

Bindura Nickel Corporation Smelter Operations

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Keywords: Pyrometallurgy, furnace, Bindura, nickel

Abstract – The smelter at Bindura Nickel Corporation processes concentrates from its own mines and other external sources. Concentrates are dried, smelted, and converted to a desulphurised matte (leach alloy) for further processing at the refinery. The smelter comprises a drying plant, submerged arc electric furnace, electrostatic precipitator, and three Peirce-Smith type converters capable of treating 150 000 tonnes of concentrates per year. Concentrates are dried in a rotary coal-fired kiln, blended with fluxes, and smelted in a six-in-line submerged-arc 15MW electric furnace. Slag is tapped and granulated for disposal, and matte is tapped at regular intervals for blowing in Peirce-Smith converters. The paper details the 37-year history of the smelter, including furnace rebuilds and operating parameters as they have evolved in response to changing feed compositions. Special challenges, particularly relating to the treatment of high talc concentrates, are also described.

INTRODUCTION

Bindura Nickel Corporation (BNC) commenced production at the Trojan Nickel Mine, located near the town of Bindura, Zimbabwe, in July 1968. Subsequently, BNC developed three other nickel-copper mines in Zimbabwe over the following seven years. Of these, only Trojan and Shangani mines are still in operation.

The Smelter was commissioned in the same year, using two blast furnaces treating concentrates from Trojan and Madziwa mines. The blast furnaces were decommissioned in 1976, with the commissioning of the present electric furnace. Technological advancement, and the coming in of Shangani and Epoch mines, necessitated the replacement of the blast furnaces. The smelter capacity was upgraded from 600 to 1 300 t Ni per month.

The Smelter processes the nickel-copper concentrates and toll feed material into a leach alloy, which typically contains 65 per cent nickel, 25 per cent copper, 1 per cent cobalt, 6 per cent sulphur, 0.6 per cent arsenic, and 0.4 per cent iron.

After receiving the concentrates from the mines, they go through three major unit operations, namely drying, smelting, and converting, to produce the leach alloy.

The closure of Epoch and Madziwa mines, the stoppage of toll treatment material, and the changing feed composition, have presented special challenges

to the smelter operation during the past seven years. Feed material has drastically reduced from about 150 000 metric tons of concentrates per year before 1999, to present levels of 80 000 tons per year. This has resulted in running smelter operations inconsistently, affecting critical efficiencies like in-process inventory control, power, brick, and paste consumptions.

The MgO content in Trojan concentrates has been on the increase from 1999 onwards. Trojan concentrates constitute 75 per cent of the feed. The resultant high MgO in slag (22%) has presented a challenge of operating at very high temperatures (>1500°C) compared to the normal temperature of 1390°C before 1999. The high slag and matte temperatures, experienced as a result of high MgO, pose a major risk to furnace integrity. There have been several interventions to try to reduce the risk. These include changing the fluxing philosophy and operational control procedures.

PROCESS DESCRIPTION

The process flow diagram depicting the major items of process equipment is shown in Figure 1. The flowsheet consists of three major steps, namely concentrate drying, smelting, and converting.

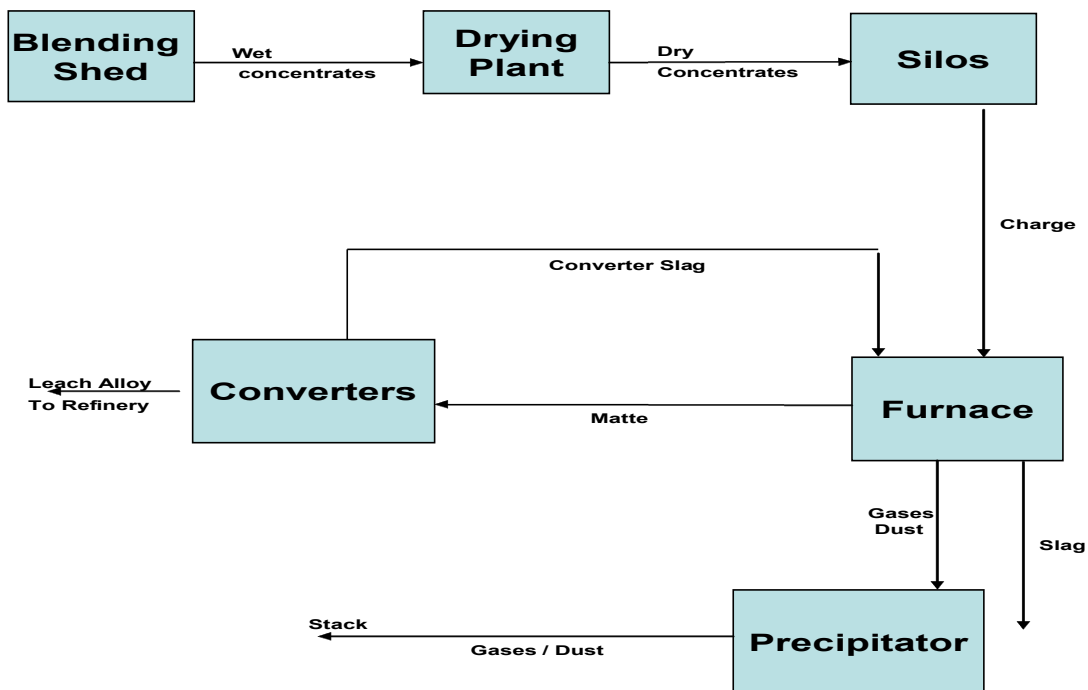


Figure 1: Bindura Smelter plant equipment (process flow block diagram)

Drying

The concentrates from the mines are dried in a coal-fired rotary drying kiln, where the moisture content is reduced from 15% to 4-5%. The hot gases used for drying are admitted through the feed end, to give a co-current flow of hot air (750°C) and wet concentrate feed. The lifter configuration ensures that the

material is lifted and showered across the hot gas stream for good contact. The hot gas gives up its energy in evaporating the water content of the concentrates, and carries with it the resultant water vapour with some dry concentrate particles that are collected through the ducting system to the cyclones. The cyclone underflow is discharged onto the drum discharge conveyor, while the overflow passes through a multi-vane gas scrubber for further gas cleaning. The scrubber slurry is sun-dried, and recycled via blending with fresh concentrates. The dry product is temporarily stored in a silo, and subsequently fed into the furnace.

Table I: Typical chemical analyses of concentrates, mass %

	H ₂ O	Ni	Cu	Co	SiO ₂	Fe	MgO	S
Trojan	13.5	9.0	0.7	0.2	26.0	20.0	20.0	15.0
Shangani	11.6	12.8	1.4	0.4	18.0	24.0	12.0	20.0
Blend	4.2	10.5	2.1	0.3	32.0	22	17.0	17.0
Dry Concentrates	4.3	10.2	2.3	0.3	30.0	21.2	17.2	16.0
Scrubber Solids	19.5	8.4	2.6	0.3	26.5	22.0	17.1	14.2

Smelting

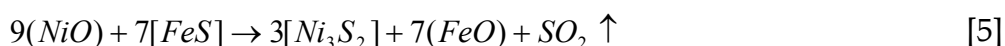
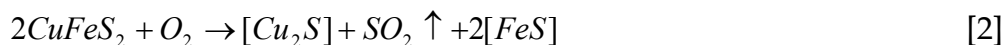
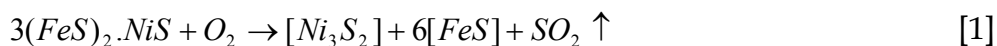
Dried concentrates, reverts, and leach residues, blended in the correct proportions, are conveyed into a surge bin above the submerged-arc electric furnace, in batches. Gravity choke-fed pipes keep the furnace supplied with charge. The furnace has six in-line self-baking Söderberg electrodes, which are fed by three single-phase transformers whose movements are controlled by a winch mechanism. The slag resistance to the current supplied generates energy to achieve and maintain smelting temperatures.

The charge is thermally treated, to melt it and bring about physical and chemical changes, which result in the concentration of the mineral values in a crude matte phase, while rejecting the gangue to the slag phase. The molten bath separates into two immiscible phases: the slag phase and the matte phase. The slag phase floats on top of the matte phase because of its lower relative density. Slag is tapped and granulated for disposal, while matte is tapped at regular intervals for further processing in the converters.

Table II: Chemical analysis of matte and slag, mass %

	Ni	Cu	Co	S	FeO	SiO ₂	MgO	Temp
Furnace Matte	26.5	5.0	1.20	27.2	Fe 34.5			1300°C
Converter Slag	0.93	0.42	0.93		65.5	29.0		
Furnace Slag	0.23	0.11	0.23	0.77	30.5	42.5	22.0	1500°C

Smelting Reactions



Converting

The units in place are Peirce-Smith type converters, which basically consist of horizontal steel cylinders, lined with chrome-magnesite brick. The opening is at the top, and the cylinder can rotate about its axis. Compressed air is delivered through a bustle main along the back, from which a horizontal row of tuyeres provides passage through the converter lining into the interior.

The first stage of converting is devoted to iron removal by oxidation and slagging, reducing the iron levels from 40 to 0.45%. The oxidation reaction is exothermic. After most of the iron has been slagged, skimmed off, and sent back to the furnace, more matte is added, and the process is repeated until a sufficiently large volume of white metal is obtained. Temperature control during the slag blow is by doping with reverts. After the removal of the last slag, during the clean-off period, the second blowing stage (leach blow) starts, with the aim of reducing the sulphur levels from 26 to 6.5%. During this stage, doping is by leach alloy scrap.

The final leach alloy is granulated with water sprays, and is dispatched to the Refinery for further processing.

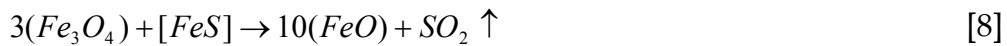
Table III: Chemical analysis data, mass %

	Ni	Cu	Co	S	Fe
Furnace Matte	26.5	5.0	1.20	27.2	34.5
Leach Alloy	70.5	14.8	0.98	5.72	0.40
Converter Slag	0.93	0.41	0.92		FeO 65.5
Ni Scrap	99.0				

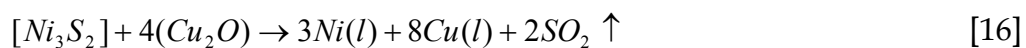
Converter reactions

The major chemical reactions in the converters can be represented by the following equations for iron removal and sulphur removal.

The iron removal process can be represented by the following equations:



The sulphur removal process can be represented by the following equations:



EFFECTS OF FEED SHORTAGE ON THE OPERATION

The closure of Epoch mine in 1998, and Madziwa mine in 2001, and the reduction of toll treatment, have resulted in low feed supply to the Smelter. The quantity of feed material has gone down significantly, from about 150 000 tons of concentrates per year before 1999, to present levels of 80 000 tons per year. This has resulted in running the smelter operations inconsistently, affecting critical operating efficiencies such as in-process inventory, power, paste, and diesel consumptions. This has resulted in a higher unit cost of production.

In-process inventory control

In-process inventory control becomes a major challenge, if the furnace is not fed adequately and consistently. Running the operation inconsistently creates build-up in the furnace and converters, and increases the rate of reverts generation.

Power Consumption

Specific power consumption is affected mainly by feed consistency and material composition. The furnace is sometimes put on holding power, and power input is not used for smelting. The deteriorating concentrate quality has also negatively impacted on specific power consumption. The combination of these two facts resulted in the specific power consumption increasing from 550 kWh/t of concentrates, as shown in Figure 2.

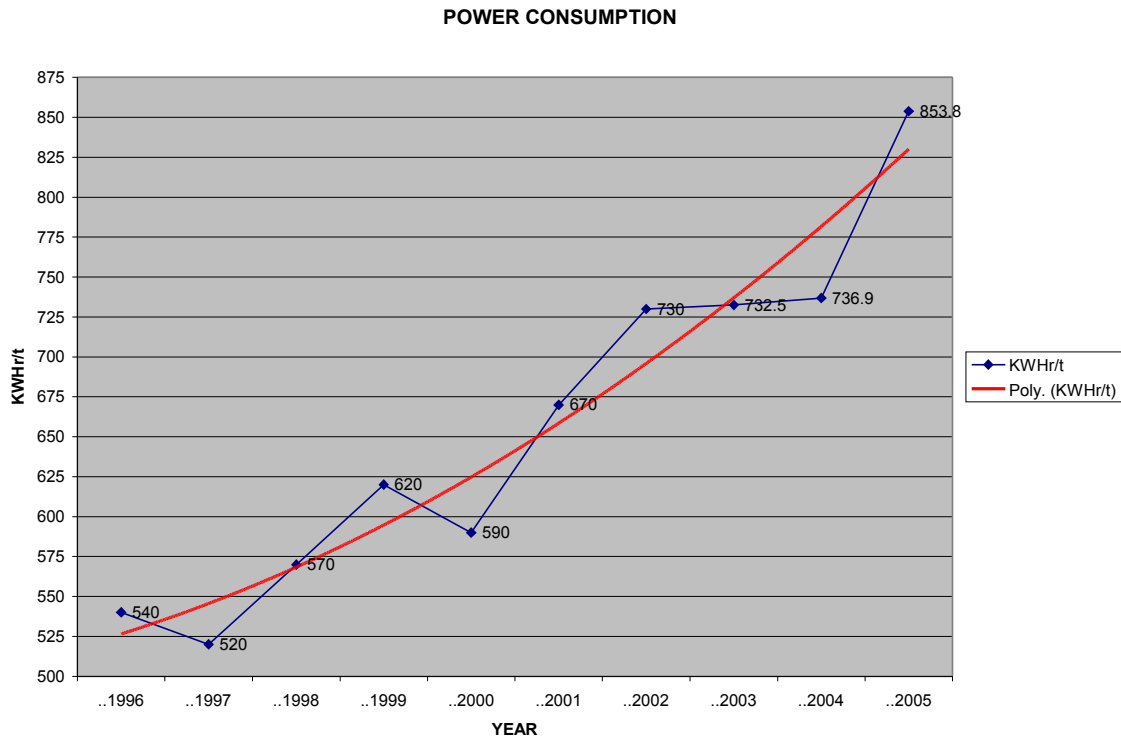


Figure 2: Increase in power consumption (kWh/t) due to low feedstock and high MgO

Paste Consumption

Like power, paste consumption is also affected by lack of feed, although it is affected mainly by electrode breakages. Paste consumption could have been better, because there has been a great improvement in electrode breakages, as a result of proper attachment of casings, and protecting paste from contamination. The paste consumption trend is shown in Figure 3, and the number of electrode breakages in Figure 4.

PASTE CONSUMPTION

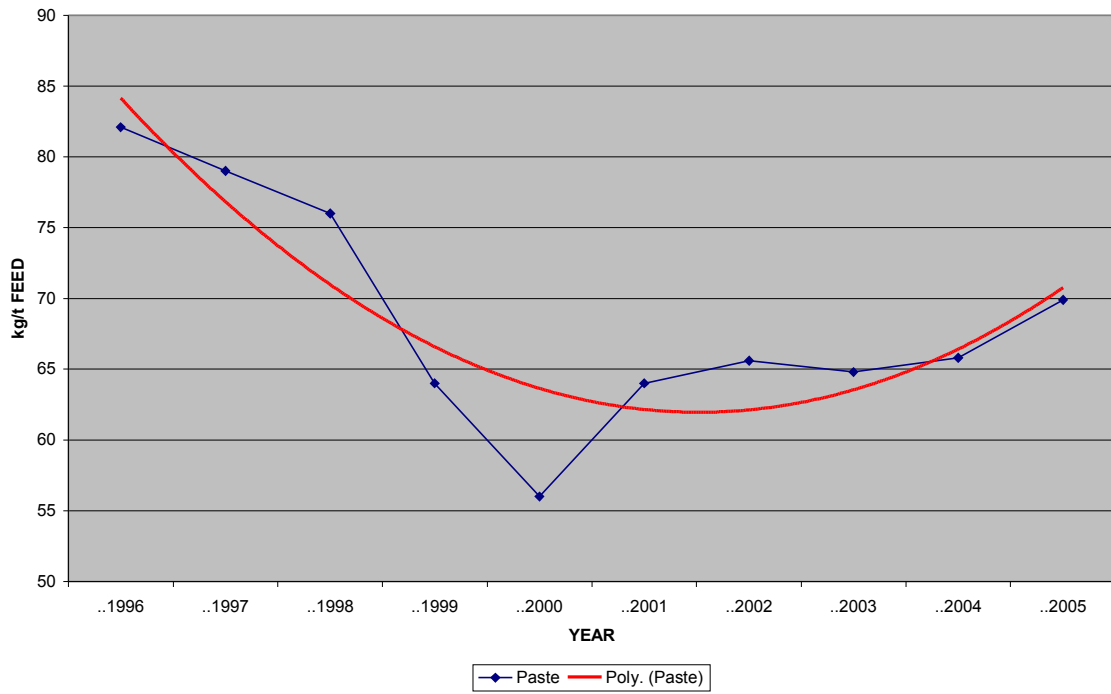


Figure 3: Downward trend of paste consumption over the years

ELECTRODE BREAKAGES

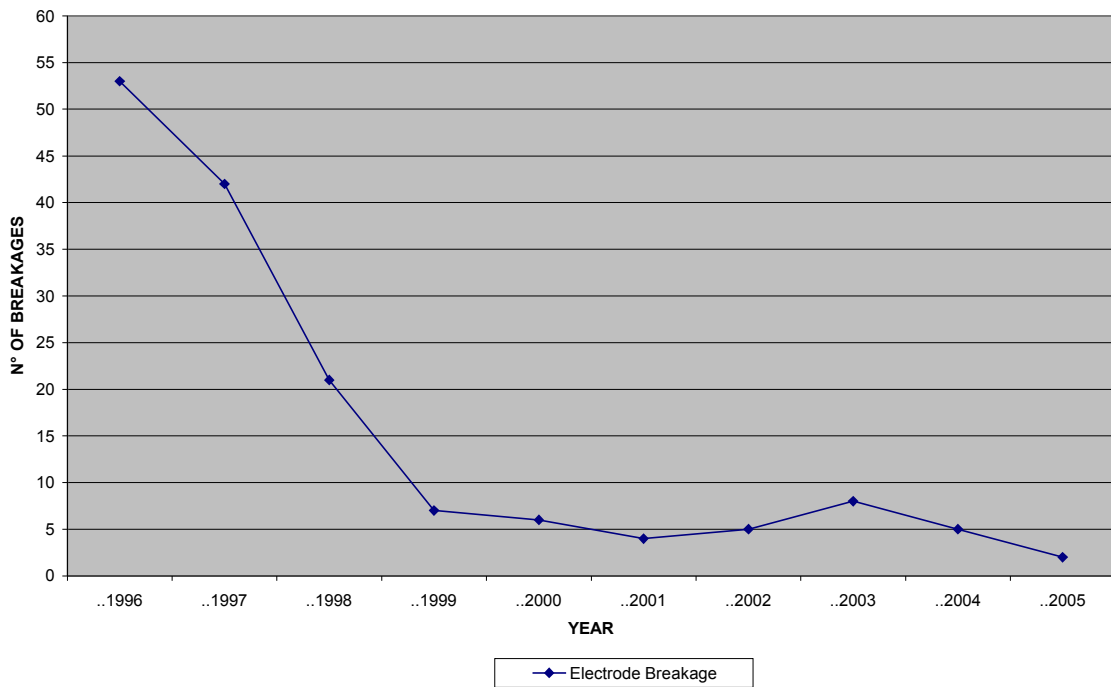


Figure 4: Number of electrode breakages over the years

Diesel Consumption

Diesel usage for converter pre-heating increased significantly in 2005. Converter pre-heating using diesel was frequent because of low matte generation in the furnace, due to low feed, as shown in Figure 5.

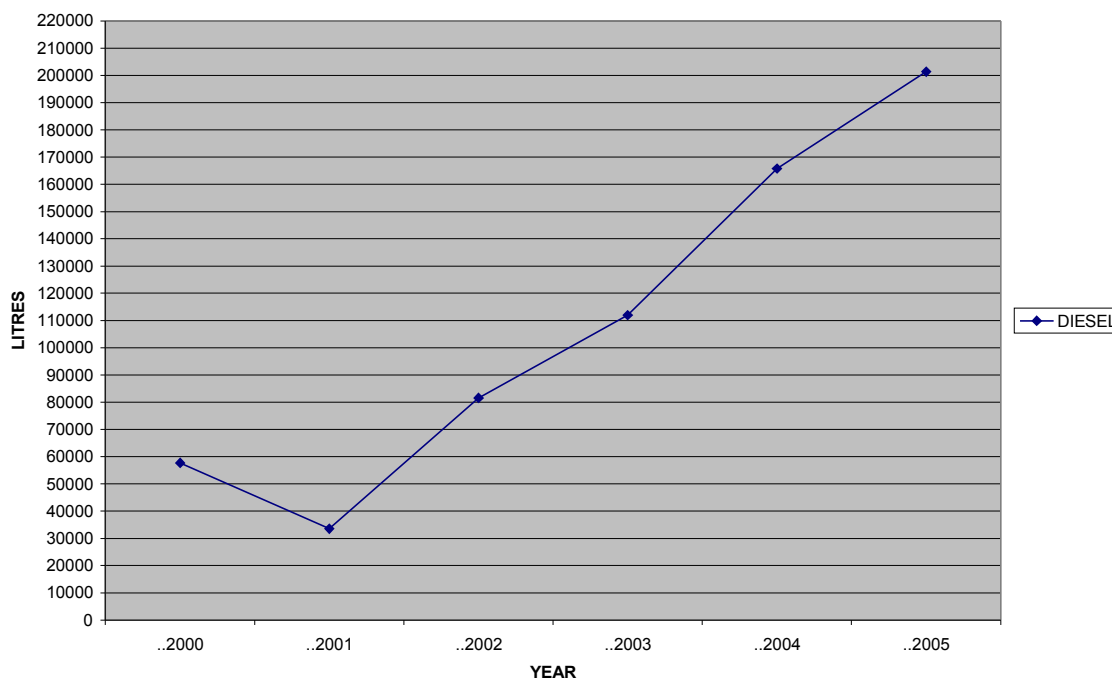


Figure 5: Diesel consumption

EFFECTS OF CHANGE IN MATERIAL COMPOSITION

During the past six years, there has been a significant change in the composition of concentrates from the remaining two mines, as shown in Tables IV and V. The major change has been an increase of MgO in Trojan concentrates, and a decrease of mineral to gangue ratio. MgO levels in Trojan concentrates have moved from 10% in the 1990s, to present levels of 22%, as shown in Figure 6. There was no major shift of MgO, but there has been a significant drop in mineral to gangue ratio in Shangani concentrates, as shown in Figure 7.

Table IV: BNC concentrate specifications - pre 1998

	%H ₂ O	%Ni	%Cu	%Co	%Fe	%MgO	%SiO ₂	%S
TROJAN	13.5	10.5	0.7	0.2	30.0	11.0	25.0	22.0
SHANGANI	11.6	12.7	1.4	0.4	25.0	10.0	20.0	24.0
MADZIWA	10.2	9.0	3.8	0.2	30.0	8.0	28.0	26.0
EPOCH	10.1	16.5	0.7	0.3	15.0	11.0	20.0	25.0
BLEND	12.0	11.5	0.9	0.2	25.0	10.0	22.0	24.0

Table V: BNC concentrate specifications - post 1998

	%H ₂ O	%Ni	%Cu	%Co	%Fe	%MgO	%SiO ₂	%S
TROJAN	16.0	9.5	0.4	0.2	20.0	20.0	26.0	15.0
SHANGANI	13.0	13.0	1.2	0.4	24.0	12.0	18.0	20.0
BLEND	15.0	10.5	2.1	0.25	22.0	17.0	32.0	17.0
PRE -1998	12.0	11.5	3.2	0.2	25.0	10.0	22.0	24.0

TROJAN CONCENTRATES GRADE AVERAGES

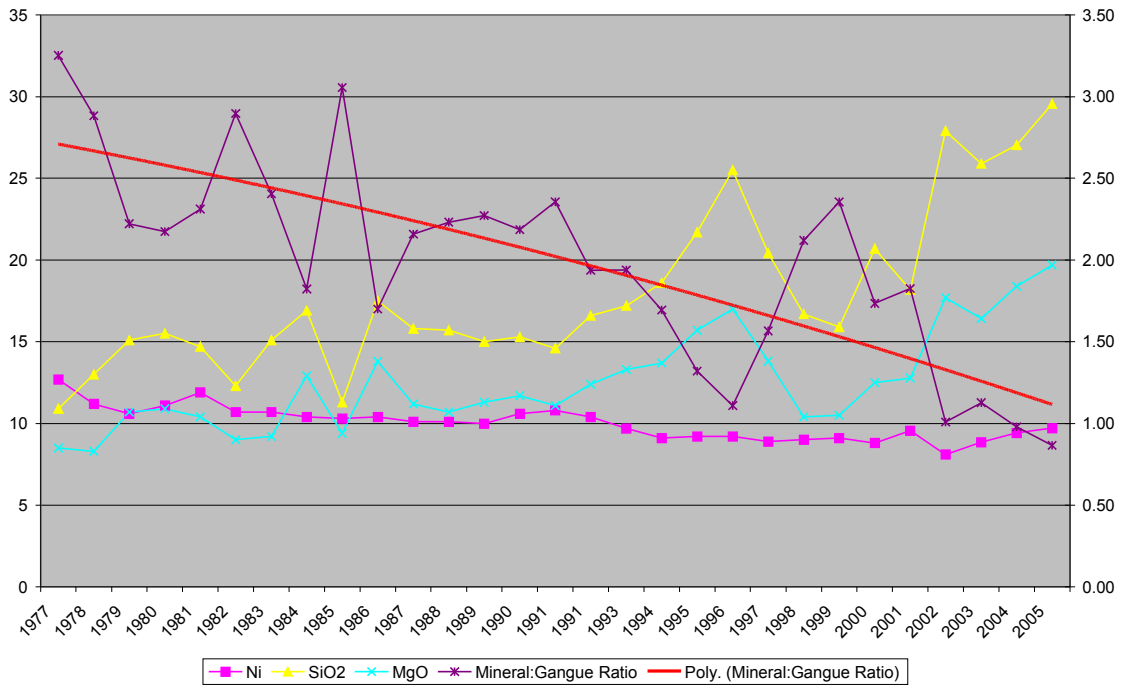


Figure 6: Trojan annual concentrates grade averages

SHANGANI CONCENTRATES GRADE AVERAGES

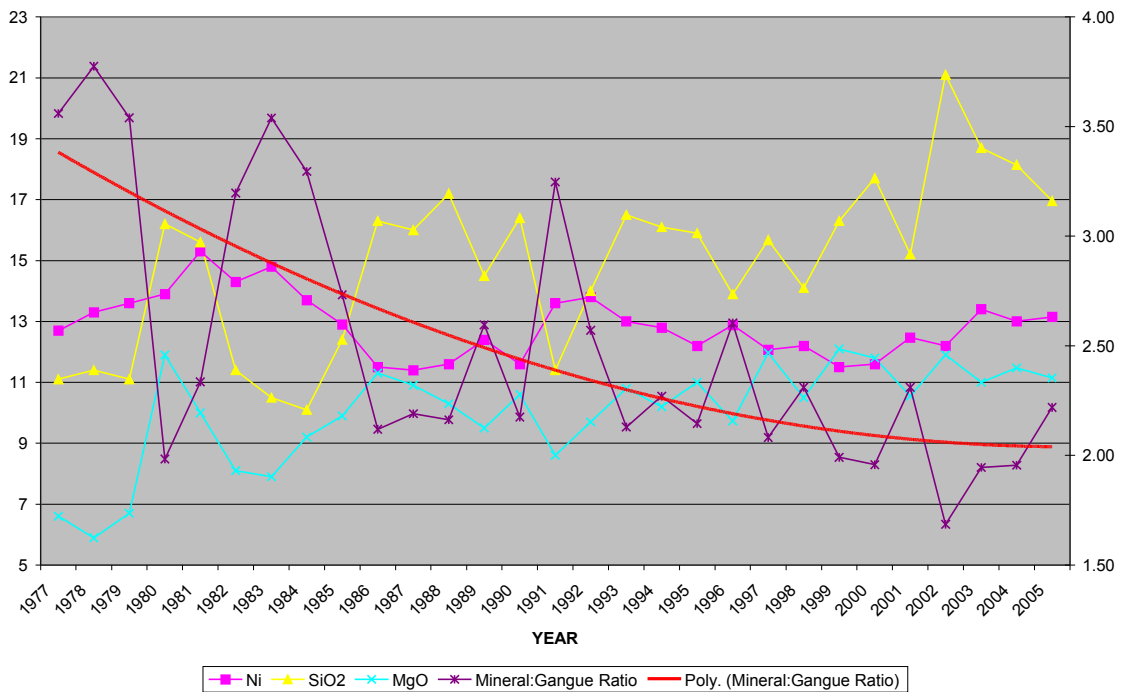


Figure 7: Shangani annual concentrates grade averages

Effects of High MgO

On 6 May 2002, a breakout of molten material through the hearth of the six-in-line electric arc furnace was experienced. The immediate cause of the breakout was discovered to be high slag temperatures, which were then averaging 1500°C, instead of the normal 1390 to 1400°C. The high temperatures were a function of high MgO levels in the feed blend, averaging 16% compared to a target of 12%. This, in turn, resulted in high MgO in slag (20%), which requires high temperatures of around 1500°C to flow. At this temperature, the usually protective layer of build-up was allowing molten material to attack the frozen slag between bricks. The relationship between high MgO in slag and high slag and matte temperatures is demonstrated in Figure 8.

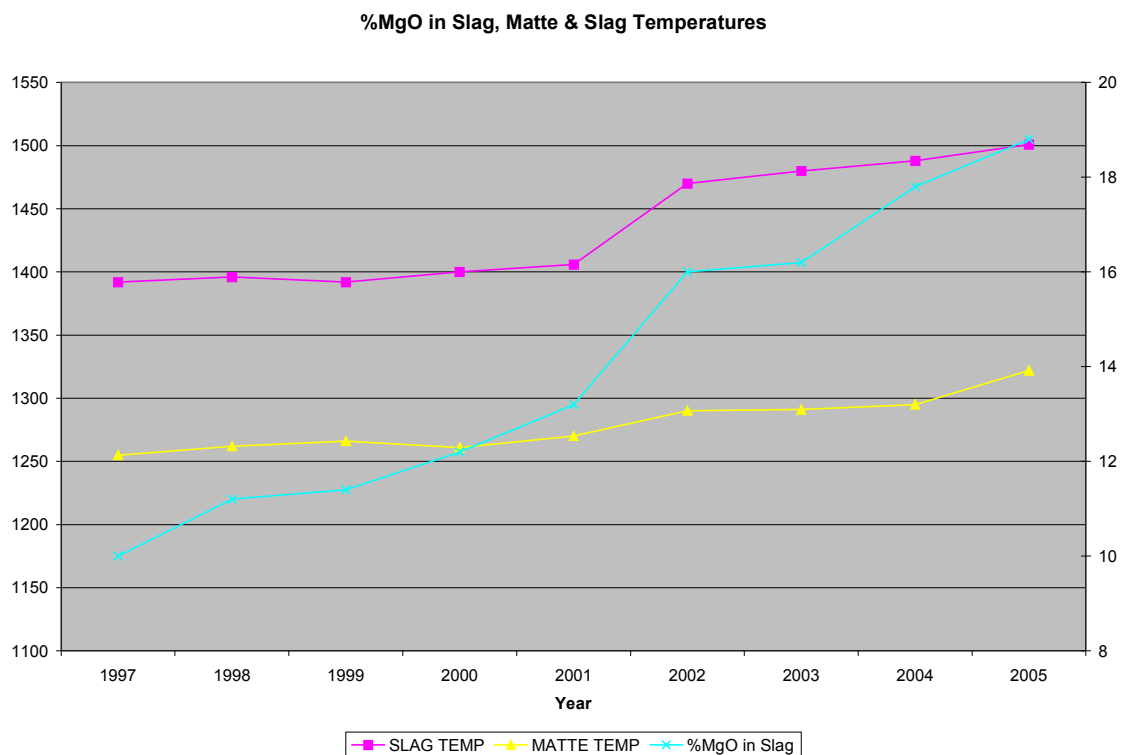


Figure 8: MgO in slag (mass %), and matte and slag temperatures (°C)

Slag Chemistry

The three chief constituents of the furnace slag, melt at the following temperatures:

FeO	-	1377°C
SiO ₂	-	1723°C
MgO	-	2832°C

FeO-MgO-SiO₂

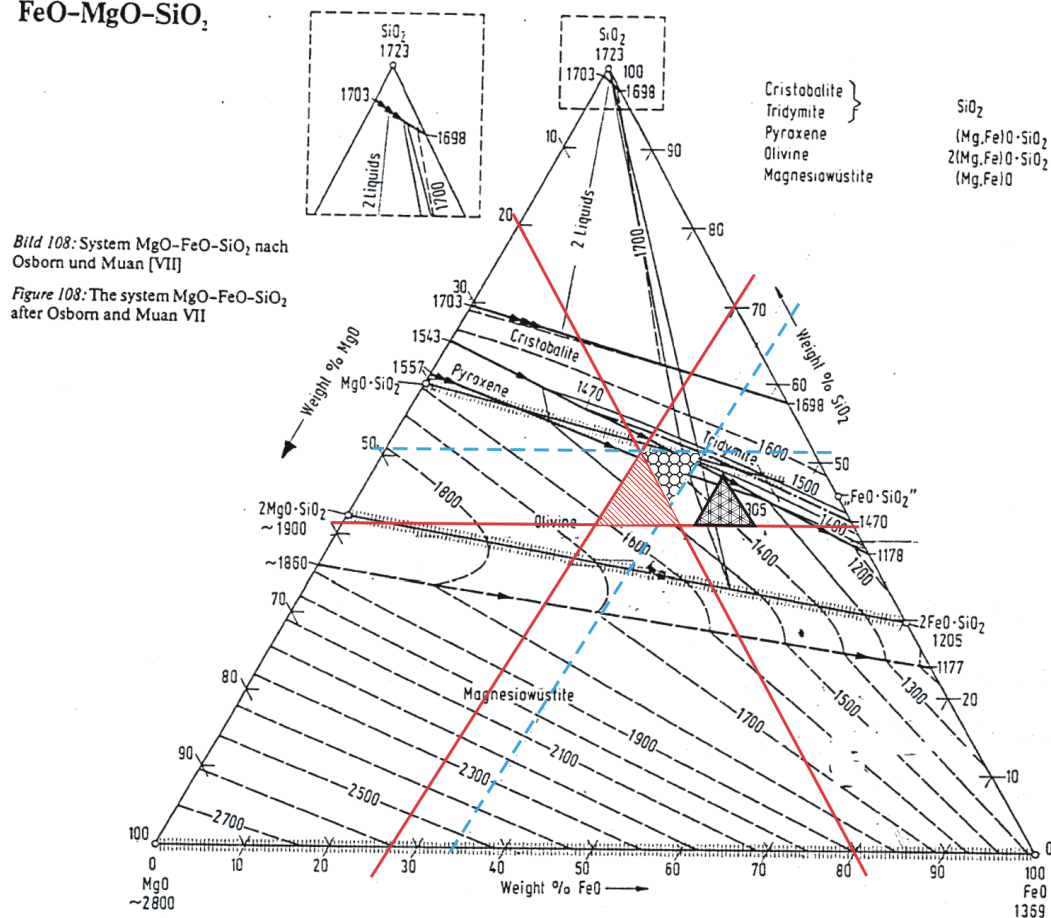


Figure 9: FeO-MgO-SiO₂ ternary diagram

The BSR slag used to form in the olivine (Mg,Fe)₂SiO₂ stability region when MgO constituted 10% (region represented by black triangle). Olivine, an orthosilicate, can melt at temperatures as low as 1200°C when MgO is zero. At 20% MgO in slag, the olivine formed melts at >1500°C, as shown in Figure 9. At present, the equilibrium operating point for the FeO-MgO-SiO₂ ternary system at BSR has shifted from the temperature range of 1390-1440°C to 1460-1580°C, because of the significant increase in MgO in slag. There is also a significant drop of FeO in slag.

Stability of the olivine phase increases with increase in the MgO content of the slag.

MgO RESEARCH CARRIED OUT

After the furnace breakout of 6 May 2002, a lot of research and studies were done to find out how best to deal with the high MgO in Trojan concentrates. The study carried out at Trojan revealed that the MgO in heads had increased over the years, as shown in Figure 10.

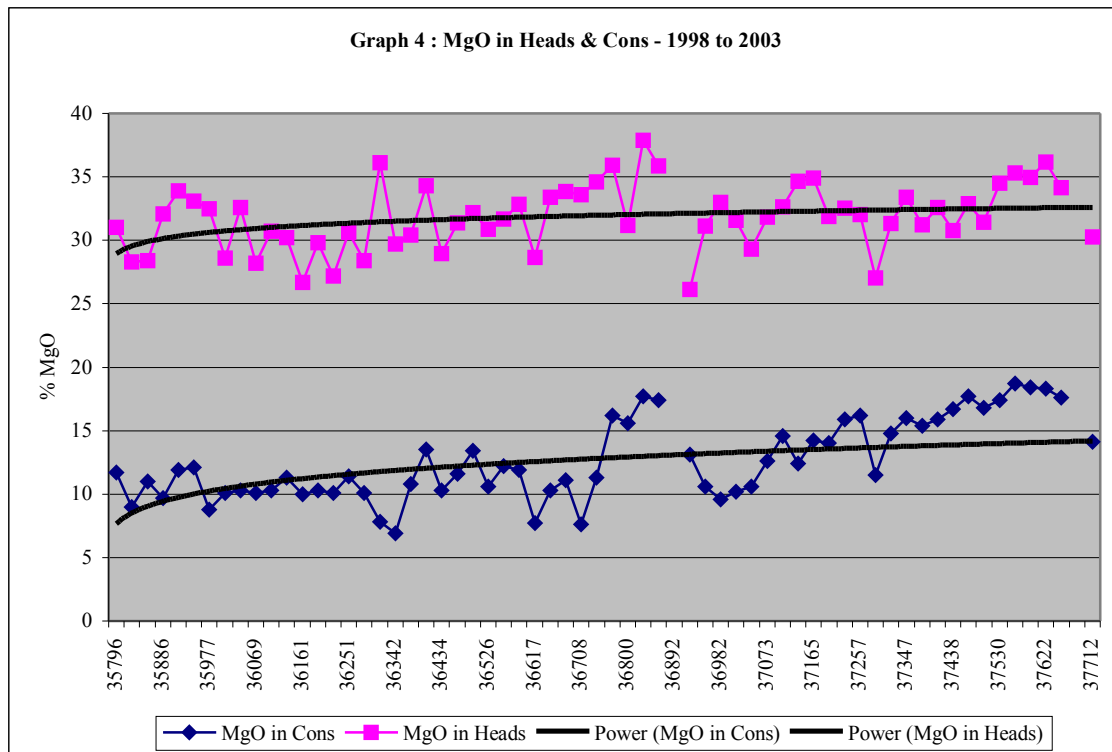


Figure 10: MgO in heads and concentrates – 1998 to 2003

Flotation tests were carried out using different selective depressants, varying flotation pH, and reducing mass pulls.

After realizing that there was no immediate solution to this MgO issue at the Concentrator, some interventions were mooted at the Smelter.

Fluxing with lime rock

A study carried out by the University of Zimbabwe’s Department of Metallurgy showed that fluxing with lime rock could reduce the viscosity of the slag at lower temperatures. Fluxing using lime rock was done, giving good results. There was a limit to the amount that could be added to prevent washing away the furnace protective build-up on the hearth and side-walls, thus exposing the refractory brick to molten material. A maximum of 4.5% of feed was added.

The other limitation was the availability of the product, as there was a sole supplier who kept on increasing the commodity price to an extent that it became uneconomical for the Smelter. Other economical ways to mitigate the effect of high MgO had to be investigated.

OTHER WAYS TO MITIGATE THE EFFECT OF MgO

Basicity Ratio Control

Slag viscosity decreases with an increase in basicity ratio, up to 1.3. The driving force is the increase in the de-polymerisation of the silicate network. Beyond a basicity ratio of 1.3, viscosity increases with an increase in basicity ratio. In this

case, the driving force is an increase in the chemical potential of solid compounds, *i.e.* a high proportion of suspended solids.

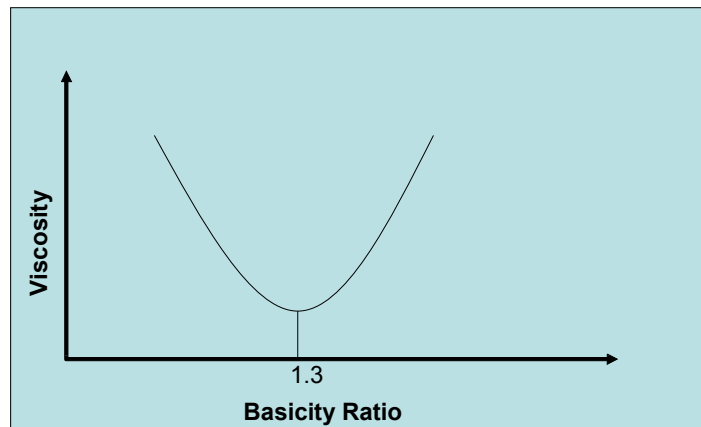


Figure 11: Slag viscosity / basicity relationship for silicate slags

After having looked at this, it was decided to use basicity ratio as the control parameter, and the smelter started using SiO_2 as a flux to drop the basicity ratio, targeting 1.2. This gave some positive results, until recently, when the MgO in Trojan concentrates shot up to 22%, resulting in MgO in slag rising to 21%, requiring temperatures of around 1530°C for it to flow.

Fluxing with Iron Pyrites

There was a significant drop of Fe in Trojan and Shangani concentrates. This resulted in a deficiency of Fe in furnace matte to the converter. Energy generation in the converter was affected, and production of FeO was decreased. Slag chemistry control, using FeO from the converter return slag, was affected. A decision was reached to flux using iron pyrites to boost Fe in matte. The result was quite positive, as we could boost the converter temperatures and thus be able to process recycled materials. There was a better slag chemistry with more slag return from the converters. The limitation came in the price of the commodity.

Minimizing of Furnace Burn-downs

The risk of a furnace breakout is increased when the molten material gets into direct contact with refractory brick. This will happen when the build-up, which separates the molten material and the refractory brick, is smelted. Normally, this happens when the furnace is superheated during burn-downs (applying power without feed) to remove excess build-up.

Under the current conditions, where the smelter has high operating temperatures, they have minimized furnace burn-downs to maintain the build-up between the bath and the refractory brick. The limitation to this is ending up with a reduced furnace capacity.

Monitoring of Thermocouple Readings

There are thermocouples installed in the hearth, side-walls, and end-walls of the furnace, for temperature monitoring. These readings are now being trended and monitored more frequently than before, to detect if there is any significant temperature rise on the hearth or side-walls.

THE HISTORY OF FURNACE REBUILDS

After it was commissioned in 1976, the furnace was partially rebuilt in 1979 and 1981, and totally rebuilt in 1993 and 2003. The next overhaul is scheduled for early 2013.

1981 Furnace Rebuild

The roof, side-walls, and end-walls were replaced, after roof collapse caused by an explosion. The explosion was due to high moisture content in furnace feed, which had exceeded the upper limit of 5%.

During 1981 commissioning, there was a major breakout, which emptied the furnace. This was as a result of widened gaps between hearth bricks, created by movements during the rebuild. The furnace was successfully re-commissioned without a further breakout, after the slag between the gaps had frozen.

1993 Furnace Rebuild

A decision was made to rebuild the whole furnace, including the hearth replacement, after the major breakout that had occurred during commissioning in 1981. Original hearth life was 17 years.

During commissioning, metal trickles occurred under all electrodes. It was concluded that the trickles were through the gaps provided during installation of earth strips.

2003 Furnace Rebuild

After the hearth failure, which occurred on 6 May 2002, it was decided to rebuild the whole furnace in 2003. The rebuild was done within the budgeted time of 61 days.

The metal trickles that occurred were quite minor and easily contained by cooling with pressurized water.

Other noteworthy incidents

Over the years there have been several furnace slag and matte breakouts. In April 1990, the furnace suffered a matte breakout through a worn matte-end wall. A hot repair was successfully completed in two weeks, using a procedure that was developed in-house to replace a complete matte-end wall.

The most recent matte breakout through the hearth is the one that occurred on 6 May 2002.

CONCLUSION

The closure of Madziwa and Epoch mines and the reduction of toll treatment have resulted in a reduced tonnage of feed to the Smelter. This has brought about special challenges to the whole smelting operation. Critical efficiencies such as in-process inventory, power, brick, and paste consumptions are significantly affected, resulting in a high unit cost of operation.

Another important thing to note is a significant change in the composition of the concentrates from the two existing mines. The high MgO, and a low mineral to gangue ratio in the concentrates, have posed a major risk to the integrity of the furnace. Measures have been put in place to manage the risk.

ACKNOWLEDGEMENTS

The author would like to thank the management and staff of Bindura Nickel Corporation in general, and Bindura Smelter & Refinery (BSR) in particular, for their support, and permission to publish this paper. Special thanks also go to the Production Manager (BSR) - B. Manhando, and to Projects Metallurgist - E. Katsande, for the contribution they made to put some shape and focus to the paper.

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