FURNACE UPGRADE WITH HATCH TECHNOLOGY AT PT ANTAM FeNi-II IN POMALAA, INDONESIA

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ABSTRACT

The existing PT Aneka Tambang (Antam) ferronickel smelter located at Pomalaa, Indonesia consists of two RKEF lines with reduction furnaces nominally rated at 17 MW and 18 MW, respectively. The low power densities and heat fluxes allowed both furnaces to operate with falling water film shell cooling systems. The furnace campaigns comprised a 5-yearly cold shut -down for metal taphole area rebuild and a 10-yearly sidewall and hearth perimeter repair. Towards the end of these campaigns the furnaces would typically be operated at below nominal power due to excessive sidewall temperatures.

In January 2001 Hatch performed a smelter study which proposed options which indicated the possibility of a single furnace operation for the smelter, elimination of lime addition and transition to shielded-arc operation with associated efficiency and throughput gains.

This paper discusses the process of uprating the second–line furnace capability from 18 MW to 32MW following the decision by Antam to implement the recommendations proposed by Hatch.

It will cover the development of scaled-up furnace design basis by Hatch and Antam with the enabling application of Hatch cooling and binding technology. To optimise the capital cost and maximise Indonesian supply content and post installation support, the scope was carefully and clearly divided between Hatch and Antam. The challenges, set backs and valuable learning experiences gained during the implementation of the retrofit include;

- *The support and re-use of existing roof system and challenges presented in re-use of existing crucible support steel.*
- *Training and technical assistance for Antam operators to perform refractory and copper cooler installation and maintenance of crucible integrity technologies.*
- *Hearth integrity during start-up and development of an initial charge and start-up procedure to achieve planned thermal expansion of the hearth prior to bath formation*
- *Implementation of a sidewall hold-down system within the refractory sidewall due to space constraints*
- *Existing furnace foundation reinforcement to overcome lateral forces on furnace piers during crucible support steel expansion*
- *Conversion of an open-loop gravity feed cooling water system to a closed loop pressurised system with integrated emergency gravity feed and backup system*
- *Existing water treatment system and pumping system improvement and modification to meet copper cooling system requirements*
- *Integration of the new instrumentation control system designed by Hatch to increase performance of the furnace monitoring system and operation*
- *Uprate transformer capacity from 25 MVA to 40 MVA to meet with requirement of Shielded- Arc Furnace Operation.*

1. INTRODUCTION

PT Antam operates electric smelting furnaces to carbothermically reduce nickel oxide calcine and produce ferro-nickel product at its plant in Pomalaa, South-East Sulawezi, Indonesia. The Antam furnaces at the smelter were originally built-by others and designed to operate at low hearth power density (< 120 kW/m^2) with nominal power input of 18 MW. This allowed for falling water film shell crucible sidewall cooling at the low heat fluxes delivered by the process. Metal tapping was conducted through a single conventional refractory-bricked taphole arrangement with no cooling. Slag tapping was performed through a conical water-cooled copper tapping block and insert arrangement. Furnace campaign life typically consisted of a local repair at metal taphole 5-yearly and sidewall and hearth perimeter rebuild every 9-10 years.

Hatch conducted a study on the smelter in January 2001 and concluded with recommendation that FeNi I or II nominal power input could be upgraded with the introduction of sidewall cooling. The upgraded power input capability per furnace would allow one furnace to be shut-down at its next scheduled major sidewall and hearth rebuild, and allow processing of the total calcine capacity from kiln I and II through one furnace. This would allow Antam to improve operating efficiency of the smelter and possibly increase throughput by upgrading both furnaces and installing additional kiln capacity. In September 2003 Antam approached Hatch to perform basic and detailed engineering for the modernisation of the FeNi II line furnace at the next major shutdown scheduled for August 2004.

This paper describes the engineering, construction and start-up of the upgraded rebuilt furnace FeNi II and includes recent operating data.

Table 1-1: Furnace Design Features

Design Improvements	Purpose
Lower side-wall forced air-cooled copper fins	Forced-air-cooled copper cooling fins were added to the lower sidewall below metal level to replace water film cooling in this zone. This eliminates risks of refractory hydration, explosion during run-out and assists with freezing metal fingers to reduce metal penetration of the brickwork.
Water-cooled copper metal and slag tapholes	Water-cooled copper tapholes increase tapping integrity and reduce furnace downtime by prolonging tapping channel campaigns through cooling of the refractory. Replacement of tapping channel refractory, usually subject to funneling wear deep into the furnace, is facilitated from outside the furnace. This avoids lengthy shutdown and repair from inside the furnace.
Water-cooled copper waffle coolers at slag/metal interface	Provide intense cooling needed to deal with high heat fluxes and concentrated "knife edge" refractory erosion at the slag/metal interface.
Deep water-cooled copper plate coolers in the slag zone	Water-cooled copper cooling elements were added in the slag zone to stabilize refractory wear, increase furnace life and enable the existing crucible to operate at 32 MW.
Vertical binding system (hold-downs)	A binding system was added to provide vertical refractory compression in order to improve the contact between the bricks and the copper cooling elements, and to promote tight brick joints resistant to metal and slag infiltration.
Slag launder angle increase and modification to water- cooled steel sections with radiant heat covers by Antam	Prevent freezing, launder blockage and overflow during tapping by increasing slag velocity. Water-cooled launders allowed cooling of slag skulls with water to facilitate rapid cleaning and availability of launders for tapping to cope with increased slag tapping frequency.

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Table 1-1: Furnace Design Features (Continued)

Crucible monitoring hardware and software controls	Thermocouples and RTD's in copper coolers and refractory allow monitoring of furnace integrity with alarm and trip conditions to alert operators. Heat flux and refractory residual brick thickness are also calculated and reported to the operator from this data.
Modification of cooling water system to pressurized system	To achieve the header pressure required to overcome pressure drop in copper cooler circuits and minimize the number of circuits. Incorporate the existing head tank as a back-up supply during changeover to emergency diesel pump.
Water treatment and pumping system modification to meet copper cooler requirements	To meet copper cooler operation requirements consistently and particularly for hardness of softened water and new design and set up of flow and pressure of cooling water.
Rotary Kiln No. 1	Refurbishment of Rotary Kiln No. 1 to achieve a capacity of 45 tph charge, due to a declining capacity down to 35 tph charge after almost 27 years operation.

2. DEVELOPMENT OF FURNACE DESIGN FEATURES (BASIS)

2.1. Process Design Basis

The furnace design power was set at 32 MW being Antam's estimated power input level needed to smelt the maximum calcine capacity that could be delivered by the existing calcine transfer system (understood to be about 60 tph). Antam planned to continue operating the FeNi I furnace until around 2008 when it was due for major rebuild of sidewall, hearth and metal tapholes. FeNi II would thus be operated initially at a power level, which would match the production from FeNi II kiln alone (+/- 24 MW). When the FeNi I furnace was temporarily unavailable, or shut down in the future, the FeNi II furnace would operate at 32 MW to process the calcine from FeNi I and II kilns.

In order for the FeNi II furnace to operate at 32 MW a number of existing systems such as process off-gas, feed system, slag handling and furnace power and electrode control need to be upgraded. These upgrades remain outstanding.

Table 2-1 lists the key process parameters for the existing Fein II operation and the design parameters for the upgraded furnace, and can be summarised as follows:

- The upgraded furnace is designed for operation in the existing "brush-arc" operating mode, i.e., with the electrode tips at, or just slightly above, the slag surface. Under these conditions, the slag superheat level will increase from an estimated 100°C in previous operation to 150°C, resulting in an increase in slag tap temperature from 1580 to 1630°C. This would be the worst-case design for the crucible cooling system with total power density being applied to the bath. The transformer envelope, however, was designed to allow operation in the more efficient "shielded-arc" operation in the future when ancillary systems described above have been upgraded.
- The metal tap temperature was expected to increase proportionately with the slag tap temperature, plus an additional amount due to the higher metal fall. The metal superheat was expected to increase from about 200°C currently to an estimated 280°C, resulting in an increase in metal tap temperature from 1450 to 1530°C at 32 MW.
- Future operation at higher voltage in "shielded-arc" mode will reduce the heat intensity in the bath, with the benefits of reduced slag and metal temperatures similar to the existing operation.
- The furnace energy consumption is expected to decrease from about 530 kWh/t dry ore in previous operation to an estimated 510 kWh/t dry ore at the higher power level because of the improved thermal efficiency and the absence of lime flux, partially offset by the higher slag and metal temperatures.
- Tapping frequency of metal and slag would almost double.

Table 2-1: Comparison of the FeNi II Furnace Key Process Design Parameters

Parameter	*Units*	*Existing Operation (Typical)*	*Upgraded Design*
Power	MW	18 -20	32
Hearth Power Density	kW / m^2	120	214
Slag Tap Temperature	°C	1,580	1,630
Metal Tap Temperature	°C	1,450	1,530
Slag - Metal Tap Delta T	°C	130	100
Slag Liquidus Temperature	°C	1,480	1,480
Slag Superheat	°C	100	150
Metal Liquidus Temperature	°C	1,250	1,250
Metal Superheat	°C	200	280
Freeboard Gas Temperature	°C	700-1000	1100
Heat Losses	MW	2.5	3.6
Total Energy	kWh /t Dry Ore	530	510
Ore Rate	tph	37.7	62.8
Slag Rate	tph	30.1	50.2
Metal Rate	tph	4.3	7.1

2.2. Crucible Design Basis

The crucible design basis was developed to ensure that furnace integrity is not compromised when operating at 32 MW, with the associated changes in process parameters and these design changes are described in more detail below.

2.2.1 Crucible Foundation Reinforcement

Although the weight added by the replacement of copper for refractory in the sidewalls led to a minimal increase in overall weight of the crucible, maximum operating slag level did increase from the original furnace crucible design limits. The foundation design was reviewed and found to be lacking for transfer of horizontal loads during furnace expansion and contraction. A number of options were considered and ultimately a design, which allowed ease of installation, was considered due to the limited access made available by the existing foundation design.

The design consisted of tension plates installed between the foundation piers to resist bending forces on the top of the piers from horizontal loads created by friction of expanding/contracting grillage beams supported directly on the concrete piers. Stiffeners were placed between the piers to resist horizontal forces during contraction.

2.2.2 Shell Modifications

The existing furnace shell consisted of a 22mm thick continuous steel cylinder, reinforced with vertical and horizontal stiffeners at the metal and slag tapholes openings. The shell was cooled by a falling water film. To enhance effectiveness of this cooling method, vertical (flat-bar) steel cooling fins / ribs were attached to the furnace perimeter, spaced every 85 mm and extending vertically 1,200 mm from the skew level to bottom plate. The furnace shell / furnace roof (cover) interface was formed by a shelf at the top of the shell, upon which the suspended-roof water-cooled spider beams were supported.

The existing shell had yielded, bulging outward by approximately 40 mm radially at the skew elevation, due to ratcheting of the hearth from thermal cycling during campaigns. Preparation of the existing shell for accommodation of the plate and waffle coolers would require considerable effort (removing existing cooling fins and cutting cooler openings); in conjunction with the existing shell condition (rusted externally, deformed at skew level and condition internally unknown) and accordingly, it was recommended that the existing sidewall shell plate be replaced to eliminate risk and minimise shutdown duration.

The shell was replaced from bottom plate to just short of the shelf supporting the furnace roof (cover). The new shell was designed in three sections; lower shell 50mm thickness in hearth zone, middle shell 38mm thickness in the slag zone and 25mm thickness in the freeboard zone. The shell was reinforced with vertical and horizontal stiffeners around openings and at load concentration points. The shell was designed to contain the refractory and transfer vertical loads from the sidewall hold-downs to the bottom plate, and provides support to the furnace roof.

2.2.3 Sidewall Cooling

The sidewall cooling of the furnace required uprating to cater for the design 24 MW nominal power input level with brush-arc electrode operation (i.e., 24 MW bath power), but also to cater for 32 MW operation in the future in brush-arc to shielded–arc operation. This would allow the total calcine capacity from FeNi I and II to be processed through the FeNi II furnace. The scale up was performed using empirical power density and heat flux data from commercial furnace operations to determine an expected and peak heat flux design basis for the cooling system. The sidewall heat flux design basis for the coolers is given in Table 2-2 below:

Table 2-2: FeNi II Sidewall Heat flux Design Basis in Slag Zone

Criteria	*Heat Flux kW/m2*
Average sidewall heat flux	40
Design for cooling water system	80
Design for individual coolers	160

2.2.3.1 Slag Zone Cooling

In general, slag zone erosion is a thermal problem that cannot be solved by selection or design of refractory alone. Erosion will continue until the sidewall is thin enough to conduct sufficient heat to maintain a thin layer of frozen slag at the refractory hot face. The frozen slag, being chemically inert when in contact with the molten slag, forms a barrier to further corrosion of the refractory [1], [2]. Heat transfer through the wall is enhanced substantially by inserting water- cooled copper elements in the furnace brickwork.

Hatch has engineered refractory cooling solutions for over 45 furnaces worldwide. The new and retrofit furnaces are able to run at higher power densities, allowing more throughput in smaller vessels. The range of water-cooled copper technology available, includes:

Water-cooled copper finger coolers (which penetrate into the furnace brickwork, but with the water passages limited to the portion of the cooler outside the wall)

Shallow-cooled copper plate coolers, which are similar to the finger coolers in that water remains outside the wall, but offer higher heat removal capability

Deep-cooled copper plate coolers, which are cast plate coolers with internal cooling coils so that water is within the sidewall near the hot face, and offers higher heat removal capability than shallow-cooled plates

Copper waffle coolers (which are cast copper elements with internal water cooling) offering the highest heat removal capacity [3]

To withstand the heat fluxes set as the design basis and allow doubling the throughput and almost double the power density in the existing furnace (116 kW/m^2 to 207 kW/m^2), deep-cooled plate coolers were selected. The arrangement of the plate coolers in the sidewall is shown in Figure 2-1.

2.2.3.2 Slag/Metal Interface

As experienced in previous campaigns of the FeNi II furnace and at other ferronickel furnace operations, severe corrosion of the refractory in the metal-slag interface zone occurs over time. This "knife-edge" corrosion takes place as a result of continuous cycling and removal of frozen slag protection in the tidal zone by the metal, when metal temperatures can exceed slag liquidus temperatures, and through chemical attack by slag that can continuously corrode and erode the refractory in this zone.

As can be seen from Table 2-1, at 32 MW operation, the metal temperature expected would be higher than the slag liquidus temperature, thus promoting the above phenomena in the slag/ metal interface. To overcome this, the strategy was to maintain a narrow slag/ metal interface tidal zone by having cooling sufficiently intense to withstand high heat fluxes generated by the metal when lapping at the maximum level.

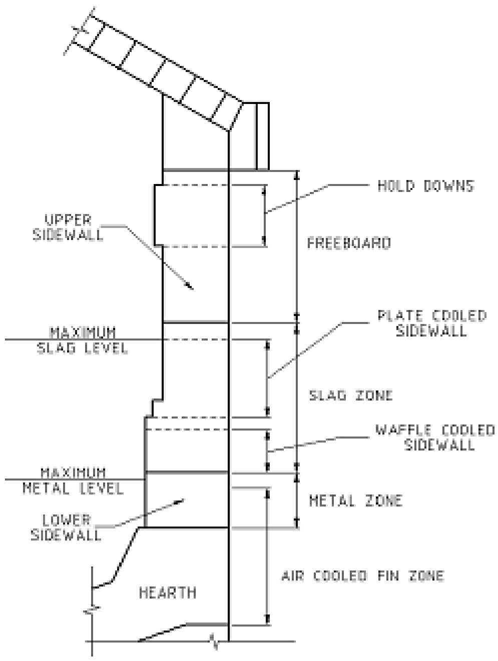

Figure 2-1: Typical Cross Section Schematic Through Furnace Sidewall

Waffle coolers were thus selected and positioned at the maximum metal level with instrumentation installed at the bottom of the cooler to detect high metal levels and so initiates an alarm to tap metal. The waffle cooler was expected to possibly allow the operation of a thin metal level overlap if the metal operating temperature or slag liquidus were such that accretion could be maintained on the waffle cooler and safely allow operation. Operation in this mode would then circumvent the risk of the "knife-edge" erosion discussed above. The arrangement of waffle coolers in the sidewall is shown in Figure 2-1.

2.2.4 Lower Sidewall Cooling

The lower sidewall cooling system consists of copper fins bolted to the outside of the steel shell in the metal zone and skew area. These copper fins are enclosed by platework to form a duct. The copper fins are cooled by air, which is forced through the duct by fans. The air-cooling system uses two fans, one operational and one standby.

Air-cooling the copper fins maintains the temperature of the furnace shell plate within acceptable limits for structural integrity. In turn, the sidewall refractory in the metal zone is cooled, reducing the chance of liquid metal penetrating the refractory bricks. Additional benefits are elimination of a water-cooling system, which could be prone to leaks and resulting in refractory hydration and explosion during metal run-out.

2.2.5 Refractory

The sidewall refractory arrangement was modified to facilitate the copper cooler configuration and a tongue and groove brick design in the lower part of the wall to assist with sidewall stability. The risk of brick hydration from cooling water leaks was mitigated in the design by the use of non-hydratable alumina-chrome refractory on the cold-face of the sidewall, which has the highest chance of being exposed to water. The magnesia bricks in the metal and metal/slag interface zones were also tar impregnated to resist premature wear in the tidal zone

Another improvement to the refractory design was the change of upper hearth radius from 32000 mm to 27471 mm, which improved the hearth brick taper to 1.8mm. Although this taper is still considered to be on the marginal side (3mm preferred) even with the introduction of tongue and groove brick design, this produced an improvement from the existing design without significant changes in skew and taphole elevations.

When considering taper lost due to differential temperature between hot and cold faces of the brick and manufacturing tolerances of typically +/- 1mm, when these tolerances add up in the unfavourable direction there can be the possibility of a reverse taper and potential loss of hearth integrity.

2.2.6 Vertical Binding System (Sidewall Hold-downs)

Spring-loaded vertical binding (sidewall hold-down) mechanisms were included to apply a vertical compressive force to the refractory bricks in the wall. This provides a sealing pressure in the bricks to prevent metal and slag infiltration into brick joints due to ferrostatic forces and resulting sidewall growth and interference with roof systems and potential run-out propagation. The hold-down force also facilitates good contact between the plate coolers and the bricks, which promotes heat transfer and effectiveness of cooling system of the refractory.

Typically a ring beam is placed on top of the refractory wall to distribute the hold-down load from spring assemblies on the perimeter. However by keeping the existing roof system design this was not possible and an enclosure was designed to incorporate the ringbeam in the sidewall. Spring mechanisms apply a downward load to the ringbeam to exert a vertical compressive force on the refractory wall. Since the springs are attached to the furnace shell plate and the shell plate is welded to the furnace bottom plate, the net effect is that the spring forces "compress" the refractory bricks between the bottom plate and the ringbeam.

2.2.7 Metal and Slag Tapholes

2.2.7.1 Metal Tapholes

The existing furnace configuration had only one metal taphole. Due to the increased throughput and opportunity to optimize operating factor, two metal tapholes were installed. The metal tapblocks are an assembly consisting of a three-sided water-cooled copper blocks assembly (comprising lintel, and left and right hand sides) with cast-in water pipe and one water-cooled copper faceplate. Both the tapblock hotface and the tapping channel are waffled. The metal faceplate also has a single groove. The waffle grooves are filled with castable and are shaped to retain the castable or frozen accretion. The copper "dog-house" formed by the three-sided block and skew cooler is lined with refractory surround brick and tapping modules that forms the tapping channel. A replaceable water-cooled copper faceplate with a refractory insert is secured to the front of the tapblock with wedges. The faceplate compresses all the bricks inside the copper module to keep joints tightly sealed.

To facilitate a change in metal taphole elevation if it was established that frozen accretion could be maintained on the waffle cooler and allow metal to run into the waffle cooler as discussed in 2.2.3.2, the bricking arrangement was designed to adjust taphole elevation, as shown in Figure 2-2 indicating the possible configurations.

2.2.7.2 Flanker Coolers

The areas of the sidewalls near the furnace metal tapholes are clearly subject to the highest duty in the furnace and the reason these areas were locally rebuilt by Antam every 5 years. Metal and slag bath heat fluxes are amplified due to the flow of molten material near the tapholes, which translates into a wear profile, typically extending approximately 2 metres beyond the centre line of each taphole.

For this reason, the higher capacity waffle flanker coolers were installed adjacent to, and above, the metal tapholes. Because these cooling elements extend down below the maximum metal level they are subject to much higher heat loads than that experienced by the waffle and plate coolers in the slag zone. These waffle coolers are also designed with a waffled hotface and cast-in water pipe. The refractory-filled waffles ensure that these cooling elements are able to withstand the high heat flux which may be generated should fingers of molten metal penetrate the refractory and contact these coolers' hotfaces. The arrangement of the flanker coolers is shown in Figure 2-3 below.

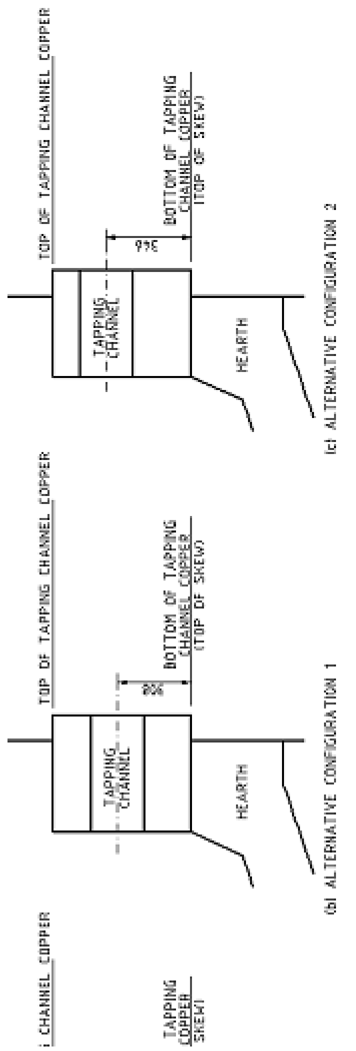

Figure 2-2: Metal Taphole Tapping Channel Bricking Configurations

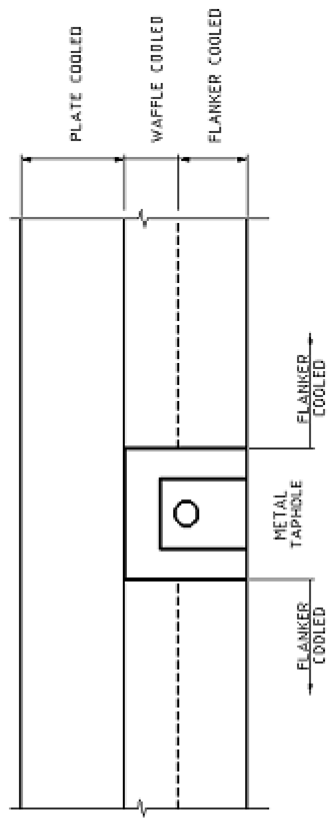

Figure 2-3: Metal taphole with flanker and waffle coolers adjacent to and above the taphole

2.2.8 Cooling Water System

The existing cooling water systems on the furnaces are "open-loop" and comprised a treated "softened" and untreated "non-softened" cooling water circuits. Heat rejection was in the form of "open circuit" evaporative cooling towers. Cooling water pressure and flow was accomplished through gravity feed from a head tank supplied by pumps from the covered cold well. In order to obtain the pressure at the header distribution units to over-come the pressure drop through the copper cooler circuits and achieve design flow, the cooling water system was modified. The cooling system was converted to a pressurized system using the existing pumps supplying the head tank. The existing system had an emergency diesel pump system for "black-out" and pump trip events. The head tank was incorporated to provide cooling water during the period of emergency diesel pump start-up.

A lesson learned from the use of existing 16 year old large bore piping subjected to chemical treatment of the cooling water for softening, was the need to clean the line with acid cleaning prior to "hot" commissioning. Scale build-up from years of operation spalled off the pipe walls and blocked cooling water circuits feeding the copper coolers. This required the dismantling of piping at header concentration points to unblock them.

2.2.9 Water Treatment and Pumping System Upgrade

The capacity of existing water treatment plant was 30 m^3 /h of softened water. During the period of construction Antam installed a new water treatment plant with a capacity of 2 x 50 m^3 /h. The total capacity of the water treatment plant was increased to 130 m^3 /h. Installing the increased capacity of water treatment was necessary based on anticipated future requirements including the FeNi I furnace operation and other equipment uprating. A new arrangement and modernisation of piping distribution, pumping system and instrumentation to control operation of water treatment and pumping system operation was also included in the upgrade to fulfill the copper cooler operation.

The new pumping system capacity was increased from 350 m^3 /h to 620 m^3 /h and additional new cooling towers were installed to control the temperature of cooling water at 40°C as required by the copper coolers.

2.2.10 Rotary Kiln No.1 Upgrading

The existing capacity of Rotary Kiln No. 1 had declined from an average of 42-tph charge to 35-tph charge during almost 27 years of Kiln operation. Upgrading Rotary Kiln No.1 based on current operation and performance has seen and improvement in Rotary Kiln capacity to 45 tph charge and has also improved calcine quality. Some of the refurbishment work conducted on Rotary Kiln No. 1 during the shut-down is as follows: replacement of all old roller and kiln pad shoes, adjustment of kiln shell, burner repair and modification, replacement of all electrode wiring in the electrostatic precipitator, and refurbishment of the pug mill for handling of the dust to make pellets.

2.2.11 Furnace Power Supply

The existing furnace transformer was rated at 25MVA with a transformer envelope, which covered low resistance (9-11 mΩ per electrode) "brush-arc" operation, thus having only low voltage, high current taps (max 550V). Acting on the Hatch recommendation from the study completed in 2001, Antam made a decision to up-rate the transformer to realise efficiency improvements.

The transformer rating was increased to 40 MVA (32MW) and the power voltage current (PVI) envelope was designed to allow an operating point from the existing low voltage ("brush-arc) to high voltage (shielded-arc) operation when furnace ancillaries were up-rated in the future.

2.2.12 Crucible Monitoring System

The crucible Monitoring System provides Antam with considerable value by providing information to the operators and historical information to the process engineer. This information can be used to optimize the performance of the furnace.

2.2.12.1 Copper Cooler Heat Load Measurement

Resistance Temperature Devices (RTDs) are installed to measure the cooling water temperature of the copper cooler circuits. The RTDs provide good stability and high accuracy of temperature measurement. The RTD measurements are used to calculate average heat fluxes, which are then used in the monitoring of the furnace conditions and operation. The zone-by-zone nature of the heat flux calculations allows the furnace operator to quickly detect high heat loads incident on the copper cooler zone, highlighting upset conditions in the process bath.

Additionally a cooling water outlet thermo-well for each copper cooler piping was also included. This thermo-well allows a manual RTD to be inserted. These vacant thermo-wells allow both future enhancement of heat flux resolution per copper cooler through increased monitoring or can provide additional test points for maintenance or troubleshooting of individual coolers.

2.2.12.2 Copper Temperature Measurement

Whereas the water "delta-T" across the cooler measured by the RTD's gives an average heat load incident on the copper coolers, thermocouples in the copper coolers are used to determine local peak heat flux conditions at individual copper coolers. Sidewall heat flux is determined by performance curves generated for the copper coolers and alarm/trip conditions are provided if the heat flux approaches or is beyond, the design condition. Thermocouples in the metal and slag tap blocks are used to determine local conditions at each tap block, indicating the general condition of the tapping channel and tapblock hotface. Alarms are set to ensure safe operation of each tap block. Also, when the furnace experiences upset conditions that result in a sudden increase in local heat fluxes, the "hot spots" will be detected, and alarmed, using cooler thermocouples.

2.2.12.3 Furnace Monitoring Control System

The existing limited FeNi II monitoring instrumentation reported to strip-recorders, which did not give, trended information. For high-intensity furnace operation, furnace monitoring is essential to ensure that the furnace crucible components are only exposed to conditions within the design limits and that any potentially harmful situations are identified before critical damage occurs. By monitoring process parameters, crucible temperatures, and cooling systems parameters, the smelting process can be controlled and optimized, while safeguarding the crucible integrity.

Essential functional requirements for the furnace monitoring system introduced for FeNi II were:

- Monitoring furnace cooler and refractory temperatures and alarm/trip any abnormal conditions
- Monitor cooling water circuit temperatures and alarm/trip any abnormal conditions
- Monitor cooling water circuit flows and alarm/trip any abnormal conditions
- Monitor taphole element temperatures during tapping
- Provide heat flux and residual refractory thickness in front of copper coolers
- Trending of the measurements to allow the process engineer to observe temperature trends.

Cooling water instrumentation and thermocouples input to a centralized programmable logic controller (PLC) system located in the control room. The remote PLC I/O's (Input/Outputs) were distributed in cabinets beside each cooling water header.

Although Antam operators were accustomed to operating with "low tech" monitoring instruments, they quickly adapted to using the control system to obtain critical data from the furnace. User-friendly HMI screens and navigation allowed the control room operator to send field operators to specific equipment to rectify faults as they occurred.

3. KEY ASPECTS DEVELOPED FOR AND LEARNED DURING CONSTRUCTION

3.1. Roof Temporary Support

One of the challenges faced during the FeNi II furnace modernisation construction was the preservation of the existing furnace roof (cover). A novel construction technique was developed and employed successfully to suspend the massive weight of the roof while allowing demolition and installation of the crucible shell plate. The weight of the roof consisted of a heavy water-cooled "spider beam" steel frame, suspended refractory and slag build-up. Although designing temporary support steel for a given load can be trivial, the critical design aspect of the support system for this particular roof system was to avoid flexing of "spider-beam" and disturbing the refractory, which is wedged in these members. The "spider-beam" arrangement was hung from the centre and supported on the shell at the perimeter and the temporary support had to incorporate the adjustment of the support frame to elevation of the roof supports and to distribute the load to prevent the roof perimeter shifting in elevation so creating bending of the roof members.

The roof could not be supported from the foundation because this would interfere with construction, and would impact the desired minimum and compressed work schedule. As a result, a temporary support frame shown in Figure 3-1 was designed so as to allow assembly in the furnace prior to demolition and dis-assembly after installation of the vertical binding system ring beam and new shell. The temporary support steel comprised a ring beam from which vertical posts and bracing were supported and incorporated a jacking system to adjust support point elevation and load transfer and equalization.

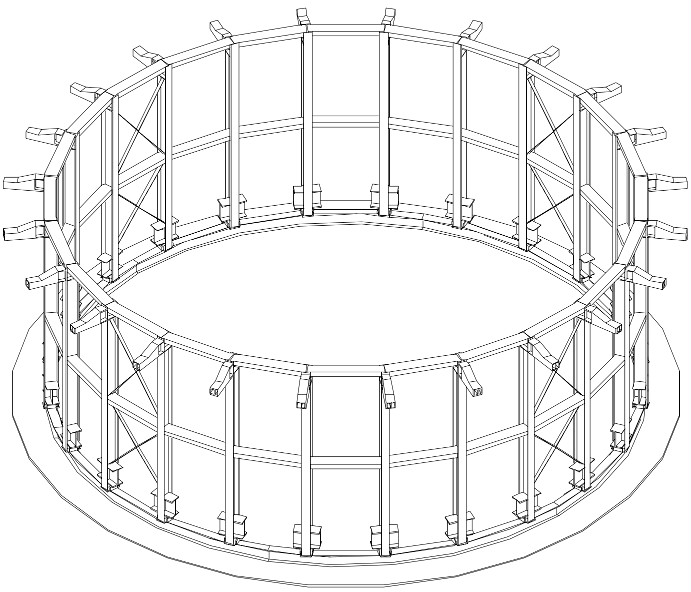

Figure 3-1: Temporary Furnace Cover Support System - Complete System (Note Shell Not Shown For Clarity)

The furnace roof remained suspended for a number of weeks, until the shell installation was completed and roof load transferred to the new shell. By salvaging the roof, construction time and cost were considerably reduced.

3.2 Delay due to Bottom Plate and Grillage Damage

Typically during rebuild of a furnace down to bottom plate, replacement of the bottom plate is normally not anticipated (other than when hearth run-out has been experienced) due to crucible refractory load maintaining the form of the plate. Other than "dogging" of the plate to the grillage beams to achieve installation elevation tolerance, the bottom plate is normally re-used and thus no provision is made for replacement. Taking this approach introduced an unfortunate delay in the schedule, because after demolition of the hearth, extensive bulging (as much as 0.5 metres) of the bottom plate and lifting of the grillage beam sections had occurred. Due to the location of the site being on a remote island, steel sections required to effect repairs were weeks away and this repair being on the critical path led to a delay in schedule.

The lesson learnt from this experience is to make provision for materials and possible installation, which are normally rejected due to additional cost. If the calculation were performed for the cost of lost production in this example, the additional cost for having made provision for the materials up front would have been insignificant.

One other challenge encountered during the bottom plate levelling to tolerance was the restricted access to the grillage beams beneath the bottom plate, which was typically under 1m. Ingenious methods were developed for the anchoring and adjustment of the bottom plate to achieve the tolerance level required for refractory installation.

4. FURNACE START-UP AND OPERATING DATA FROM FENI II

The important objectives of any circular furnace start-up are to ensure refractory dry-out with a pre-heat phase of start-up and then to achieve sufficient temperature in the hearth to combust expansion paper and expand refractory. This ensures that sufficient pressure is generated on the hearth to provide integrity for the final phase of bath building. Calculations of expected temperatures, expansion movements and pressure were performed for start-up and monitored by sacrificial thermocouple and physical measurements, respectively. The development of the FeNi II start-up procedure became a fully engaged effort of Antam with Hatch knowledge and experience as well as review and input of leading ferro-nickel producer's worldwide.

The critical parameters developed for the start-up procedure were;

- Ramp-up rate of refractory temperatures to avoid large temperature gradients and allow controlled brick movements
- Temperature monitoring of refractory and start-up charge to avoid molten material before sufficient expansion
- Start-up charge selection to achieve low carbon high iron content to create a build-up (salamander) to protect the hearth from infiltration but allowing heat transfer to fully expand the hearth.
- Limiting the amount of carbon to ensure low silicon in metal for initial metal tap

All the above critical parameters were recorded and trended during start-up and planned ramp-up rates were achieved. This can be seen in the start-up graphs in Figure 5-1

Hearth physical movements were also monitored and checked against calculated expansion at temperature milestones and found to correlate directly. The graphs of hearth expansion are provided in Figure 5-2.

Because the furnace heat flux design basis was scaled up from empirical data from operating furnaces, it was useful to compare actual heat flux operating data from the FeNi II furnace although not yet at nameplate capacity of 32MW. The heat fluxes recorded in the slag zone were well within the average design basis set of 40 kW /m^2.

The furnace was ramped-up to 25MW with electrode resistance being increased to 25 mΩ to achieve as close to shielded-arc operation as the ancillary systems would allow. The furnace operated exceptionally well at this level with power set point matched with kiln production. Slag temperatures recorded were below those expected due to the higher resistance operation, with Antam achieving the associated benefits. Metal temperatures were initially higher than expected and 1530 °C was achieved at 25 MW operation, whereas this was expected at 32 MW. The Hatch operational support team post start-up worked with Antam to adjust the kiln

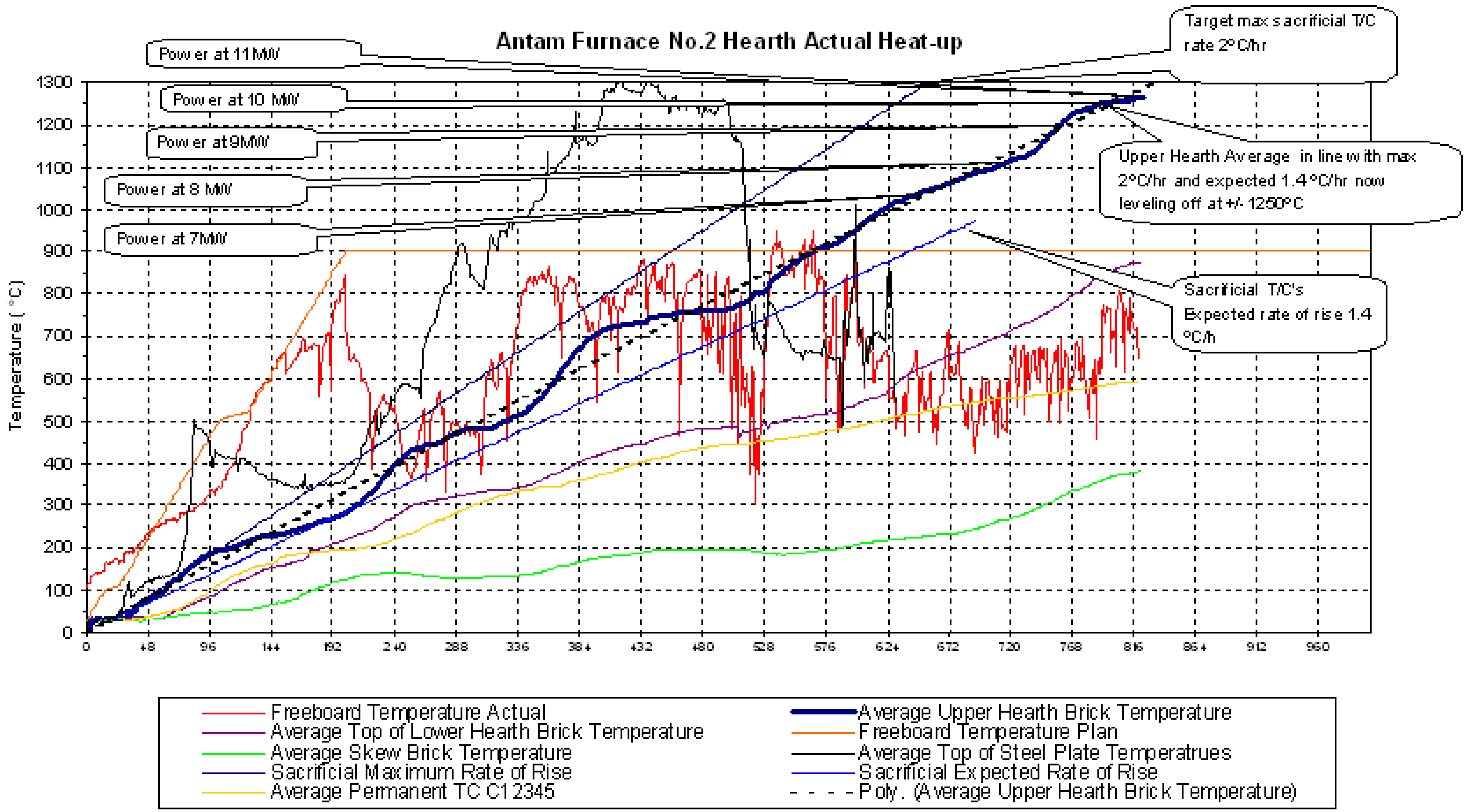

Figure 5-1: FeNi II furnace hearth heat-up data

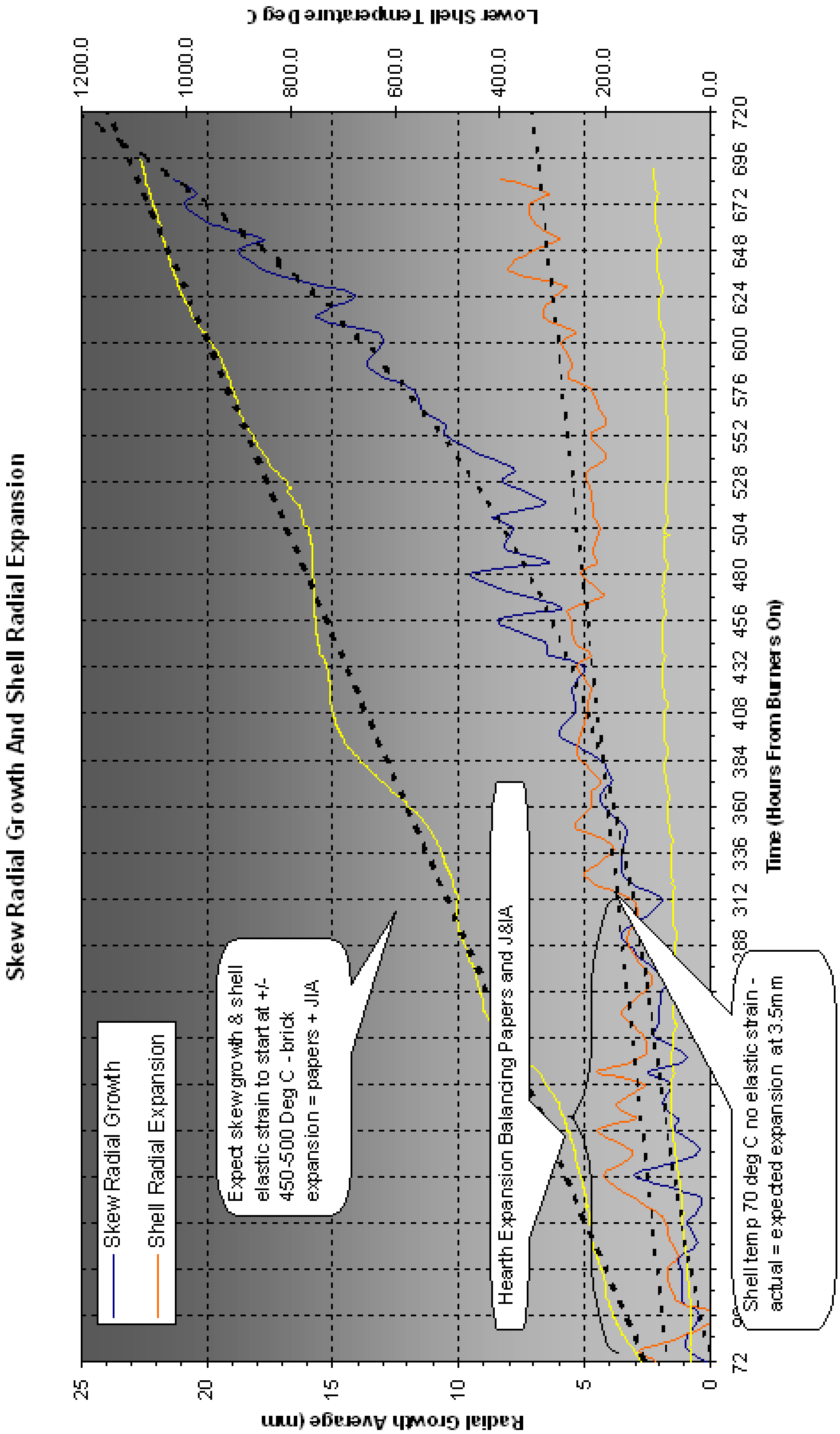

Figure 5-2: FeNi furnace hearth and shell expansion data

chemistry, which seemed to be the problem and were able to lower the metal temperature to 1450 °C achieving, as with the slag, lower than expected operating temperatures.

5. CONCLUSIONS AND RECOMMENDATIONS

The success of this modernisation project in a remote location with operation and engineering personnel inexperienced in some aspects of high-intensity furnace technologies as implemented, demonstrates the ability for knowledgeable and experienced owner teams integrating with a technology supplier like Hatch to achieve efficiency improvements in furnace operation and profitability. Antam have now achieved the trend that has dominated the ferronickel industry, to increase throughput in an existing crucible installation.

The careful division of scope and battery limits allowed the Indonesian content to be maximised where possible and to obtain the most competitive costing, quality of supply, schedule and installation from vendors who are familiar with Indonesian codes and requirements.

The major lessons learned and achievements realised in this upgrading and modernisation project have been:

- Components having lead times, which can cause schedule delays if not available, should be procured even if replacement is not planned. Financial justification due to lost production should be a “no brainer” during risk assessment.
- Re-use of existing piping systems which have been subject to cooling water chemically treated for softening should have acid cleaning before commissioning to avoid blockages from scale spalling from pipe inner walls.
- Development of a sound start-up procedure, and careful monitoring and control is the key, and achievable as demonstrated in this project, to obtaining maximum integrity during the high-risk phase of hot commissioning and ramp-up.
- Operation in high voltage, shielded-arc mode is highly desirable to achieve the objective of lowest bath power density for a given throughput and resulting efficiency and tapping integrity benefits with lowest molten product superheats.

The full benefits of the FeNi II furnace transformer and crucible input power capability to allow a single furnace operation for FeNi I and II will require upgrading of the furnace ancillaries, specifically feed system, power and electrode control, process off-gas and slag handling. These systems should be addressed at the earliest opportunity to take advantage of the efficiency benefits or increased production from the Pomalaa smelter in the future.

6. ACKNOWLEDGEMENTS

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