (Figure 20:), with excessive incidents of offgas blockages further hampering stable furnace operation.

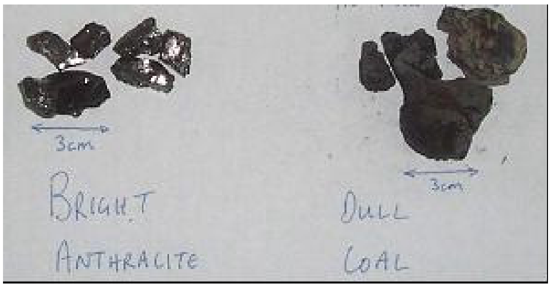

Figure 15: Rotary kiln discharge calcine – bright unreacted anthracite (left) and duller reacted coal (right) - note large sizes

Figure 16: Choke-fed calcine feed piles with combusting reductant-rich valley towards electrode

Figure 17: Typical gas burner away from electrode caused by over-reducing conditions

Figure 18: Generation of product gas sufficient to cause ejection of calcine feed

It was corroborated that a similar anthracite-related metallurgical control issue was experienced in "immersed electrode" operation at PT Antam in 1998. Irregardless of the mode of furnace operation ("immersed-, brush- or shielded-arc"), these incidents highlighted the need to better control and characterise the composition and reactivities of reductant feedstocks charged to the rotary kiln, in order to optimise smelting conditions in the furnace. It also specifically emphasised the desirability of operating with less reducing conditions, with limited reductant in the calcine fed to the furnace, and a closer approach to production of a more "oxygenated" alloy (considerably lower alloy carbon and silicon contents) especially when operating at the more thermally efficient high-power, "shielded-arc" operations[13] and [14].

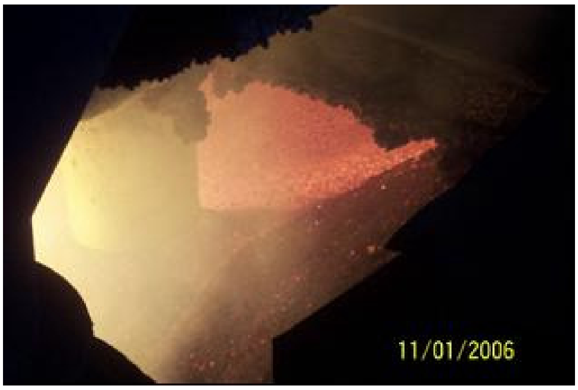

Figure 19: Arc flaring resulting from a combination of higher impedance operation and loss of calcine "shield" around the electrode

Figure 20: Over-reducing conditions, excessive fuming and deposition of white magnesia and silica oxidised products

5.6 Si Reversion And CO Boil Events

The phenomenon of Si reversion and CO boil is described in detail elsewhere[10] and is well known in nickel laterite smelting. It involves formation of C-rich alloy droplets by C dissolution, especially in the vicinity of the hotter electrode tips and from other high-order carbonaceous reductants (particularly anthracites, compared to lower rank coals). The higher alloy C contents, coupled with higher local temperatures, in turn promote highly endothermic reduction of the silica-rich slag to Si in the alloy droplets. As the alloy droplets fall through the slag to the colder metal, they can undergo refining of their alloy Si and C contents – through exothermic SiO_2 and endothermic CO generation, but especially with over-reducing conditions, alloy droplets of significant Si and C contents can join the bulk metal. The relevant reactions can be written as:

C Dissolution: $C = \underline{C}$ $\Delta H^\circ_{1500^\circ C} = 0.52$ kWh/kg C dissolved (1)

Silica Reduction: $2\underline{C} + (SiO_2) = \underline{Si} + 2CO$ $\Delta H^\circ_{1500^\circ C} = 5.23$ kWh/kg Si reduced (2)

$\underline{Si}$ Refining/Reversion: $\underline{Si} + 2(FeO) = (SiO_2) + 2Fe$ $\Delta H^\circ_{1500^\circ C} = -3.25$ kWh/kg Si refined (3)

$\underline{C}$ Refining/CO Boil: $\underline{C} + (FeO) = CO + Fe$ $\Delta H^\circ_{1500^\circ C} = 2.39$ kWh/kg C refined (4)

This is an inherently non-equilibrium condition – especially when lower temperature conditions prevail locally, such as near the wall cooler elements, or if cold reverts are dumped into the metal[10]. Thus, especially when high $\underline{Si}$ and $\underline{C}$ contents prevail in the alloy there is always a potential to trigger a substantial, and sustained, Si reversion and CO boil.

A classic event began to develop in mid-December, fuelled by a financial year-end drive to process batches of recycled ingot and scrap. This cold material readily acted as a trigger to induce local instability and cause reversion of highly reduced alloy (as high as 2.85% $\underline{Si}$ and 2.5% C; a natural consequence of the highly reducing nature of the Antam practice). Consequences of the exothermic Si reversion and potential CO boil induced included:

- Bottom hearth temperatures exceeded 800ºC (Figure 21:)
- Lower sidewall shell temperatures exceeded 110ºC alarm limits (Figure 21:)
- Metal-slag interface refractory temperatures rose above 150ºC (Figure 21:)
- Shell and hearth skew growth were observed, followed again by some contraction as the thermal conditions subsided;
- Vigorous slag boils observed at times within the furnace, especially following periods of cold reverts addition;
- Precipitous drop in alloy Si and C contents below 1% Si and 2% C, respectively (Figure 22:), while silica in the slag spiked from approximately 56% to 60.7% SiO_2 temporarily (reaction product of Si reversion)
- Energy released by exothermic Si reversion, coupled with stirring induced by thermal buoyancy and even more powerful CO boil effects caused metal temperature to rise above 1580ºC closely approaching slag temperatures that also increased, to above 1620ºC (Figure 22:). The magnitude of the process temperature rise correlated well with the predicted heat released by the extent of alloy Si reversion recorded.

Despite enforced procedural power-downs when 1580ºC metal or 1600ºC slag temperatures, respectively were exceeded, the furnace ultimately tripped when metal-slag refractory exceeded 180ºC. The duration of the event was of the order of 2 weeks in total. The key contribution of the HATCH Operational Support team to Antam management during this period was diagnosis of the Si reversion and CO boil event; guidance on understanding of the underlying mechanism; and assisting with procedures to limit the extent of any resulting thermal excursions.

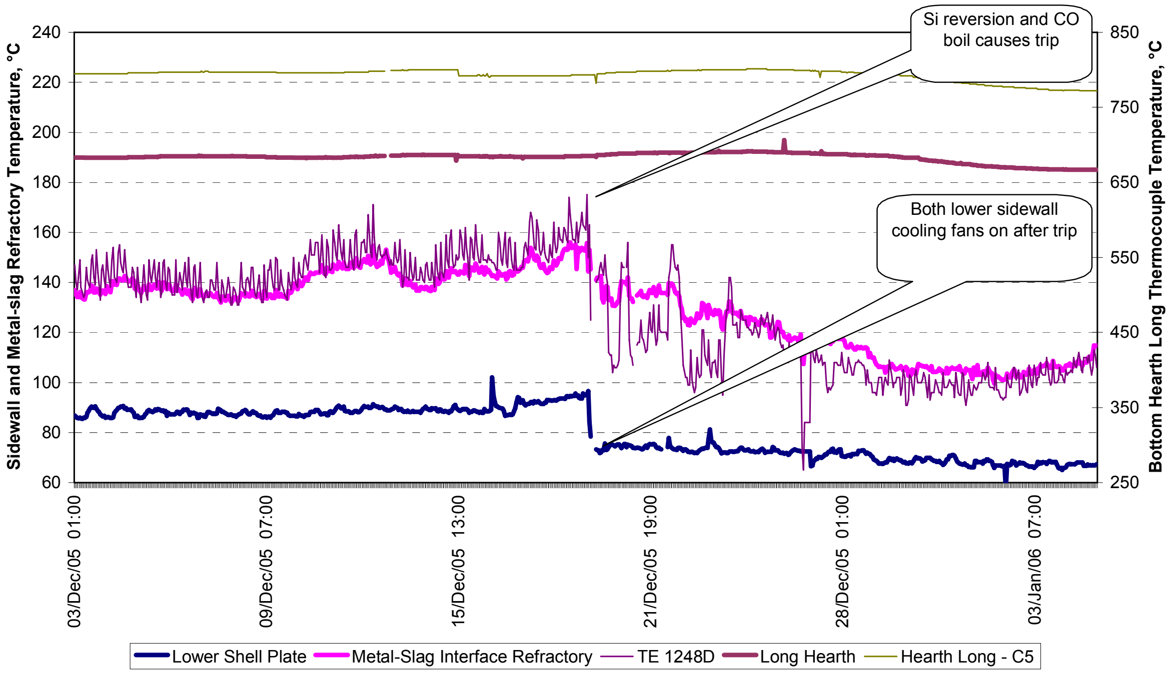

Figure 21: Si reversion and CO boil increase temperatures and sidewall heat fluxes, causing hearth thermocouples to rise and lower sidewall and metal-slag refractory temperatures to spike

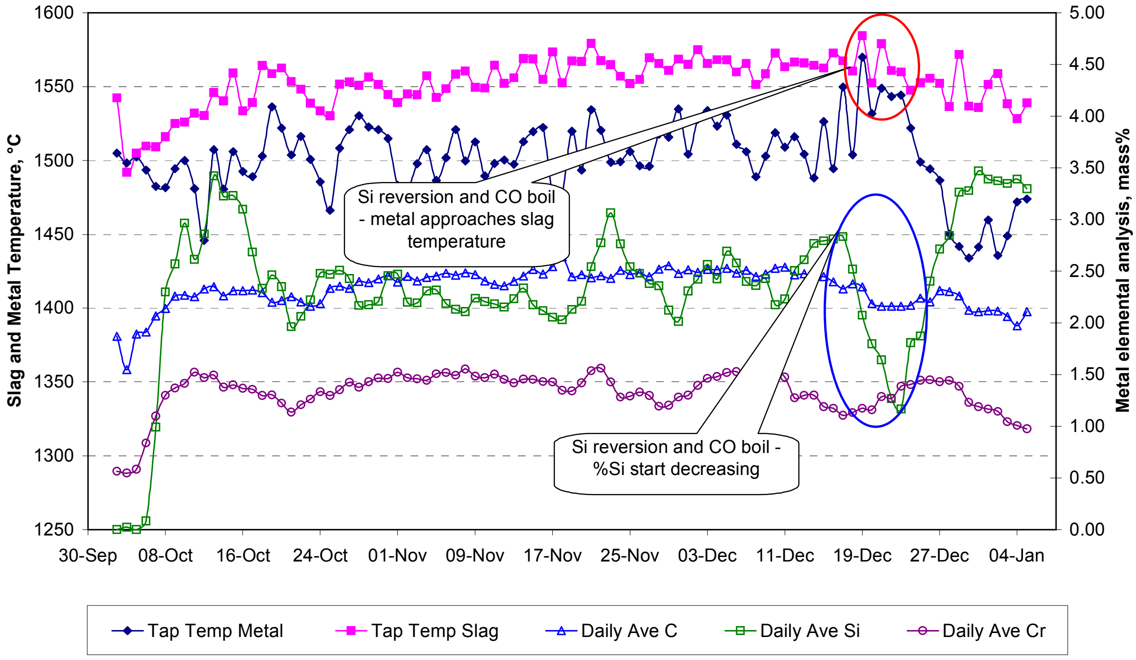

Figure 22: Si reversion and CO boil initiates rapid increase in metal temperature (maximum 1580ºC) as Si content of metal drops to 1% Si

6. CONCLUSIONS AND RECOMMENDATIONS

Formal adoption of HATCH Operational Support facilitated a fast and safe ramp-up to a stable and sustainable operation at the initial target power level of 24MW on the FeNi-II furnace operated by PT Antam. It was effective in facilitating transition of the operating and engineering staff from conventional "immersed-electrode" mode of nickel laterite smelting to the requirements of higher-intensity smelting under "brush-arc" to "shielded-arc" modes of operation. Operational Support also afforded Antam the opportunity to expose their staff to the additional requirements for operational safety and sustained productivity associated with higher-power smelting with greater technical and specialist guidance, with attendant lower risk to disruption of production.

The ultimate value of the Operational Support experience can probably best be judged by the fact that PT Antam has already requested HATCH to provide further assistance in the ramp-up of the larger FeNi-III 42MW furnace recently commissioned on the same site in Pomalaa, Indonesia.

7. ACKNOWLEDGEMENTS

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