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Hatch Developments in Furnace Design in Conjunction with Smelting Plants in Africa

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Abstract – The paper describes the development of furnace designs by Hatch in conjunction with the smelting plants in Africa to meet the intense process requirements in certain applications; continued improvement in operating efficiency through increased throughput from existing crucibles; and improvement in campaign life and furnace integrity. The era of Hatch in Africa has seen the doubling of furnace power in retrofit projects using existing crucibles to developing the highest intensity immersed electrode operations in the world. This has resulted in minimized OPEX and CAPEX per unit of production. Through the continued development of its cooling, binding and furnace power supply technologies and working with the experienced and knowledgeable personnel at the smelting facilities in Africa, Hatch has managed to meet the challenges of ever increasing furnace process requirements associated with increased power density and superheats prevalent in the operations. In addition to developing furnace crucible designs, Hatch has also intensified its 'after sales service and support' with the construction, commissioning and start-up technical assistance and operational readiness and operational support for ramp-up to nameplate capacity and beyond. The key areas of furnace risk associated with high superheat molten material tapping has also seen the development of diagnostic systems to mitigate risks and produce early warning signals for the operators.

INTRODUCTION

Hatch has been applying world-leading furnace crucible cooling, binding, and electro-technologies in the African pyrometallurgical industry for almost three decades. Hatch furnace technologies have been continually developed and improved in conjunction with smelter operators from most of the platinum group metal (PGM) producers, as well as from ilmenite, copper, and ferroalloys smelting operations. A list of furnaces in Africa incorporating Hatch technology outlines the extent to which local clients have increasingly sought partnership with Hatch to deliver innovative and cost-effective smelting solutions (Table I).

Table I: Furnaces built or retrofitted by Hatch in southern Africa

Platinum Group Metal (PGM) Furnaces:

Client Name		Anglo Waterval Smelter	Zimplats	Impala Platinum	Lonmin	Anglo Polokwane Smelter	ACP
Date Operating Hatch Components		1992, 1993	1998	1991, 1999	2002	2003	2002, 2005
Final Product		PGM Furnace Matte	PGM Furnace Matte	PGM Furnace Matte	PGM Furnace Matte	PGM Furnace Matte	PGM Converter Matte
Furnace Type		Electric	Electric	Electric	Electric	Electric	Top submerged lance
		AC, 6-electrode rectangular	AC, 3-electrode circular	AC, 6-electrode rectangular	AC, 3-electrode circular	AC, 6-electrode rectangular	PGM matte converting
Furnace Power (MW)		2 x 34	1 x 12	2 x 40	1 x 27.5	1 x 68	N/A
Hatch Technology	**Bindings**	Wall hold downs and hearth binding	Wall hold downs	Wall hold downs and hearth binding	Wall hold downs	Wall hold downs and hearth binding	Wall hold downs and hearth binding
	Sidewall Cooling	Drilled & Plugged Plate Coolers	Drilled & Plugged Plate Coolers	Drilled & Plugged Plate Coolers	Waffle Coolers + Cast Plate Coolers	Waffle Coolers + Drilled & Plugged Plate Coolers	Waffle Coolers
	Tapholes	1-piece slag & 3-piece drilled & plugged matte blocks	1-piece slag block & 4-piece cast matte block	1-piece slag & 4-piece drilled & plugged matte blocks	1-piece slag & deep matte waffle blocks	1-piece slag & matte blocks	1-piece slag & matte blocks
	Air Cooling	Bottom forced air	Sidewall air cooled fins and bottom forced air	Bottom forced air	Sidewall air cooled fins and bottom forced air	Sidewall air cooled fins and bottom forced air	Bottom forced air
	Electrical	High Voltage	Out of Scope	High Voltage	High Current	High Current	N/A

Other Smelting Furnaces:

Client Name		Chambishi	M3 Samancor Ferrochrome	RBM	Highveld
Date Operating Hatch Components		2002	2003	1977, 1986, 1989	2003, 2005
Final Product		Ferrocobalt	Ferrochrome	TiO_2 Slag & Iron	Iron
Furnace Type		Electric	Electric	Electric	Electric
		DC, 1-electrode circular	DC, 1-electrode circular	AC, 6-electrode rectangular	AC, 3-electrode circular
Furnace Power (MW)		1 x 40	1 x 45	4 x 72	1 x 28; 1 x 36
Hatch Technology	**Bindings**	Wall hold downs	None	Wall hold downs and hearth binding	Out of Scope
	Sidewall Cooling	Waffle Coolers	Cast Plate Coolers	Drilled & Plugged Plate Coolers	Out of Scope
	Tapholes	1-piece slag & matte blocks	Out of Scope	-	Out of Scope
	Air Cooling	Out of Scope	Out of Scope	Bottom forced air	Out of Scope
	Electrical	Out of Scope	Out of Scope	High Voltage	High Voltage

The Hatch technologies have enabled smelters to double, or nearly triple in some cases, the existing furnace input power and resulting metal/matte production, with retrofit installation of the requisite Hatch water- and air-cooled copper-cooling technologies. Unit operating and capital costs have been commensurately decreased. However, these increases in furnace crucible input power levels correspond to increased hearth power density (being electrical power input divided by the hearth plan area) with an associated increase in the superheat of molten products, and increased crucible wall process heat-flux intensities.

Hatch has continually developed its cooling technologies to match these increased process intensities and heat flux requirements; for instance in developing one of the world's first water-cooled copper matte-converting crucibles for the highly intense top-submerged lance (TSL) injection process. This has allowed the converting operation to run continuously without the need for the regular refractory re-lining which is prevalent in existing designs.

The same intense cooling technologies have been applied to open bath smelting in the ferroalloys applications, specifically in DC electric smelting in Africa, but also for AC furnaces, especially for ferronickel smelting.[5]

While the highly robust cooling technologies have enabled furnace linings to operate with greatly improved integrity and long campaign lives, even when subjected to intense heat flux, robust horizontal and vertical binding technologies have been developed to prevent bath leaks forming between cooling elements and long-term furnace growth resulting from the thermal ratcheting created by heating and cooling cycles.

This paper covers the specific technical challenges and achievements of a selection from the many projects in Africa where Hatch-customised furnace technologies have been applied with success, while some of the setbacks overcome, and challenges encountered, with continued intensification of furnace smelting technology are also described.

DEVELOPMENTS IN FURNACES AT RBM

There has been a special working relationship between Hatch and Québec Iron & Titanium (QIT) that can be traced back to the 1950s when Dr Gerry Hatch was employed, first as Research Director and later as Works Manager for QIT. This relationship strengthened, and, by the 1970s, Hatch was undertaking all QIT's project work.[1] Establishment of Richards Bay Minerals (RBM) by QIT, Union Corporation of South Africa, and the Industrial Development Corporation (IDC) of South Africa proved to be no exception to this, when Hatch was retained to design the processing facilities for this major enterprise. Hatch has continued to be involved in RBM's smelter expansions and rebuilds ever since.

The original integrated processing plant designed by Hatch was commissioned in 1977. The pyrometallurgical processing of ilmenite concentrate involved roasting in innovative three-stage fluid-bed calciners, followed by cooling in indirect fluidized coolers, and further upgrading via magnetic separators, and, finally, selective carbothermic reduction and smelting in two high-powered six-in-line, rectangular furnaces (Table I). The main product was 85% TiO_2 low-alkali slag, with iron as a by-product.

Hatch was next retained to implement the third smelting furnace in 1986 and later the million-ton expansion project that was commissioned in 1991 and included a fourth high-intensity furnace; additional magnetic separation capacity; a second ladle injection station and pig caster; an innovative fluid-bed classifier; enlarged feed and product storage silos; along with modernised environmental systems and process control equipment.

Construction was completed in 19 months, with Hatch assisting in all construction supervision, commissioning, and start-up activities. The project received the 1991 South African Project Management Institute Award for the Best Managed Project in South Africa. This success bears testimony to a highly competent owner's team and the excellent understanding and co-operation established over several years through close interaction with the Hatch project team.

DEVELOPMENTS IN FURNACES AT IMPALA PLATINUM

Up until 1990, Impala Platinum operated four electric furnaces in Rustenburg, smelting PGM concentrates, and saw an opportunity to improve their productivity by constructing a new high-power Furnace No. 5, with approximately the same capacity as the total of their existing four furnaces. Impala and the Gencor management selected Hatch to deliver a new state-of-the-art furnace with a design capacity of 40 MW, and with sidewall copper coolers, robust binding systems, high capacity tap-blocks, and electrode seals.[2] The smelter building, feed system, and utility systems were engineered by Gencor's engineers (GET). This group was later acquired by and merged into Hatch Africa.

Impala had identified the need for furnace upgrades after suffering years of severe sidewall erosion and furnace re-builds every 2-3 years. Frequent slag and matte tap-hole maintenance was also an issue. Hatch installed five rows of sidewall plate coolers to enable operation at up to 40 MW. Hatch re-designed the binding system with much higher forces to keep the bricks tight especially during furnace re-starts. Newly designed spring-tensioned sidewall hold-downs were installed. Three slag tap-hole blocks were installed, together with two 3-piece, water-cooled matte tap-holes. High-capacity furnace transformers and 40 kA bus-work and upgraded fail-safe spring-tensioned electrode power clamps and slipping devices were installed.[11] The project was successfully executed through a close union of Hatch Technology Supply and Gencor installation engineering.

One year after the 1991 start up, Impala's Furnace No. 5 was operating at 40 MW, which was an impressive 267% increase over their previous highest-powered 15 MW furnace. A more significant achievement in the furnace operation was the reduction in unit power consumption from 850 to 650 kWh/t concentrate.

Subsequently Impala replaced their No. 3 Furnace with a Hatch-designed furnace similar to the previously-supplied No. 5 furnace, which has produced equally impressive smelting operational results.

DOUBLING OF FURNACE POWER AT ANGLO PLATINUM – WATERVAL SMELTER

In 1992, Anglo Platinum approached Hatch to approximately double the power capacity of their Furnace No. 1 at the Waterval Smelter from an existing 18 MW to a future 34 MW. The furnace power supply upgrade presented a unique opportunity to take advantage of three unused furnace transformers and Hatch experience with interconnecting furnace transformers. This unique technology for doubling furnace transformer capacity was first implemented by Hatch at Falconbridge's ferronickel facility in the Dominican Republic in 1984.[3,4,5,6] It was also recognized that computer control upgrades were required to operate with the doubling of the smelting power.

Doubling of power input to the furnace also required the rebuild of the furnace crucible and an upgrade of the electrode systems. Hatch was retained to design the rebuild of the furnaces, comprising an upgraded robust binding system, sidewall cooling using an arrangement of water-cooled copper plates (Table I), and electrode columns using Hatch's proprietary fail-safe spring-applied power clamp and seals.[11]

The feasibility assessment of parallel transformer interconnections is dependent upon several key studies, which include:

- Determination of the required electrode voltage, current, and immersion to go from 18 MW to 34 MW operation
- Secondary bus reconnection methods for the required voltage and current
- Assessment of the health of the spare furnace transformers, and their ability to operate at higher electrode voltages
- Vault layout and reinforcing requirements
- On-load tap changer impacts
- Furnace circuit breaker switching transients

The project commenced with electrode immersion measurements combined with furnace transformer capacity diagrams to project the future ranges of electrode immersion, current, and voltage for 34 MW operation. This analysis is shown in the PVI diagram provided in Figure 1.

The electrical circuit diagram presented one of the most challenging aspects of this project, as it encompasses the selection of the primary circuit breaker, and the furnace transformer primary and secondary interconnections. After substantial transient simulations, switchgear equipment selections, and secondary bus-work layout options, the project 'Three Line Diagram' was frozen (Figure 2).

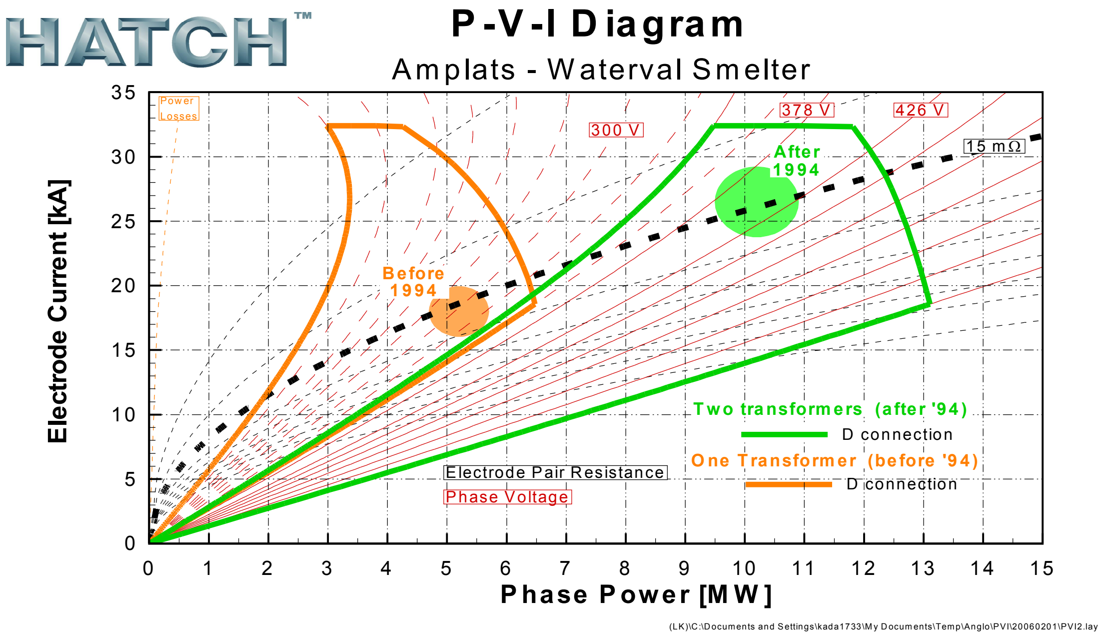

Figure 1: P-V-I Diagram – Waterval Smelter

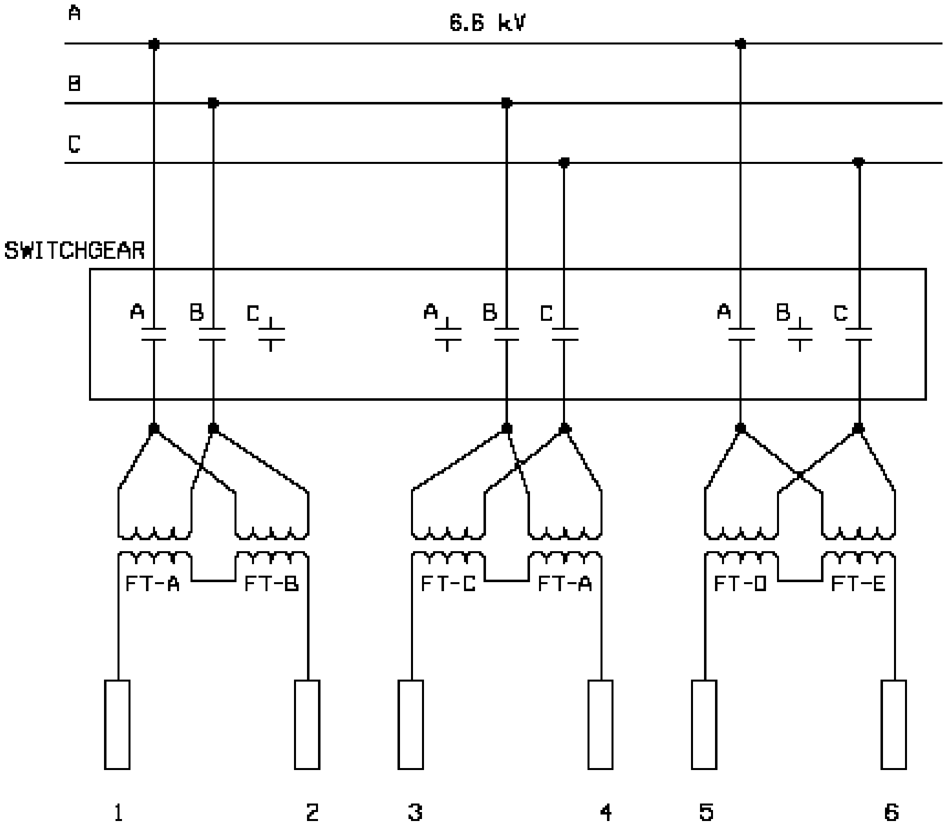

Figure 2: Three Line Diagram

It was determined that a single 6.6 kV high-amperage circuit breaker supplying two furnace transformers, with primary windings in parallel and secondary windings in series, was the optimal design basis. On this basis, the project proceeded with bus-work manufactured by Fuchs, RSA, according to Hatch detailed drawings. A diagram showing the interconnected secondaries of the furnace transformers is provided in Figure 3.

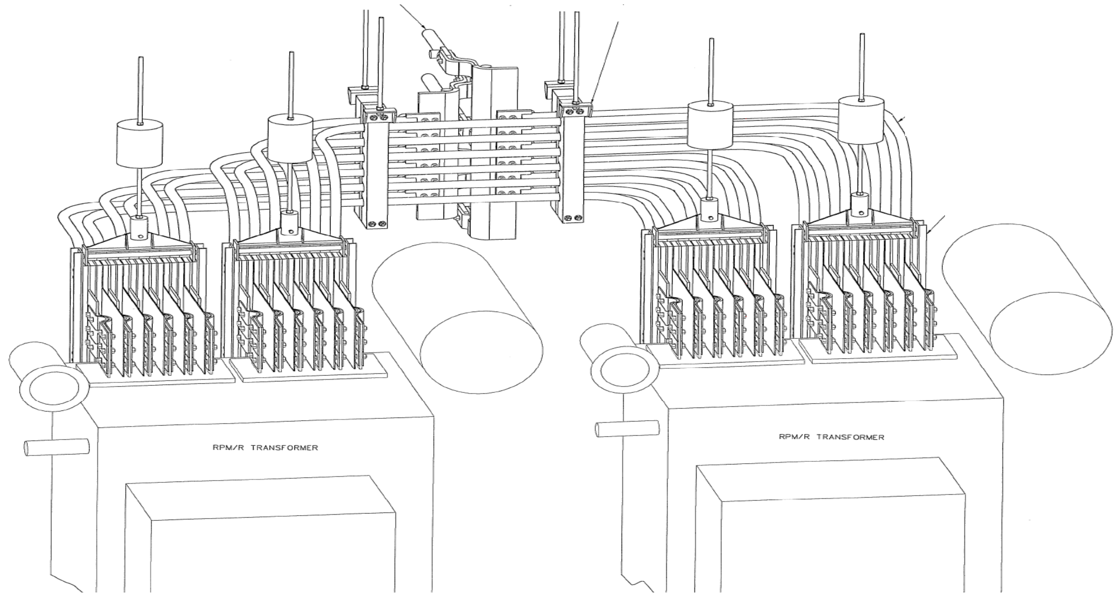

Figure 3: Furnace Transformer Interconnecting Bus-work

The vault reinforcement was designed and supervised by the in-house engineering team according to a Hatch layout.

A combination of proven Hatch technology supply, well coordinated Anglo Platinum installation engineering, and excellent bus-work manufacturing in South Africa, culminated in a highly successful, cost effective, and reliable power supply and controls installation.

DEVELOPMENTS IN FURNACE DESIGN IN ZIMBABWE – ZIMPLATS

The furnace at the Zimplats operation in Zimbabwe was commissioned in 1997 as part of the BHP Hartley project and was the application of a standard Elkem immersed-electrode smelting furnace for PGM smelting. The process parameters expected and specified for the furnace, based on project study work and typical parameters achieved in existing PGM smelters with similar concentrate compositions, were not achieved in practice, and much higher slag temperatures were experienced, typically 100-150°C higher than expected. As a result, the naturally air-cooled sidewall lining failed six months after commissioning and the furnace power was still limited to half nameplate capacity even after repairs were completed to re-instate the original Elkem design.

Hatch was contracted to perform a fast-tracked retrofit design, supply, and installation for a revamped furnace sidewall lining system and tap-hole arrangements (Table I), including a vertical sidewall binding system.[7] As part of the crucible sidewall re-design, furnace maintenance aspects and bottlenecks were addressed as part of the project. One of the main causes of low furnace availability (~70%) was scheduled and unscheduled maintenance associated with the electrode system supplied by Elkem.

The electrode system, because it was a standard design for ferroalloys, had the electrode power clamp system designed to operate in the furnace freeboard and included necessary water-cooled jacket and shielding requirements. The power clamp water-cooled jacket shielding arrangement required to protect the contact clamps, increased electrode clamp maintenance times due to the removal time required, and introduced explosion risk in the furnace in the event of undetected leaks. Hatch, in conjunction with smelter personnel, incorporated a re-designed simple, naturally air-cooled electrode sealing arrangement and raised the elevation of the electrode power clamp out of the freeboard to operate above the furnace roof. This allowed the removal of all the unnecessary water-cooling requirements and associated risk and provided immediate access to the electrode power clamp system, thereby improving availability. Following the electrode design changes, availability increased to 100% on the electrode system, with very low maintenance requirements that could be scheduled in other planned shutdowns.

As with all Hatch customised furnace designs, the appropriate cooling technology was selected by performing thermal modelling and developing an expected sidewall heat flux design basis from operating data. The actual sidewall erosion is compared with Hatch modelling of the expected residual refractory thickness on the sidewall. Figure 4 shows a photograph and centre model output prediction. Contrast the predicted residual refractory thickness at the expected sidewall heat flux with the proposed solution (Figure 4 shows the model output on the right), which provides a stable sidewall cooling arrangement using shallow-cooled copper plate coolers.

After completing sidewall cooling selection and design, fast-track detailing and equipment procurement allowed implementation of the solution within one year, with a construction period of five weeks. Innovative planning and design to minimize the shutdown duration allowed for the suspension of the existing roof system (+100 t) while the furnace shell and sidewall lining from skewback up was replaced. Patent-pending lower-sidewall air-cooling technology was also introduced to improve lower hearth integrity and maintain steel shell temperatures within design limits.

Figure 4: Expected and Actual Sidewall Erosion for Existing Lining, with Hatch Upgraded Solution presented on the right

As part of the re-build, the ergonomics of the existing tapping platforms was improved through structural changes to open up the area and allow easier access during tapping operations.

The furnace operated successfully at nameplate capacity until the Hartley site was shutdown by BHP in 1999. Following re-commissioning in 2003, the furnace is still operating with the existing arrangements today. Continued development in some areas, such as slag and matte tap-blocks, is ongoing with smelter personnel, to improve component integrity based on operating experience.

DEVELOPMENT OF THE WORLD'S FIRST ROBUST CRUCIBLE FOR A TOP SUBMERGED LANCE (TSL) FURNACE – ANGLO PLATINUM

In the late 1990s, Anglo Platinum decided to replace their traditional Peirce-Smith Cu-Ni-PGM matte converter operation at the Waterval Smelter with top submerged lance (TSL) technology. The primary objective of the project was to reduce sulphur emissions from the smelter, enabled by the ability to maintain and capture a steady stream of high-strength SO_2 off-gas from the new stationary converting furnace process. Secondary objectives included increased capacity, improved quality control, and reduced reverts generation.

The Anglo Converting Process (ACP) was developed by Anglo Platinum in conjunction with process technology supplier Ausmelt of Australia. Engineering, procurement, construction management, and commissioning of the entire R1.6 billion facility was executed by Hatch Africa. Commissioned in 2002, the facility is presently performing very well processing granulated smelting-furnace matte from Waterval and other Anglo Platinum smelting operations.

During their planning of the project, Anglo Platinum recognized that a major problem with all existing TSL converting furnaces was severe refractory wear caused by intense agitation in the bath by the top submerged lance. Campaign life for most of the available TSL matte-converting plants ranged from 6 months to 2 years. Based on the successful implementation of integrity-enhancing technology in many other furnaces, including the Waterval electric smelting furnaces discussed earlier, Hatch was awarded the task of designing the crucible for the ACP process.

Key aspects of Hatch's proprietary furnace technology included in the ACP crucible design included (Table I):

- **Copper Waffle Coolers**. A continuous ring of Hatch high-capacity cooling elements was installed throughout the bath zone of the crucible and in the transition from the bath zone to the membrane wall converter freeboard in order to accommodate the high heat fluxes generated by the intense process. The waffle coolers have enabled continuous operation without the need for regular refractory relines associated with other TSL furnaces.
- **Furnace Binding System**. A novel patent-pending circumferential binding system was installed to maintain compressive binding load on the furnace refractories, thereby keeping brick joints tight during all phases of operation, including cooling cycles. Following successful prototypes of circular furnace binding systems in other installations[6,8], Hatch provided a 5.6 m diameter version of the design for the ACP project. The adjustable, spring-loaded system has solved operating problems that have plagued conventional circular furnace operations for decades (*i.e.* floating of furnace bottoms when insufficient forces are applied during hot conditions, and, conversely, extreme infiltration during cooling cycles which leads to commonly observed plastic deformation and failure of the steel shell). A patent-pending vertical hold-down system was also included to maintain tight horizontal joints in the refractory. The purpose of the unique three-dimensional binding system is to minimise penetration of the bath into brick joints, enhance waffle cooler effectiveness and increase furnace campaign life. By all accounts, the binding system has served the ACP facility very well, accommodating the somewhat unsteady plant start-up associated with the commissioning of brand new process technology while protecting furnace integrity during thermal cycles.
- **Furnace matte and slag tap-holes**. Tap-hole modules consist of robust, water-cooled copper blocks inside which refractory tapping bricks are placed. Tap-hole life is increased, maintenance is easier and safer, and tap-hole reliability is improved. A robust slag tapping system design, comprising a water- cooled copper block fitted with internal refractories to counter potential matte entrainment, provides a simple, economic method of slag tapping.
- **Water-cooled copper slag launder**. The robust, water-cooled launder enables easy cleaning of launder skulls and reduces wear and maintenance requirements.

Now nearly four years into the furnace campaign, the Hatch furnace technology is proving to have achieved the desired outcomes. Converter operation is very robust and there are strong indications that a campaign life of ten years can be achieved – a feat unheard of for TSL matte-converting furnaces operating without Hatch technology. A second Hatch-designed ACP converter line is presently being commissioned.

FIRST HIGH-INTENSITY PGM SMELTING FURNACE IN AFRICA – LONMIN

Lonmin contracted Hatch to design a high-powered 27.5 MW furnace for smelting UG2-rich blends of high-chrome-containing PGM concentrate (up to 3.8% Cr_2O_3). Consistent with the focused up-front process and design engineering approach routinely adopted by Hatch, the project began with supervision of test work at the Lonmin facility in their existing furnaces, CFD modelling of the stirring patterns in the furnace, and the interpretation of the data into novel engineering solutions to meet the required duty.

Due consideration of the specific process and engineering requirements has enabled the design of the highest power density furnace in the PGM industry (320 kW/m^2 hearth power density), which by causing bath stirring substantially avoids hearth build-up of chrome spinel accretions. A very high thermal capacity sidewall cooling system using copper waffle coolers (360 kW/m^2 design sidewall heat flux) was selected to deliver long campaign life with high chrome feed, as well as to withstand unusually high matte superheats (up to 650°C). In addition to the core Hatch design technologies listed in Table I, the final furnace design incorporated a flat suspended-brick roof design, and custom-designed pneumatic cylinder, electric winch electrode regulation and slipping electrode column. The electrode columns use Hatch's proprietary, fail-safe spring-applied clamping and slipping system.

Furnace construction was completed by the end of 2001, and commissioning and start-up took place in February 2002. On 26 December 2002, a run-out occurred in the south matte tap block. This occurred shortly after the taphole had been plugged. Excessive wear of the matte tap-block refractory, allowing direct contact of the water-cooled copper tap-block by matte of excessive superheat (up to 650°C) and high turbulence (exacerbated by gas evolution from the taphole clay), caused the failure.

Corrective action focused on the installation of increased taphole monitoring (additional temperature measurement and monitoring through a Matte Taphole Diagnostic System; the principles of which have been published recently[9]). Matte tapping integrity has been improved with the following changes:

- Lonmin reports that the addition of CaO flux to the furnace feed mix reduces the slag melting temperature, which consequently results in a significantly lower (-70°C) average matte temperature[10]
- design of an increased tapping channel refractory length in the matte tap-block by addition of a spout and lintel section, along with more frequent refractory maintenance

- increased matte-level monitoring and control, involving development and installation of a Matte Level Predictor to aid interpretation of automated bath soundings
- greatly increased furnace control, involving a total revamp of the furnace control system architecture and installation of the full Hatch Integrated Furnace Controller
- operator training coupled with a sustained period of operational support with Hatch engineers to expedite stability of the furnace operation following ramp-up.

An unfortunate furnace explosion in November 2003 resulted from water ingress from a failed electrode flexible water connection that was damaged by a fire on the furnace roof a couple of days previously. This caused a further setback, requiring a furnace restart in January 2004. Since that time, the furnace has operated in a very stable, predictable, and highly efficient manner, with the smelting process design of 16 000 t/month new concentrate being exceeded, even at power set-points of only 80% of the furnace design.

A planned rebuild was performed in January 2006 to implement design changes to the furnace shell, and introduction of plate coolers above the waffle coolers to facilitate 'hot' change-out of waffle coolers from the outside of the furnace. (See the section below entitled 'CORROSION IN PGM FURNACES – UPDATE').

DEVELOPMENT OF THE HIGHEST-POWER IMMERSED ELECTRODE FURNACE OPERATION IN THE WORLD – POLOKWANE

The rectangular six-in-line furnace installed in the Anglo Platinum Polokwane Smelter is the largest, high-intensity furnace for PGM matte smelting in the world.[11] The furnace employs state-of-the art technology for a nominal design input of 68 MW, with a turn-up design capability to 80 MW. This furnace provides double the smelting capacity of previously existing PGM furnaces, and was designed to offer low unit operating and capital costs through the resulting economies of scale. Although low specific energy requirements have been achieved for this demanding process, the success of the accomplishment has been dampened as a result of unanticipated, aggressive corrosion of the copper blocks at the slag-charge interface level that results in costly cooler replacements and reduction in operating factor.

Paramount to the design of the furnace was consideration of the process requirement to achieve high-intensity smelting of a high proportion of UG2 feed containing up to 4% Cr_2O_3 content. Operation at higher power densities and slag Cr_2O_3 levels necessitates higher bath temperatures to avoid undesirable precipitation of solid spinel phases at the matte-slag interface, or as build-up on the hearth.

Fundamental to addressing the chrome issue was the selection of adequate transformer capacity to permit application of the power density at deep electrode immersion (immersed up to 75% of the slag layer thickness) and the ability to operate at high hearth power densities (up to 250 kW/m^2) to substantially prevent build-up of chrome spinels on the hearth.

To match the demands of the high sidewall heat fluxes resulting from high power density, deep electrode immersion and excessive process temperatures, high-intensity Hatch waffle cooling technology was applied. Hatch robust bindings, electrode columns, and air-cooling technologies were included in the furnace design. The electrodes incorporate Hatch's patent-pending, fail-safe, spring-applied slipping and clamping arrangement.[12] This robust, simple design minimizes water above the furnace roof.

As part of the furnace technology delivery, commissioning, and start-up, the training of operations and maintenance personnel was incorporated into the deliverables, which were subsequently extended to include operational readiness and support.[13] Key experienced staff were hired to manage the operations. The remaining staff, although of the highest academic level and aptitude, were recruited locally around Polokwane, but were generally inexperienced in PGM smelting and high-intensity furnace operation. Through training and operational support, Hatch was able to assist the operations personnel in maintaining and monitoring the Hatch technologies installed, to the highest level.

The furnace has demonstrated the ability to exceed monthly smelting targets when operated near the capacity of 68 MW, but operational performance has been affected adversely by two incidents resulting from unexpected and severe corrosion of the copper waffle coolers.

CORROSION IN PGM FURNACES - UPDATE

All PGM smelting furnaces that treat dried, un-calcined concentrates which contain labile sulphur, and minute quantities of chlorides, have experienced a corrosion problem at the slag-charge interface level; such facilities include Impala Platinum, Anglo Platinum Waterval and Polokwane, Lonmin, Zimplats, and Stillwater Mining Company.

By contrast, water-cooled copper coolers have been installed in a wide variety of electric, fuel-fired and flash-type sulphide smelting and converting operations, charged with calcined or oxidised sulphide feed materials, and none have suffered this type of corrosion. This includes highly successful application of waffle coolers in TSL converting on ACP, under oxidising conditions.

An increase in corrosion of the water-cooled copper in furnace linings by both S- and Cl-bearing gases has been an unexpected and undesirable consequence of the proximity of the copper to the lining hot-face required for high thermal capacity cooling. The corrosion is not limited to water-cooled copper coolers; significant corrosion of conventional cooled or un-cooled magnesia refractories, as well as the inner surface of the steel shell on falling-water-film-cooled furnaces, has also been noted.

The precise mechanism of corrosion is under intense study, but unlike the more common dew-point acid corrosion mechanism associated with SO_2-bearing gases in other operations, the corrosion appears to be a direct sulphidation attack progressing under more reducing conditions (elemental sulphur is abundant with the sulphide corrosion products), assisted by chlorination (presumably involving HCl), leading to some chloride corrosion products (most commonly found in direct contact with the copper substrate). The corrosion is essentially restricted to the slag-charge interface zone where the evolution of labile sulphur and chlorides from the un-calcined concentrate would be expected.

Three strategies are being vigorously pursued to tackle this problem:

- Prior partial roasting of the concentrate sufficient to substantially remove only the labile sulphur (and chlorides) prior to charging into the furnace. Inco and Falconbridge have long adopted a similar approach to nickel matte smelting by performing a greater partial roast of their concentrates (typically to > 65% sulphur elimination).[14,15] The ultimate application of this technology involves dead roasting (80% removal of total sulphur), followed by partial carbothermic reduction of the roasted concentrate in the furnace, in a process named Roast-Reduction Smelting (RRS).[14] Although suggested by Hatch for study by some local platinum clients, the technology has yet to be adopted commercially outside nickel production.
- Materials selection to find a coating/material for the coolers with the required heat transfer and fabrication properties that can survive the highly corrosive environment.
- Modification to process smelting conditions within the furnace concentrate blacktop, to lower the rate of corrosion locally, in close proximity to the waffle coolers. Lime addition has only been partially successful to effect capture of labile sulphur; limestone addition with *in situ* calcination is under trial to additionally provide some local dilution of the corrosive gaseous species, and scrap iron addition is being considered for capture of corrosive species.

While partial roasting offers the surest remedy, a final solution is yet to be implemented. Consequently, on both PGM smelting sites with waffle coolers, the focus has been on the re-design of the copper coolers arrangement to permit planned rapid replacement of corroded coolers during 'hot' repairs conducted from outside the furnace. Replacement of plate coolers and tap-blocks from outside a hot, idling furnace has been accomplished, *e.g.*, at Impala and Stillwater Mining, *etc.*

DEVELOPMENTS IN DC FURNACE FREEBOARD COOLING – MIDDELBURG FERROCHROME

Samancor Chrome approached Hatch to help address sidewall erosion issues being encountered at their Middelburg M3 furnace. The M3 furnace is a 40 MW DC furnace used for the production of ferrochrome. The furnace was experiencing severe erosion of the upper sidewall refractory while the lower wall and hearth were experiencing normal levels of wear. The result was short sidewall life, limiting the furnace campaign and leading to costly furnace down time.

Hatch was asked to help investigate the cause for the erosion, working with M3 plant personnel, and to recommend a solution to be implemented on the M3 furnace. Initial investigations led to the conclusion that the wear was likely due to a combination of thermal and mechanical wear, as thermal wear alone could not account for the severe erosion observed. Given this combination of potential causes, the decision was made to install a test panel of Hatch-designed copper plate coolers. The aim of the test panel installation was to establish the process conditions present, in particular to determine the sidewall heat fluxes in the upper sidewall of the M3 furnace. Gathering actual process data was critical to ensure that the solution chosen was adequate for the conditions present and yet not over-designed.

The test panel consisted of 12 deep-cooled, cast copper plate coolers and was extensively instrumented to provide detailed process information. A novel hold-back system for the plate coolers was implemented that provided support to the test panel should severe erosion occur below the panel, while still allowing the coolers to adjust to any wall growth or movement. Installation occurred in early 2002, and the test panel operated successfully prior to a full rebuild in September 2003. The data collected during this period allowed for the calculation of operating and peak heat fluxes during the campaign, which then served as the thermal design basis for the design of a full rebuild using Hatch cast plate coolers integrated into the refractory sidewall.

The design finally implemented had to work within many constraints including a tight rebuild schedule, as well as having the least impact on the existing plant equipment. The design features of the test panel included (Table I):

- Six full rows of deep-cooled cast plate coolers in the upper wall, fully integrated into the sidewall refractory
- Two partial rows of coolers at the metal taphole elevation for added wall protection in the critical tapping area
- Piping circuit design selected such that the maximum cooling capability was provided while working within the existing cooling plant capacity
- Plate coolers designed such that the furnace shell modifications were minimized to facilitate the shortest possible rebuild schedule
- Seals provided on all plate cooler openings to reduce the amount of CO leaks during operation of the furnace

The full rebuild was implemented in 2003, with Hatch providing detail engineering services, along with construction, commissioning, and start-up assistance. With the Hatch-designed plate coolers integrated into the sidewall refractory, little to no wall erosion was observed and the improved sidewall performance helped extend the furnace campaign life beyond what had been seen previously.

DEVELOPMENTS IN SMELTING PROCESS – HIGHVELD

In the 1960s, Highveld Steel and Vanadium Corporation Limited was born out of a unique iron-smelting process developed specifically for a vanadium-rich iron deposit located near Witbank. Historically, the furnaces have run in a submerged-arc mode of operation, typical of the ferroalloy industry, with a particular practice established during the development of Highveld to maximize vanadium recovery. The furnace operation remained unchanged until, starting in the late 1990s, Hatch began working with Highveld to identify opportunities to address problems related to:

- Difficulties in controlling slag chemistry and thus vanadium recovery
- Operational instability due to the furnace operation being overly dependent on the characteristics of the feed from the kiln
- Burden conductivity being very high and particularly dependent on the fines content in the burden.

One important limitation of the submerged-arc mode of traditional operation at Highveld is the low electrode resistance (less than 1 mOhm), resulting in furnace power input being limited to about 21 MW by the existing transformer and low-voltage bus arrangement.

Hatch and Highveld together assessed the possibility of adopting the partially open-bath mode of operation with the following perceived advantages:

- Ability to make 'medicinal' additions directly to the slag bath to control chemistry
- Efficiency of open-bath mode of smelting, independent of size distribution of DRI, allowing fines to be added without destabilising the smelting process
- Enhancement of reduction kinetics, as most DRI is fed directly into the open-bath area around electrodes
- Ability to operate in a brush-arc mode at much higher resistance, thereby removing the furnace power supply as the main limitation to power input.

Ultimately, the partial open-bath operating mode was anticipated to translate into a substantial increase in power input into each furnace.

The first step of the plant-scale trial program proposed by Hatch commenced in September 2003. The results exceeded expectations; in addition to improved control and stability, a significant increase in vanadium recovery was experienced. Although the trial was scheduled for 6 weeks, Highveld continued to operate the furnace in the open-bath mode for more than 9 months. With these positive results, the next step in the program was completed by converting furnace 5 to open-bath operation in 2005, with a modest increase in power (no coolers were installed). Results after the first 5 months of operation again exceeded expectations.

Currently Highveld is proceeding with the conversion of furnace 6, and, ultimately, a full upgrade of a third furnace at 50-60 MW (including Hatch copper coolers) is under consideration.

DEVELOPMENTS IN FURNACE DESIGN FOR INTENSE SLAG SUPERHEAT– CHAMBISHI METALS, ZAMBIA

Following three unsuccessful campaigns in the first 18 months of operation, Hatch was approached in mid-2002 to perform a retrofit of the bath sidewall cooling of the Chambishi 40 MW DC-arc ferrocobalt furnace.[16] The specific requirements were to make the furnace wall cooling system much more robust thermally and to address the slag/refractory corrosion problems associated with the highly superheated (ΔT = 400°C) corrosive siliceous slag (roughly 50% SiO_2). The alloy-slag interface presented the core design challenge, where a single refractory type cannot meet the requirement of adequate corrosion resistance against both alloy and slag simultaneously.

The ultimate solution implemented required (Table I and Figure 5):

- Installation of Hatch waffle-type, water-cooled copper bath sidewall coolers and tap-blocks
- Installation of Hatch spring-loaded, sidewall hold-down system to ensure tight sidewall/hearth joints
- Changing the refractory materials as follows:
  - Slag zone – alumina-chrome ram mix
  - Metal zone – alumina-chrome in skew area, magnesia in the upper hearth course, and magnesia graphite in the lower hearth course.

The change in the refractory selection produced a favourable result, in that no significant refractory hydration effects have been experienced.

The solution implemented was somewhat novel, in that it involved operation of the entire slag bath, the slag-alloy interface and a portion of the alloy bath within a more chemically compatible refractory/slag/alloy freeze-lining. Due to the high furnace power density employed (up to 500 kW/m^2 hearth area), coupled with the large slag superheat needed to effect alloy tapping, the resulting imposed peak sidewall heat fluxes were substantial. This required cooler designs capable of continuous operation at heat fluxes of 100 and 500 kW/m^2 in the slag and alloy zones, respectively.

Not anticipated in the process design basis originally provided by the client, but identified through extended Hatch operational support with the client during the ramp-up of the retrofit furnace, was periodic silicon reversion and CO boils on the furnace (Figure 6). These events were capable of greatly magnifying the sidewall heat fluxes, which on occasion locally exceeded 1 000 kW/m^2. The furnace is currently operating at design capacity.

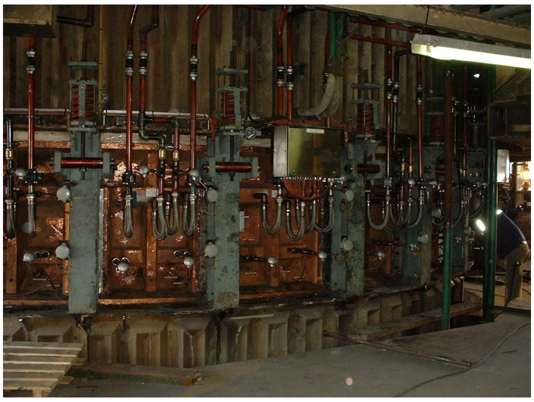

Figure 5: View of spring hold-down system and waffle coolers – Chambishi

Figure 6: Vigorous boil against waffle coolers – Chambishi

CONCLUSIONS

Hatch has developed, and is continuously improving, furnace technologies applied in the African pyrometallurgy environment, to meet the demands of the industry. The wealth of furnace design knowledge, experience, and capability of the combined forces of the Hatch and operating company staff has seen many of the smelters benefiting through increased furnace productivities and resulting efficiencies, as well as improved integrity through the custom-design of specific innovative furnace design features. Major achievements in furnace technology application have been as follows:

- Doubling furnace throughput in existing crucibles, for greatly reduced unit capital and operating costs
- Design of the first circular binding and copper-cooled crucible for the intense process of lance injection converting
- Design of highest power density electric furnaces for high-chrome PGM smelting
- Retrofit installation of cooling technologies, especially in DC ferroalloy applications, to enable sustainable operation.

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