Recent Improvements at the BCL Smelter

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Keywords: Pyrometallurgy, flash, smelting, furnace, nickel, copper, Botswana

Abstract – BCL Limited operates the only Flash Smelting Furnace on the African continent, at Selebi-Phikwe, situated in north-eastern Botswana. The furnace was commissioned in 1973 and produces a high-grade sulphide matte containing nickel, copper and cobalt, which is shipped to refineries in Zimbabwe and Norway for further processing.

This paper outlines the recent process improvements and plant expansions that have resulted in a capacity increase from 40 000 to 60 000 tons per annum of metal production.

INTRODUCTION

BCL Limited operates the only Flash Smelting Furnace on the African continent. The smelter is located in the mining town of Selebi-Phikwe (population about 50 000), situated in north-eastern Botswana, about 50km off the Gaborone – Francistown highway. The furnace was commissioned in 1973, and produces a high-grade sulphide matte, containing nickel, copper, and cobalt, which is shipped to refineries in Zimbabwe and Norway for further processing.

SMELTER PLANT DESCRIPTION

Figure 1, overleaf, depicts the schematic diagram of the overall plant.

Feed preparation consists of a pair of Niro spray dryers, each rated at 55 metric tons per hour, and a Kvaerner multi-coil steam dryer, rated at 50 t/h, supplying dried concentrate to the Flash Furnace charge bin via three 1000 ton capacity storage silos. The concentrate analysis is typically 5% nickel, 3% copper, 30% sulphur, 45% iron, and 8% silica. A pair of loss-in-weight feeders supply 120 t/h of concentrate feed to a four-concentrate burner arrangement, with flux, secondary fuel in the form of milled coal, and recycled boiler dust, being added ahead of the burners via an arrangement of bins, feeders, and drag link conveyors. This gives a total charge to the furnace in excess of 180 t/h. Process air is enriched to 30-35% oxygen, and steam pre-heated to 260°C, and supplies of the order of 60 t/h of oxygen to the process.

Matte produced from the furnace, at a grade of 30-35% combined metal, is upgraded in one of three 30′ x 13′ Peirce-Smith converters, to produce a high-grade matte to two customer specifications before being granulated and shipped out of the country

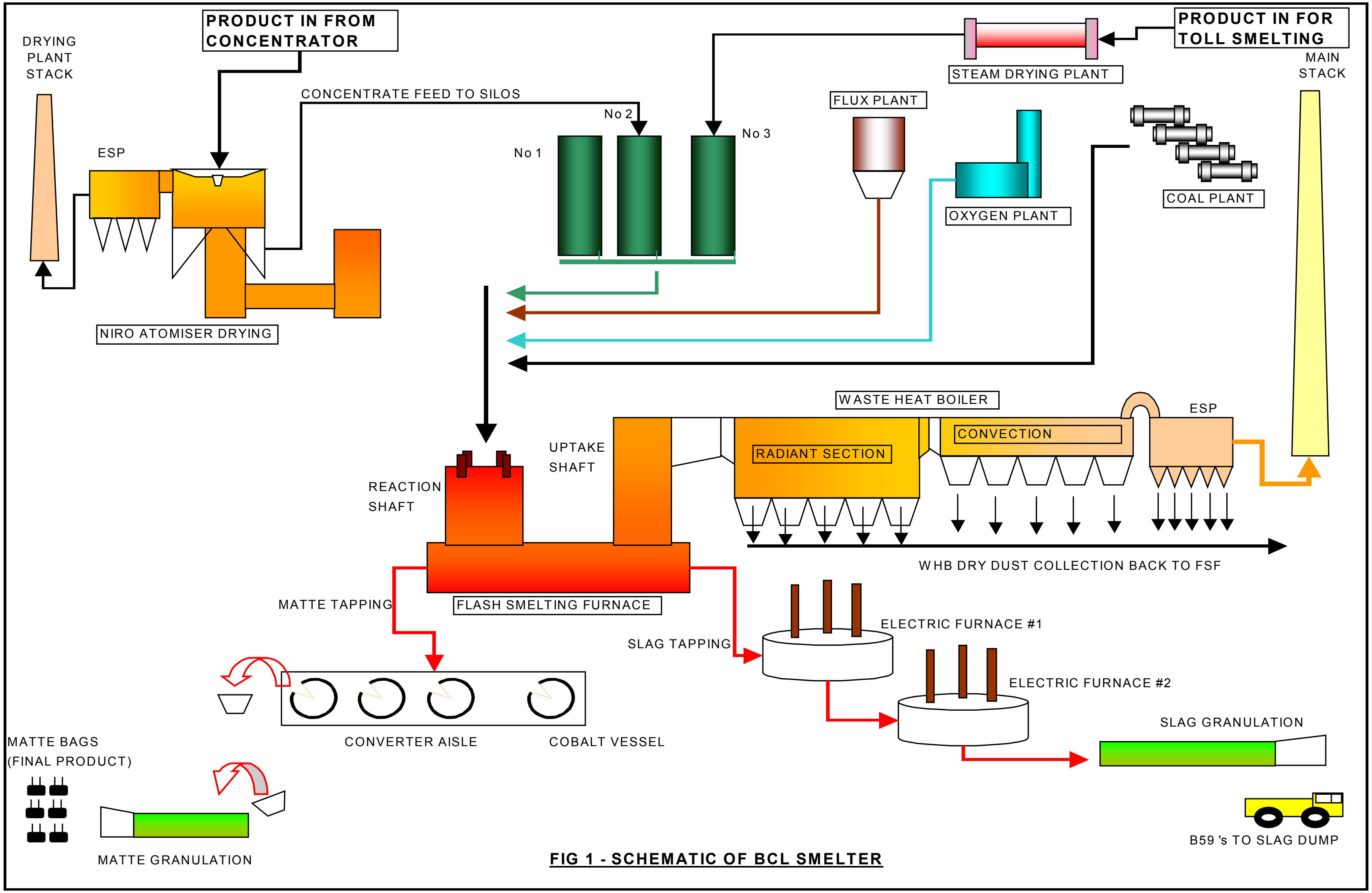


Figure 1: BCL Smelter Plant Flowsheet

for further refining. The large volumes of slag produced are tapped on a continuous basis from the Flash Furnace and, along with the converter slag, cascade through a pair of slag cleaning furnaces (both rated at 9 MVA) before being granulated and discarded.

Flash Furnace off-gas is cooled through an Ahlstrom waste heat boiler, operating at a steaming rate of 120 t/h at 67-bar pressure. The cooled gas is cleaned through a pair of Lurgi electrostatic precipitators, before being discharged via a 154 m stack to the atmosphere.

HISTORICAL PERFORMANCE

The Flash Smelting Furnace at BCL is one of the earlier generation four-burner furnaces, of large physical dimensions (see Figure 2), designed to operate without oxygen enrichment of process air. The furnace relied on high process gas flow (170 000 Nm^3/h) to provide the required oxygen input to smelt relatively low-grade concentrate feeds at the designed 70 t/h throughput.

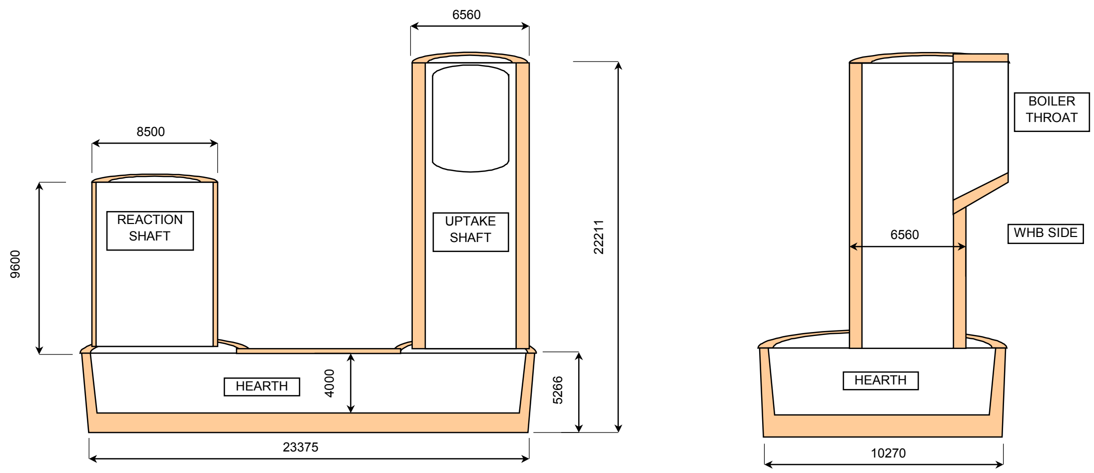


Figure 2: Dimensions of BCL Flash Smelting Furnace

The furnace was commissioned in late 1973, and, slowly over the subsequent seven years, throughput and production levels were increased, and improved until target levels were achieved. The first three furnace campaigns cover this period, each one of increased duration and throughput. It is noteworthy that the total metal output of the first full campaign was less than is produced in a current operating month. A detailed description of the operational experiences during this period has been presented previously.[1]

The first significant expansion took place during the third furnace rebuild in 1980, namely:

- The addition of a 220 ton per day oxygen plant increased the oxygen enrichment level to 25%, allowing an additional 15 t/h of fresh concentrate to be smelted.

- The installation of loss-in-weight concentrate feeders resolved serious concentrate fluidization problems. This technology, adapted to the smelting industry for the first time, is now a standard feature of all Flash Furnace installations.
- An independent sand-screening and drying facility, supplying flux directly to the Flash Furnace feed system, replaced the previous practice of adding flux to the Concentrate Drying Plant slurry feed. This had the benefit of increasing concentrate throughput capacity of the Drying Plant, as well as allowing improved control of silica levels in the Flash Furnace slag.
- The concentrate burner design was changed from the 'venturi' to the 'central jet' type and it should be noted that very little concentrate burner development has taken place at BCL since.

These modifications allowed a step change in throughput and production levels, as indicated in Figures 3 and 4.

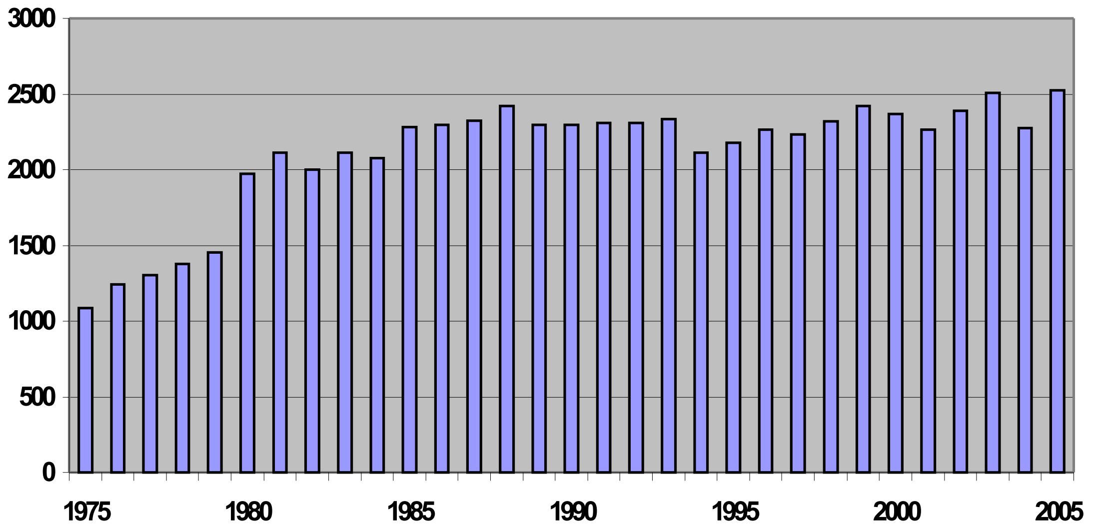


Figure 3: Daily concentrate smelting rates, tons per day (1975 to Present)

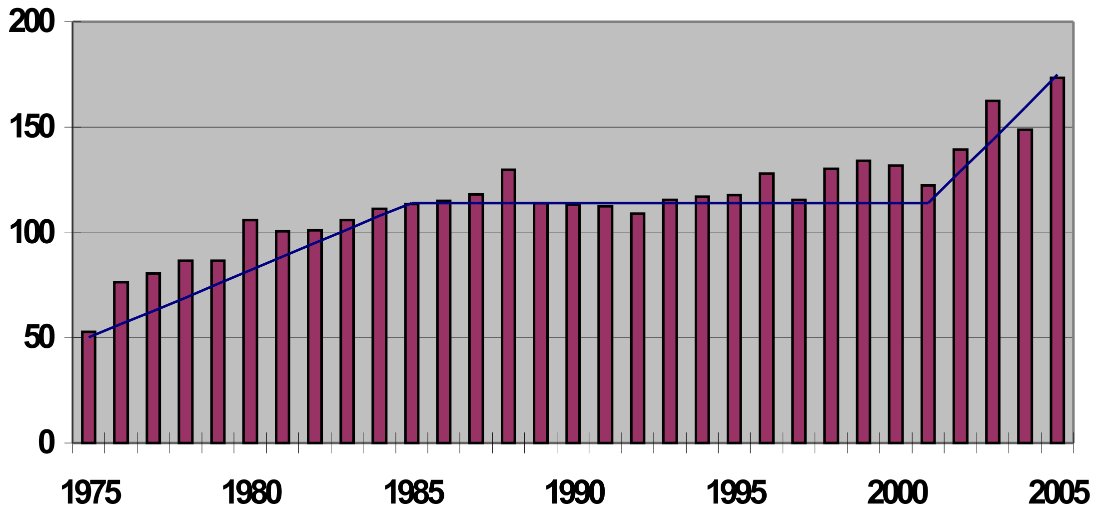


Figure 4: Metal production rates, tons per day (1975 to present)

No significant expansions, upgrades, or technological improvements occurred in the subsequent 15 years of operation. Extended periods of depressed metal prices restricted capital investment, and the BCL focus became one of survival; maximizing metal output for minimal financial input. In some ways, this proved a successful mode of operation, and both campaigns during this period (4th and 5th) were of long duration and high productivity, as indicated in Figures 5 and 6.

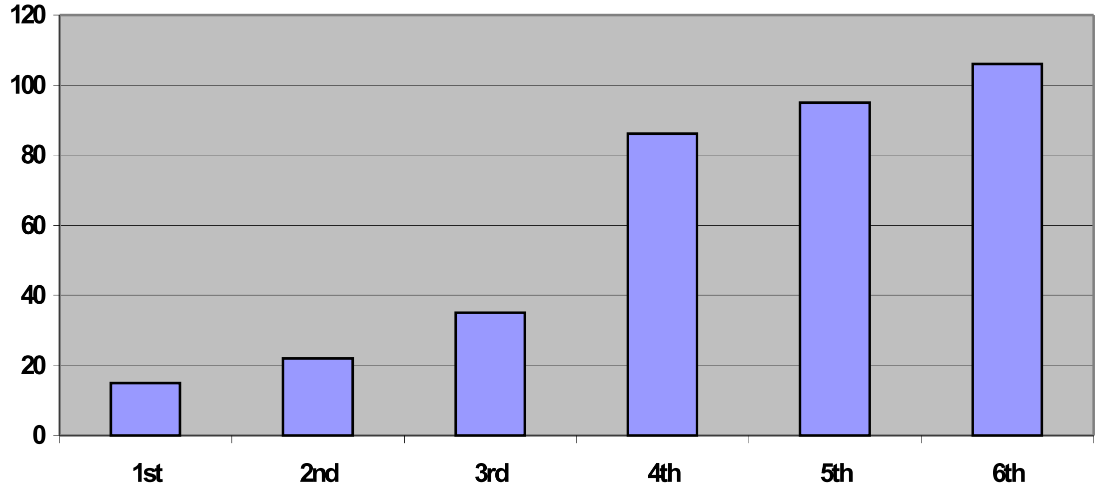
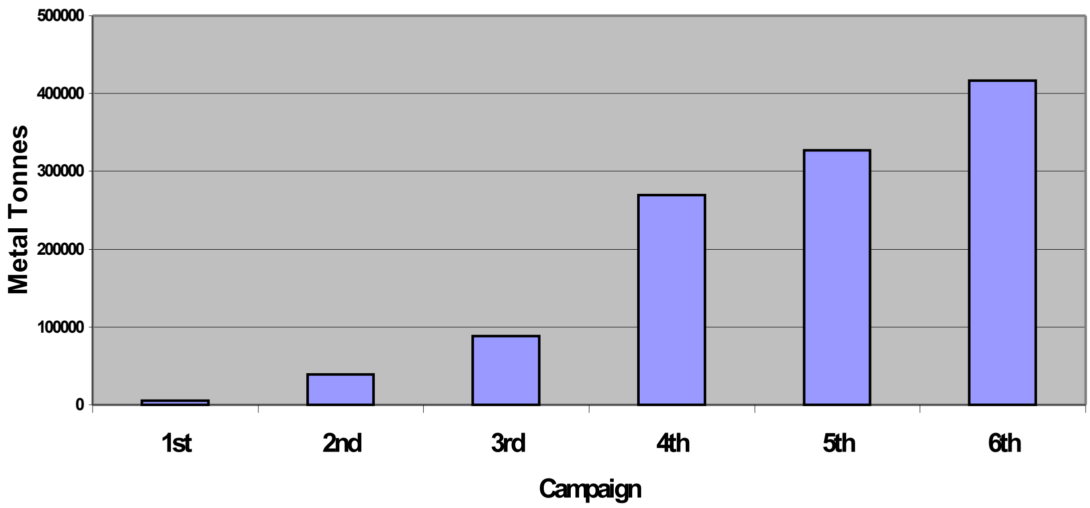


Figure 5: Flash Smelting Furnace campaign duration, months



Figures 6: Flash Smelting Furnace metal production per campaign

The move into the treatment of custom feed materials has provided the impetus to increase smelter throughput and to improve metallurgical efficiencies. The primary source of external supply has come from the Tati Nickel Mining Company deposits close to Francistown, some 160 km from the BCL mine site, which, since small-scale direct smelting of massive sulphide ore began in 1989, has developed into the supplier of one-third of the total smelter feed tonnage (see Figure 7).

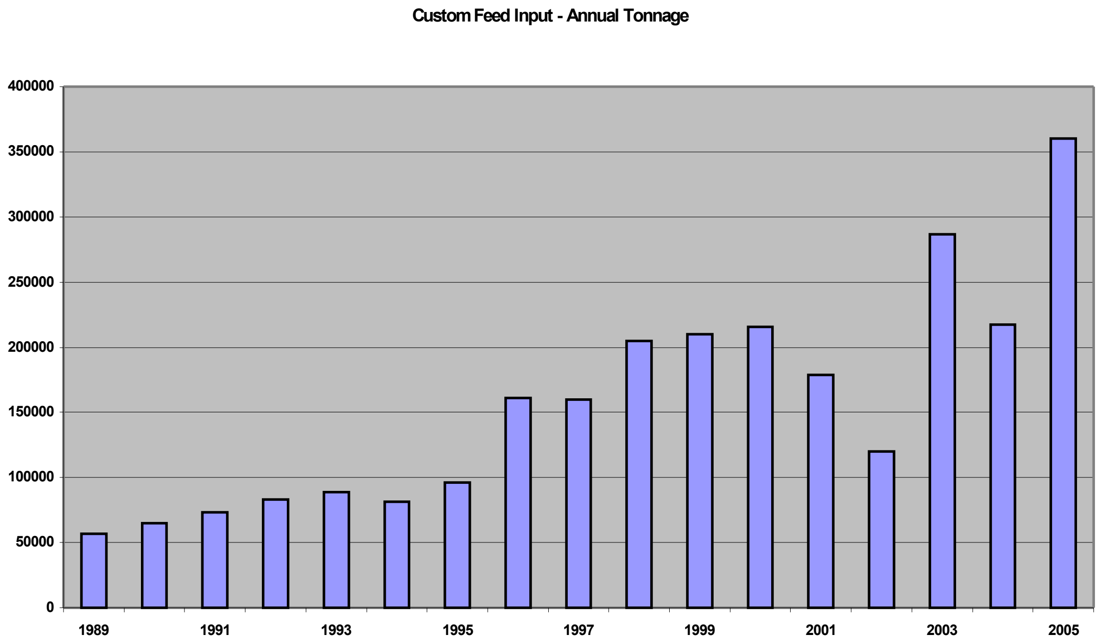


Figure 7: Custom feed input, annual tonnage (1989 to present)

During the late 1990s, the addition of a second 190 t/d oxygen plant (which helped to increase the oxygen enrichment in process air to around 28%), plus the addition of a third Peirce-Smith converter, allowed custom feed treatment levels to rise to 200 000 tons per annum. This, however, stretched both the drying capacity and Flash Furnace throughput to their limits.

With the commissioning of a full-scale wet concentrator plant at Tati Nickel in 2002, annual concentrate treatment requirements at BCL increased to some 900 000 metric tons, and smelter metal output levels increased to 65 000 tons of metal per annum. Thus, additional drying and smelting capacity was required, and 2002 saw the commissioning of a Kvaerner multi-coil steam dryer of 50 t/h capacity, together with the addition of a third oxygen plant, rated at 190 t/d, which boosted oxygen enrichment levels to around 32%. The increased overall drying capacity of 150 t/h allowed smelting rates of up to 130 t/h of new concentrate to be achieved.

Despite this doubling in throughput from the original Flash Furnace design, and the increase in oxygen enrichment of process air, very little development has gone into improvement of the cooling systems or the integrity of either the Flash Furnace itself or the associated waste heat boiler.

RECENT IMPROVEMENTS

Safety Performance

The smelter safety performance has been good in recent years. It is close to ten years ago that the last serious injury occurred, and an annual lost time injury frequency rate of close to 1.0 (per 200 000 man-hours worked) is typically achieved. Company-wide, the focus on safety, and the prevention of injuries, has intensified, and a policy of zero tolerance towards injuries has been adopted. Most attention has been given to the behavioural aspects of incident prevention and to modifying the attitude of the workforce.

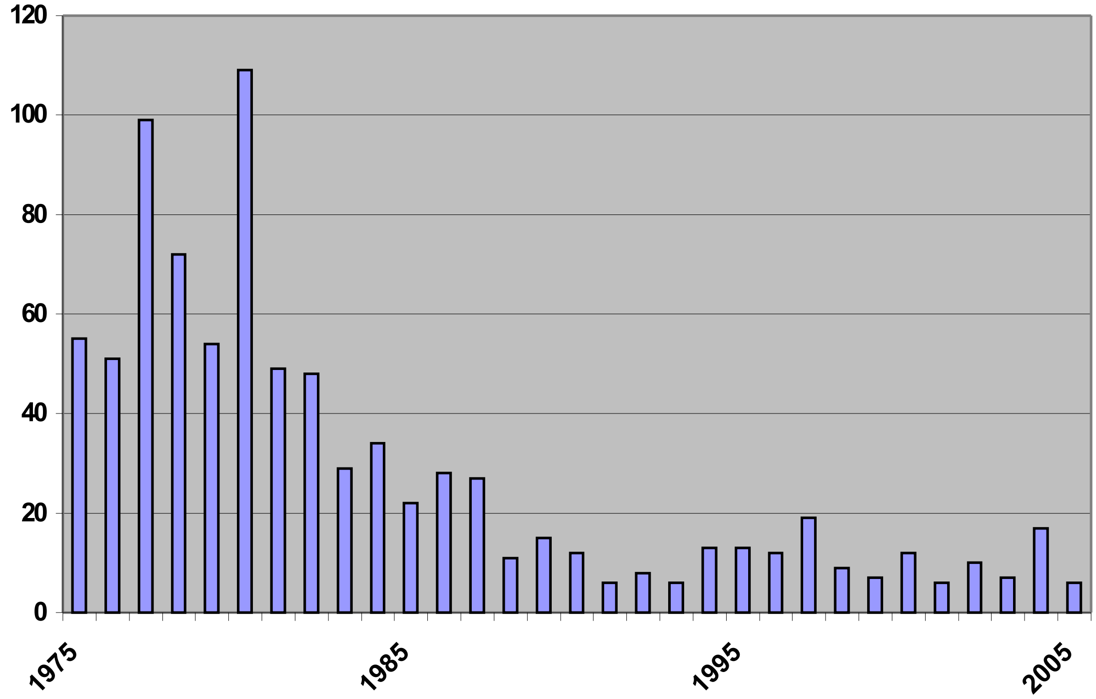


Figure 8: Overall smelter safety performance, Lost time injuries (annual) (1975 to present)

Improvements in Concentrator Nickel Recovery

Significant improvements in nickel recovery were achieved at the concentrator, with firstly the upgrading of the rougher and scavenger circuits in 1999, followed by the replacement of the 32 original cleaner bank cells with six 50 m^3 Outokumpu cleaner bank cells in 2002. An overall 3% improvement in nickel recovery was achieved. With recent increases in custom feed tonnages to the smelter displacing BCL concentrate feed to a certain extent, the lowering of the concentrator mass pull has seen a reduction in nickel recovery. This has been offset somewhat following the commissioning of mill grind control and flotation level control systems.

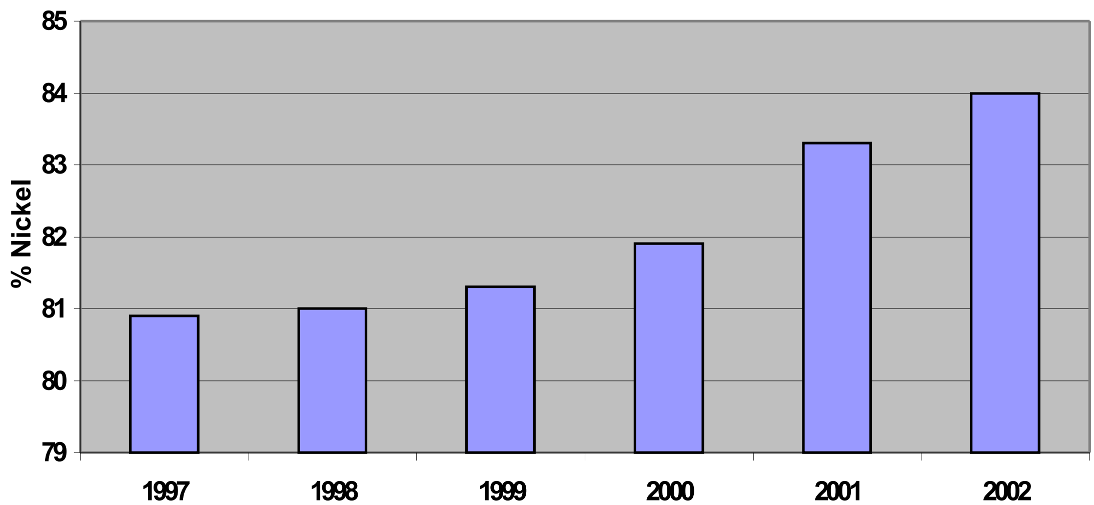


Figure 9: Concentrator nickel recovery shows improvement

Steam Dryer Commissioning

A 50 t/h rated multi-coil steam dryer was added to the circuit in mid-2002 for the drying of concentrate filter cake product (10% moisture) from the Tati Nickel operation. Commissioning of the plant proved difficult, and, as can be seen from Figure 10, plant availability figures of greater than 40% could not be achieved during the first six months of operation. This was primarily a result of the materials handling difficulties arising from the unexpected abrasiveness of the Tati concentrate and its tendency to sinter when allowed to dry. Gradually, plant reliability has been improved, essentially by the re-design of key components to improve material flow, and the use of improved materials of construction to combat corrosion and erosion. Key areas of focus included:

- The addition of screening equipment to remove lumps
- Modification to both the feed and product screw arrangements of the dryer
- Upgrading of the bucket elevator
- Simplification of the concentrate conveying and back-mixing systems
- Replacement of the filter bag-house with a wet scrubber, to reduce the incidence of fires

A major improvement in both the throughput rate and plant reliability came with the increase of the steam operating temperature from 100°C to 145°C, and an increase in pressure from 10 bar to 15 bar. The plant now operates with an availability in excess of 90%, and with design feed rates being achieved, as indicated in Figures 10 and 11.

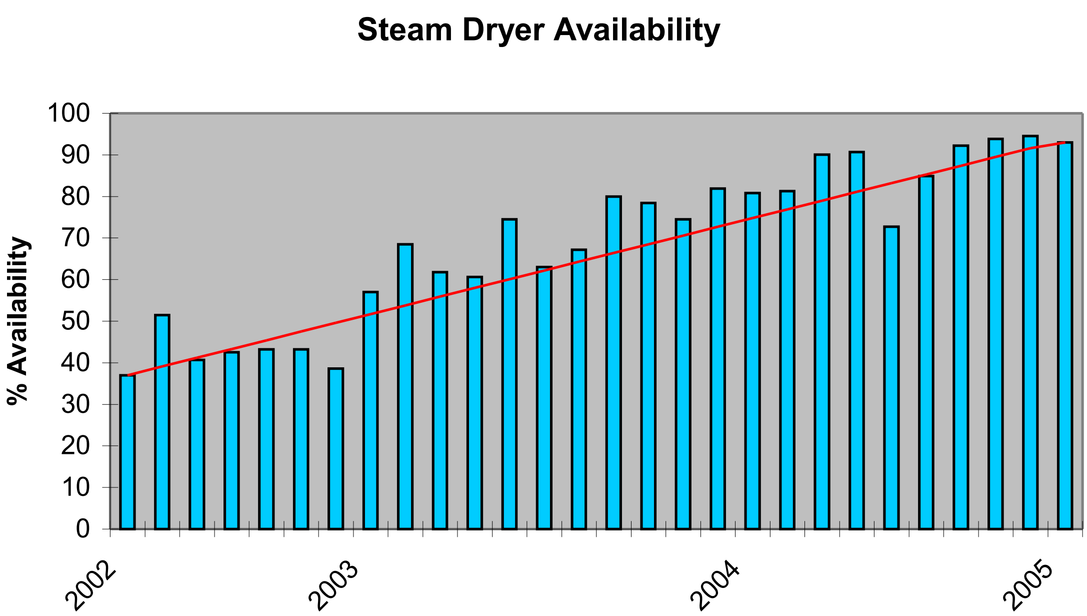


Figure 10: Improvement in Steam Dryer availability

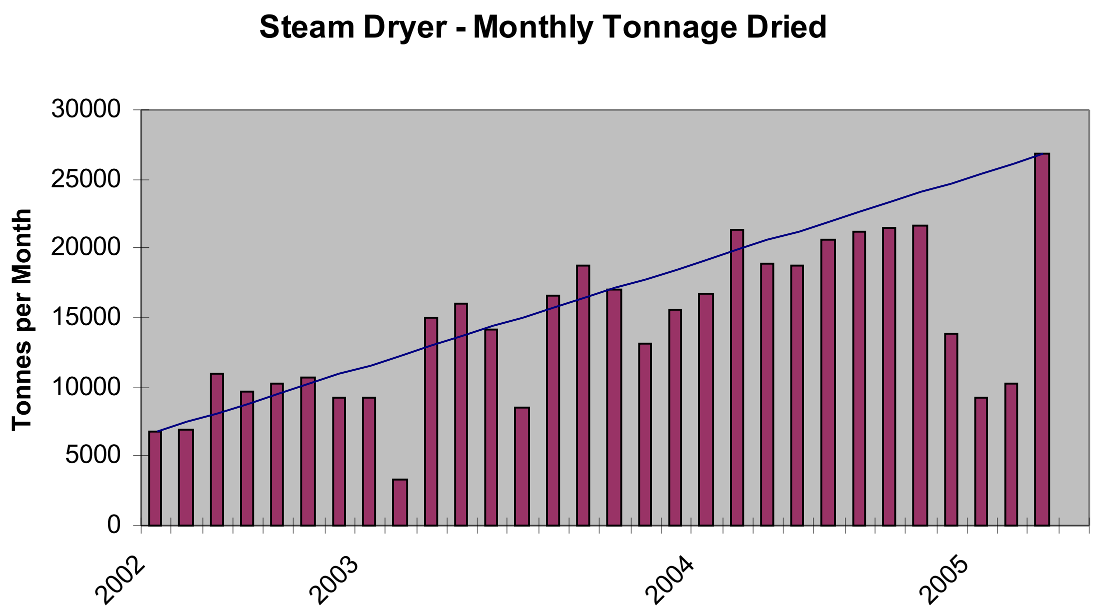


Figure 11: Improvement in Steam Dryer throughput

The addition of sulphatising air into the waste heat boiler

Control of the smelting process has always been difficult at BCL, principally due to the lack of concentrate blending and homogenisation ahead of the smelting process. The situation has deteriorated further in recent years, as more custom feed has been introduced, and the variation in feed constituents to the furnace can often be extreme. Process changes are constantly being made in an effort to maintain an acceptable matte grade for the converter section, while avoiding high metal losses to slag due to over-oxidation, and at the same time avoiding excessive levels of residual sulphur in boiler dust due to under-oxidation. During the current campaign, two three-day outages were required to dig out serious boiler pendant blockages that had occurred due to the sintering of 'sticky' sulphurous dust produced during periods of under-oxidation in the furnace.

Following visits by BCL personnel to other Flash Furnace operations, it became apparent that the introduction of air/oxygen into the waste heat boiler is common practice, and could be an effective solution to the problem, or at least minimize the risk of boiler blockages.

Much of the pre-installation work was completed during the shutdown of June/July 2004, and, in mid-December of the same year, sulphatising air was introduced via four ports into the throat of the waste heat boiler for the first time, comprising 15 000 Nm^3/h of ambient air, or 12-15% of the total process air flow. The benefits were immediately apparent, as indicated in Figures 12, 13, and 14, which show daily average values of critical parameters since start-up.

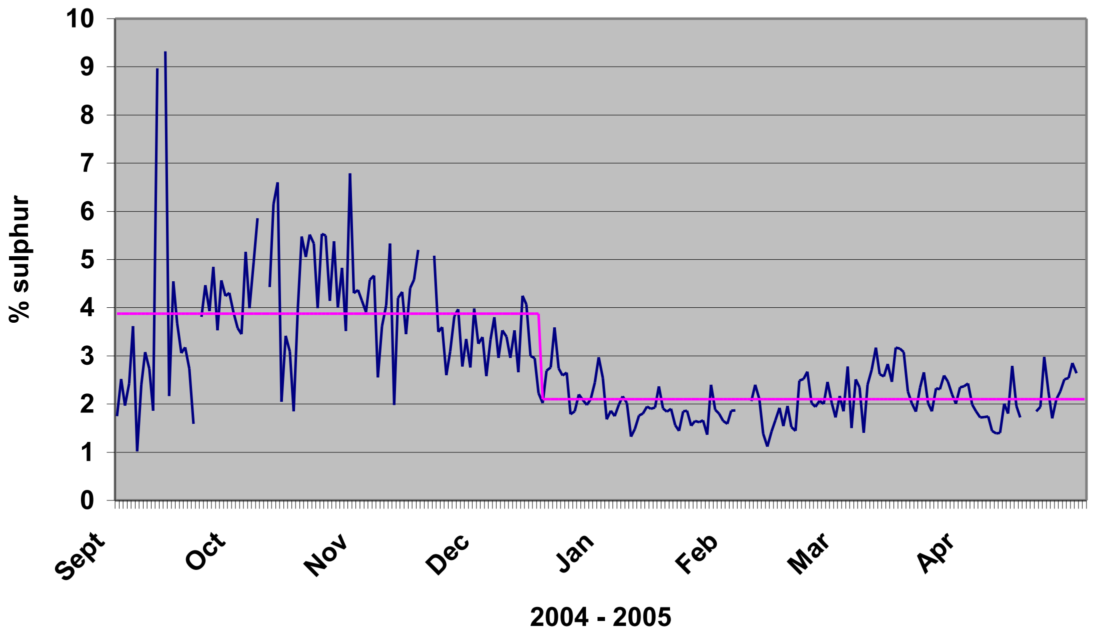


Figure 12: Sulphur levels in waste heat boiler dust

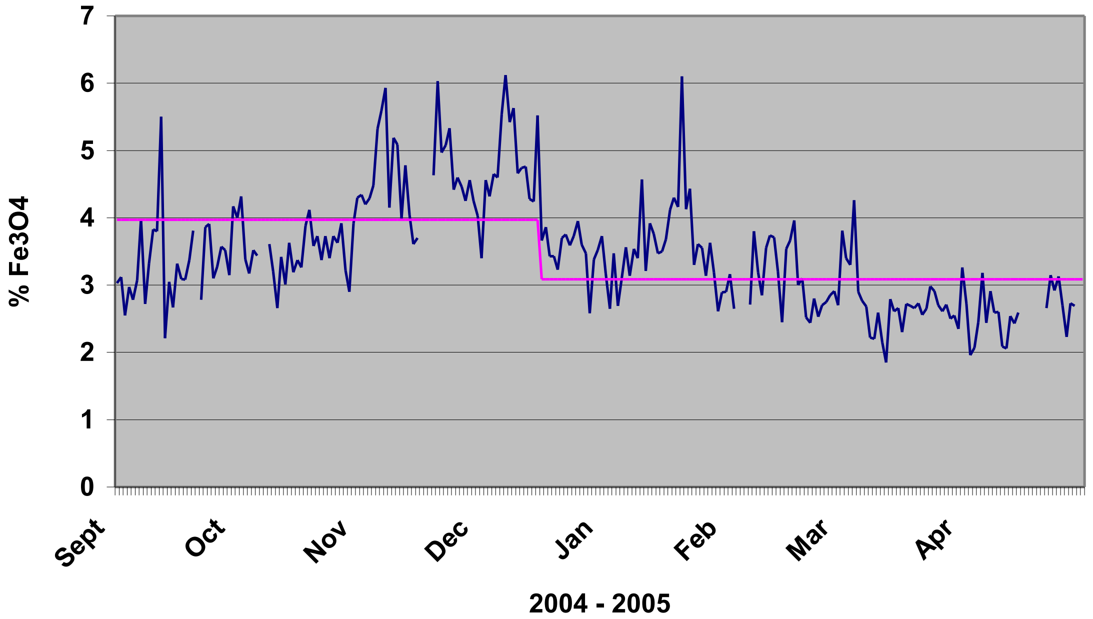


Figure 13: Magnetite levels in discard slag

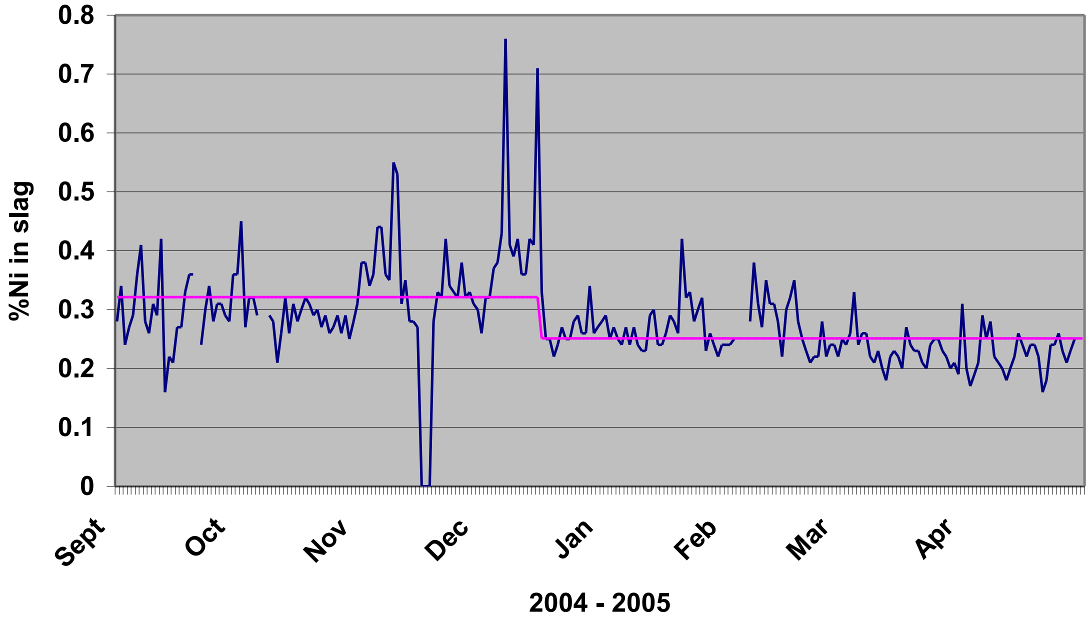


Figure 14: Nickel content of discard slag

Summarising the above, it can be seen that sulphur levels in the boiler dust have been reduced from an average of 3.9% S to 2.1%, as a direct result of the introduction of sulphatising air. Magnetite levels in furnace slag have improved from an average of 4.0% Fe_3O_4 to 3.1% Fe_3O_4, as it is now possible to lower the degree of oxidation in the furnace in the knowledge that the sulphatising air will control residual sulphur levels in dust. With this flexibility has come the biggest benefit of all: the lowering of the oxidation level in the Flash Furnace has improved the nickel loss in discard slag from an average of 0.32% Ni from campaign start to mid-December, to a level of 0.25% Ni since the introduction of sulphatising air. This has given a significant improvement in metal recovery.

Improved Converter Aisle co-ordination and efficiency

The converter aisle has historically been the bottleneck to smelter throughput. The scheduling required for the simultaneous production of two different final product specifications, and the low Flash Furnace matte grades, being key factors. The traditional philosophy has been to target large casts by maximizing the quantity of furnace matte treated in each cast. Matte grade dependent, up to fourteen blowing cycles can be required to achieve this, and cast cycle times of up to 24 hours and more were not uncommon.

A recent development has been the optimisation of charge sizes, in relation to the blowing time required, and yield predictions. Analysis indicated that smaller, more frequent, casts would lead to benefits in throughput, efficiency, and aisle recovery. In practice, each cast comprises only three blowing cycles (five for the higher-grade specification product), and, though cast sizes are much smaller, it is now possible for each converter to produce a cast in an eight-hour shift. Improvements in converter efficiency are indicted in Figure 15.

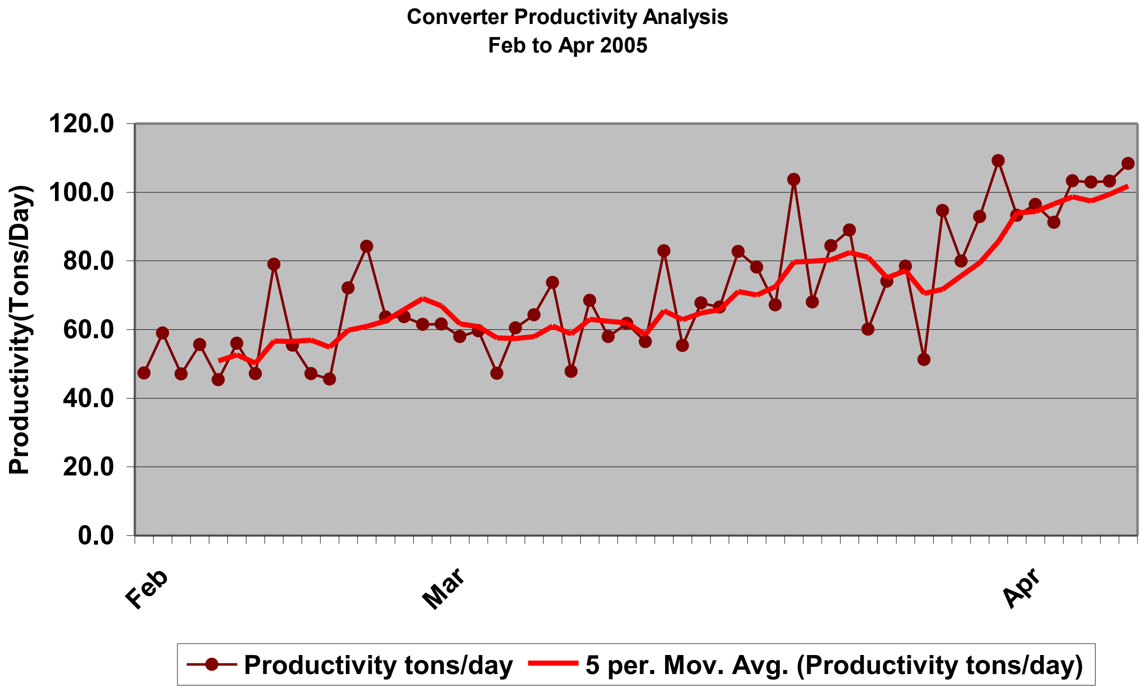


Figure 15: Improvements in converter productivity

Improvements in Flash Furnace matte tapping efficiency

Matte tapping from the Flash Furnace has historically been problematic, and typically only half of the total matte tapped has come directly from the Flash Furnace - the remainder being carried through with slag to the slag cleaning furnaces. This inconsistent performance was traditionally attributed to a combination of poor concentrate burner design and performance, custom feed quality, a lack of feed blending ahead of smelting, and extreme variations in feed analysis.

Visits to other smelters, and associated research, indicated that furnaces typically operate at a slag temperature of around 1300°C and sometimes higher. At BCL, the Flash Furnace had always been operated at a slag temperature of 1230°C, for the simple reason that historically there has always been a deficit in the supply of oxygen in process air, and energy has always been sacrificed in favour of throughput. With the recent introduction of additional oxygen capacity, this restriction has been removed, though the condition of the furnace prior to the 2004 major overhaul prevented the option of operating at elevated temperature.

The decision was made to operate the furnace at an elevated temperature from the start of the current campaign. This has proved very successful in terms of matte tapping from the Flash Furnace, where more than 80% of the total matte tapped is now recovered. Periods of excessive carry-over of matte to the slag cleaning furnaces are generally now a result of converter scheduling delays or associated downstream problems. Figure 16 depicts the significant improvement in the matte-tapping performance of the Flash Furnace.

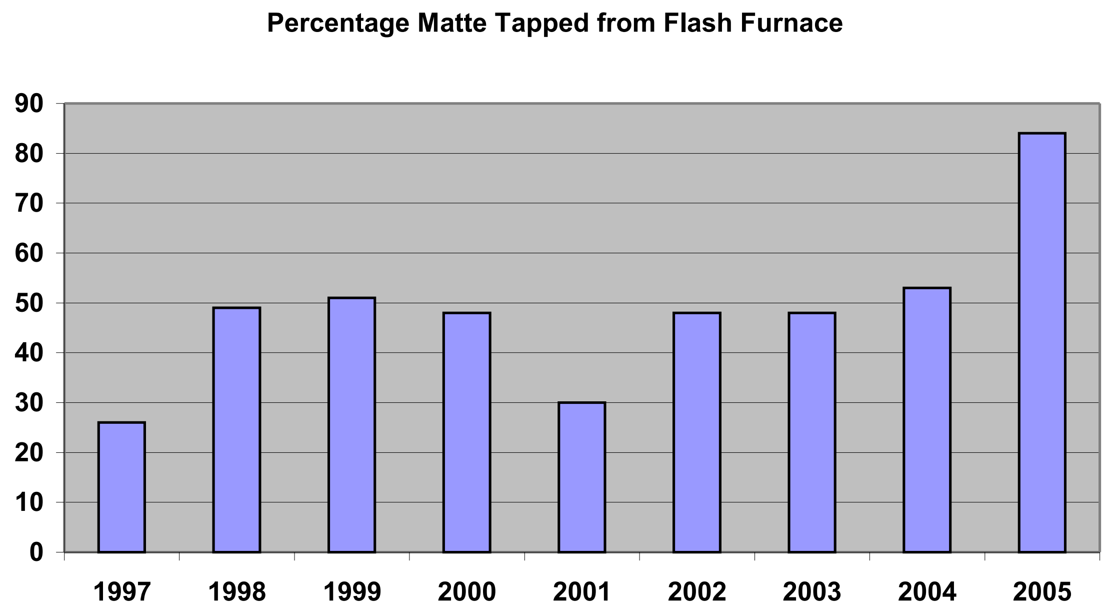


Figure 16: Improvement in matte-tapping performance of the Flash Furnace

On the downside, operating the furnace at elevated temperatures and high smelting rates has highlighted weaknesses in the integrity of both the Flash Furnace and the waste heat boiler. On the Flash Furnace, cooling water circuits are operating at their upper limits, and the reaction shaft roof, still of the original domed and un-cooled design, has already warped and buckled. The gas temperatures entering the convection section of the waste heat boiler have now increased to an average of 1100°C. The process has been optimized around a slag temperature of 1280°C, which allows effective tapping, and minimises the integrity risk.

Flash Furnace integrity programme

In January 2003, a catastrophic failure of the uptake shaft around a horizontal circumferential flange resulted in a six-week furnace outage to effect suitable repairs. This unpredicted failure, believed to be the result of excessive internal build-up leading to mechanical failure, had a severe impact on production output, and placed the company under critical financial strain.

Ahead of the shutdown in 2004, a furnace integrity programme was formulated and implemented, in an effort to improve the monitoring of critical parameters, establish routines that would lead to a higher level of attention to detail, and to identify and address integrity issues in a pro-active manner. This was done in the belief that such a programme would lead to higher levels of confidence, such that the operation and maintenance of the furnace would be more reliable, effective, and efficient.

A document is now issued on a monthly basis, detailing the status of furnace movement (buck stays, tie rods, all roofs), temperature monitoring of strategic areas, cooling water quality, and long-term monitoring of relevant trends. As an example, Figure 17 shows the average daily brick temperatures at the reaction and uptake shaft roofs for a six-month period.

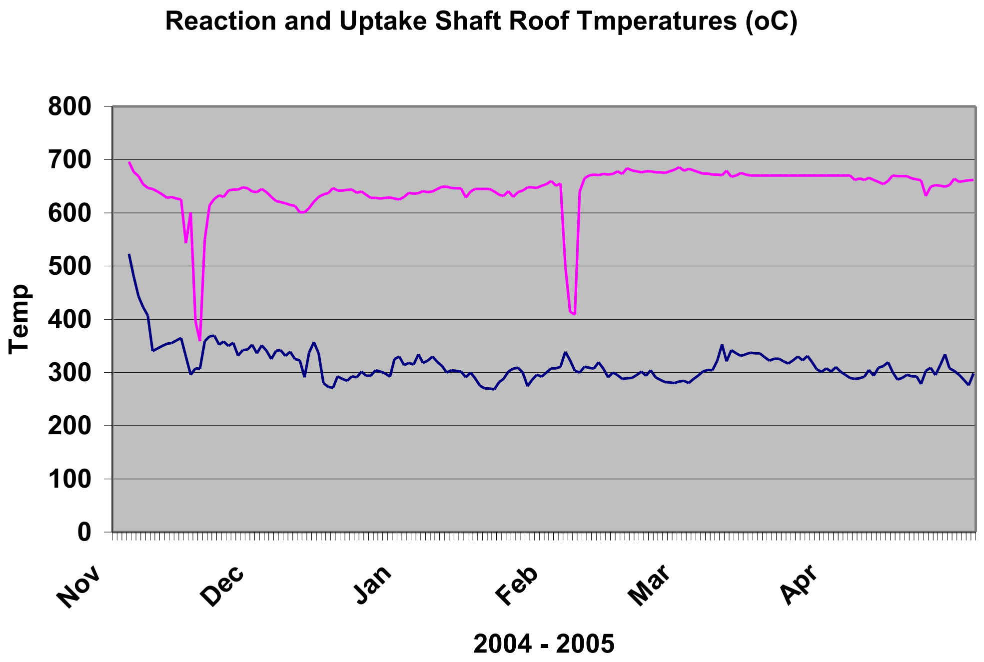


Figure 17: Flash Furnace roof temperature monitoring

Control of revert inventory

As with most smelters, control and management of the revert inventory is always a key issue, and a major source of accounting and recovery discrepancies, as well as having a serious impact on company cash flow. The BCL Smelter is no different, with the situation compounded by the relatively low temperatures of the flash furnace matte and slag products. Historically, control of the revert inventory has proved difficult, and has on occasions necessitated the sale of reverts for processing elsewhere. Figure 18 shows the revert inventory levels of recent years.

This year, a change in strategy has resulted in a marked improvement in control. Revert arisings have been reduced to approximately 150 tons per day, or approximately 13% of the overall metal input to the smelter, largely as a result of operating the Flash Furnace at a higher temperature, and the improved operation of the converter aisle. Improved converter scheduling and operation now typically allows 30 t/d to be consumed in the converters, with another 70 t/d being processed through the slag cleaning furnaces. The balance, nominally 50 t/d, is recycled through the Flash Furnace via the concentrator milling circuit. Although this displaces input capacity to a limited extent, the practice has been found to be beneficial to the overall operation of the Metal Production division.

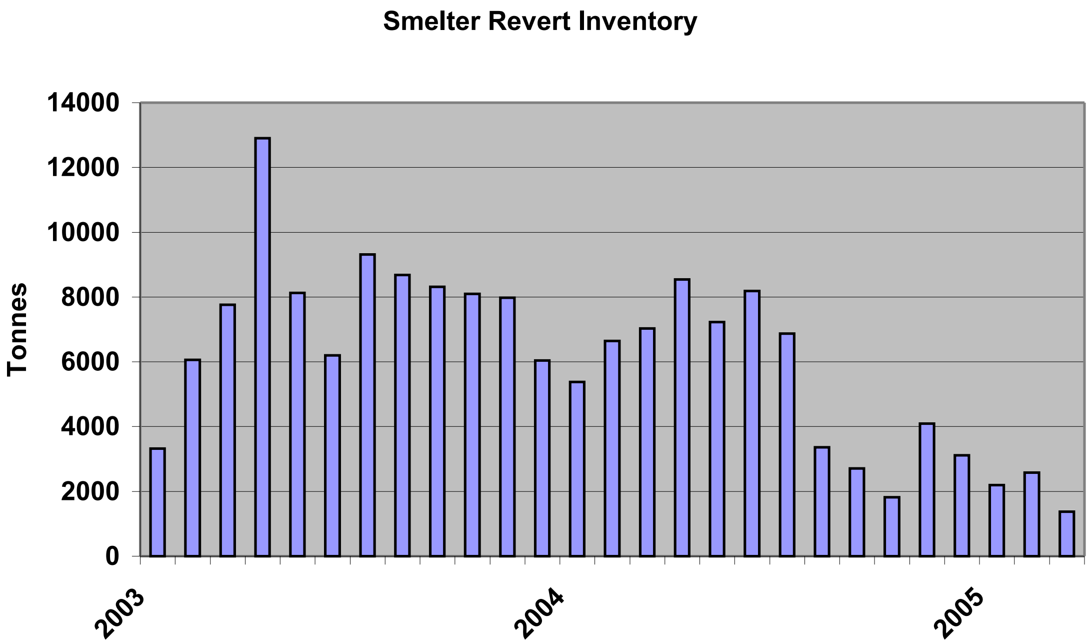


Figure 18: Smelter revert Inventory (2003 to present)

FUTURE DEVELOPMENTS

The technical development and improvements that have taken place at the BCL Smelter in recent years have been almost exclusively targeted at maximising throughput and output, with little or no input into improvements in integrity, or investment in the technology available that will prolong furnace life and reliability. A recently formulated business plan has clearly identified the following areas of development as critical to the future long-term sustainability of the Smelter.

Concentrate blending

At present, concentrate blending and feed preparation is a relatively crude affair, with up to six secondary input materials being mixed with the primary concentrate feed, using methods that are both labour intensive and heavily dependent on operator interface. The situation is complicated by the degree of variation in the Concentrator mill feed, affected by variations in the input from each of the three operating shafts, which leads to large fluctuations in overall concentrate analysis. The problem is further compounded downstream, where the BCL products are blended with the Tati custom feed material, which has a significantly different composition. The BCL slurried products and the Tati filter cake material are dried in the spray-drying complex and steam drier respectively, ahead of storage in independent silos. Blending of the two products is currently achieved by pneumatic batch conveying of the two products across to the Flash Furnace charge bin in pre-designated ratios. This practice is heavily dependent on consistent material supplies and operator interface. The efficiency of current levels of blending is demonstrated by a co-efficient of standard deviation of 7% to 9% for each of the key constituents of the Flash Furnace feed. The industry standard for the co-efficient of standard deviation for Flash Furnace feed mixtures is typically 'not more than 1%'.

Concentrate burner design
BCL operates with four concentrate burners of a design dating back more than 25 years. Current practices favour a single burner operation, with ratio control to maintain consistent combustion characteristics, designed around relatively low process gas flow with high oxygen enrichment. The uniqueness of the BCL operation, with its very high process gas flows, and inclusion of secondary fuel mixed with the concentrates, raises concerns as to the practicality of the switch to a single burner arrangement.

However, should BCL proceed with the installation of the single burner design, the expected benefits are two-fold; improved furnace integrity, particularly an improvement in the stability and longevity of the reaction shaft roof, shell, and junction, and improved burner combustion characteristics leading to an improved smelting process (though improvements here are somewhat dependent upon improvements in blending).

Reaction shaft roof design
The reaction shaft roof is still of the original domed design, dating back 35 years, and, with the recent catastrophic failures, has proved to be under-designed for the increasing levels of throughput and oxygen enrichment in process air. At this early stage of the campaign, the existing roof is severely buckled and will be changed at an appropriate opportunity. The re-design of the roof will incorporate the following features:

- Flat suspended design for ease of manufacture, installation and repair
- Modular, for the same reasons
- Copper coolers to improve integrity
- Re-designed for the new concentrate burner arrangement

Improved furnace cooling
No improvements have been made to the cooling arrangements of the furnace, with the exception of additional copper coolers at the reaction shaft junction, and the gradual replacement of the cooling coils in the settler sidewalls with copper elements. Neither the reaction shaft nor settler roofs have any form of water-cooling, and the shells of both shafts retain the original irrigated cooling arrangements. Improvement in these areas is critical to improving the integrity and campaign life of the furnace.

Installation of baffles in the Waste Heat Boiler
Increases in Flash Furnace throughput and oxygen enrichment levels have led to a large increase in the energy load to the waste heat boiler. Entry temperatures are typically 1400°C, with convection section entry and exit temperatures of 1150°C and 600°C respectively. Such temperatures result in severe thermal damage to the hoppers and down-comers at the inlet area of the

convection section, as well as exposing the electrostatic precipitators to a similar risk, at inlet temperatures close to 400°C.

Plans are in an advanced stage to install a pair of water-cooled baffles into the radiant section, as depicted in Figure 19.

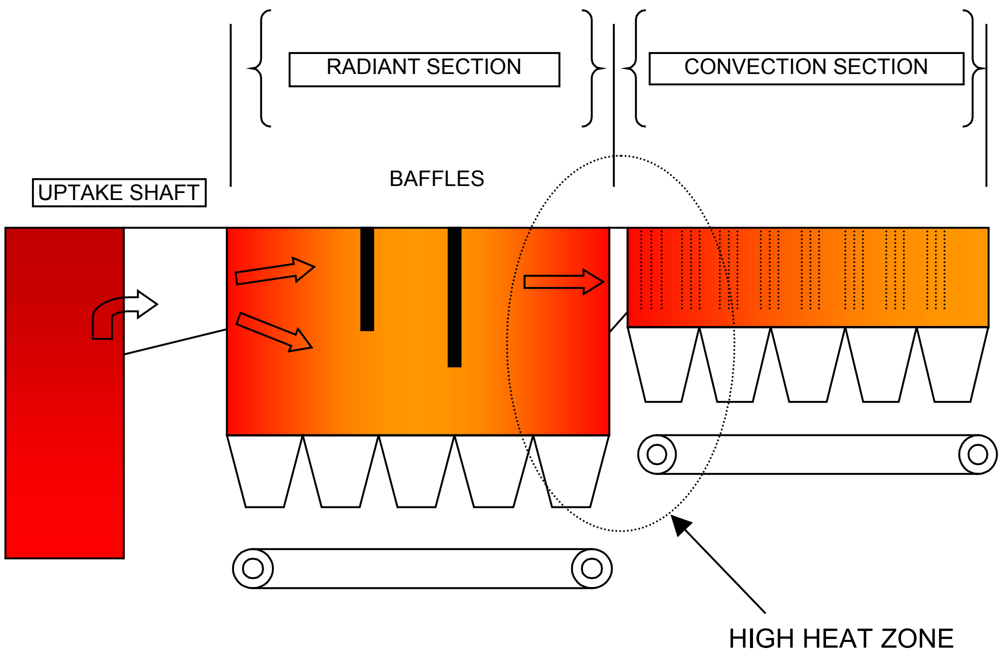


Figure 19: Planned waste heat boiler baffle installation

The installation will take place during the next statutory outage in 2006, and will have the benefits of reducing the convection section inlet temperatures, thereby reducing the risk of thermal damage to both the convection section hoppers and the electrostatic precipitators.

ACKNOWLEDGEMENTS

The authors wish to thank the major shareholders of BCL Limited, Lion Ore Mining International Limited, and the Government of the Republic of Botswana, for permission to publish this paper. Many thanks are also extended to other BCL members for their assistance in the preparation of this paper.

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