Bindura Nickel Smelter - from decommissioning, care and maintenance, to plant re-start

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Abstract – Bindura Nickel Corporation (BNC) operates two nickel mines, and treats concentrates from these mines as well as toll concentrates from the region around its Bindura Smelter and Refinery (BSR) complex. At the smelter, concentrates of at least 5% nickel content are blended and dried to 4% moisture in a coal-fired rotary kiln. Matte smelting of concentrate is carried out in a six-in-line electric arc furnace, where the furnace slag is granulated and discarded. Furnace matte is transferred via ladles into Peirce-Smith converters, where, after granulation, a leach alloy containing 68%Ni, 20%Cu, and 6%S is produced. Converter slag is recycled via the matte-smelting furnace.

The onset of the global economic recession towards the end of 2008 resulted in a collapse of metal prices, worsening the local situation that was already marred by unfavourable macro-economic conditions in Zimbabwe. As a result, BNC mines were put on care and maintenance in November 2008, followed by Bindura Smelter and Refinery in February and March 2009 respectively. The business environment has since changed, and BNC is getting ready to re-start the plant. This paper describes the decommissioning of the Bindura furnace, asset preservation during the care and maintenance programme in the past two years, and preparation for starting up of the Bindura smelter in the near future.

INTRODUCTION

The Bindura smelter includes a rotary dryer, 15 MVA submerged six-in-line electric arc furnace, and Peirce Smith converters. Concentrates from BNC's Trojan and Shangani Mines are treated, as well as toll concentrates. The smelter produces a leach alloy for leaching treatment at the refinery to produce cathode nickel.

DESCRIPTION OF BINDURA SMELTER

As noted, the smelter includes mainly the dryer, a six-in-line matte-smelting furnace, three converters, a dust recovery system, and an off-gas handling system. Table I contains the technical data for the dryer, furnace, and converters at the Bindura Smelter and Refinery (BSR).

Table I: Major components of the Bindura Smelter

Coal-fired Rotary Dryer		
Size, Diameter x Length, m	2.26 by 20.5	
Dryer Throat Temperature, ^{o}C	500 – 950	
Post-cyclone Temperature, ^{o}C	100	
Throughput, tph wet concentrates	32	
15 MVA Six-in-line Furnace		
Size, Length x Width x Height, mm	22 110 by 6 428 by 4 130	
Electrode Diameter, mm	1100	
Specific Power Consumption, kWh/t conc.	490 – 520	
Peirce-Smith Converters		
Size, Diameter x Length, mm	3048 by 7010 (C1 & C2), 3962 by 7315 (C3)	
No. of tuyeres	30 (C1 & C2), 35 (C3)	
Cycle time, mins	720 (C1&C2), 1080 (C3)	
Capacity, tons per month Ni	1300	

Drying Process

The concentrates from the mines are dried in a coal-fired drying kiln, where the moisture content is reduced from 15% down to between 3.0 and 5.0%. The hot gases used for drying are admitted through the feed end, to give a co–current flow of hot air (500 – 900^{O}C) together with the wet concentrates being fed. 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 some dry concentrate particles that are collected through the ducting system to the six cyclones. Each cyclone's underflow product is discharged onto the dryer discharge conveyor, while the overflow passes through a multi-vane wet scrubber for gas cleaning. The scrubber slurry is filtered, sun dried, and recycled through blending with fresh concentrates. The dried product is temporarily stored in silos and subsequently fed into the furnace.

Table II: Typical Composition of concentrates and blended materials, mass %

Material	%H_2O	%Ni	%Cu	%Co	%Fe	%S	%MgO	%SiO_2
Trojan Concentrates	15.0	9.20	0.70	0.20	25.0	15.80	18.0	25.80
Shangani Concentrates	12.0	12.70	1.40	0.40	23.0	22.60	12.0	20.00
Blend	4.5	9.36	0.82	0.24	24.0	15.0	15.6	30
Scrubber Solids	19.5	8.40	2.60	0.30	22.0	14.0	17.0	26.5

Smelting Process

Dried concentrates and recycled materials, blended in the correct proportions, are conveyed into a surge bin above the submerged electric arc furnace in batches. Gravity choke-fed pipes keep the furnaces supplied with charge. The furnace has six in-line self-baking Söderberg electrodes that are fed by three single-phase transformers. The slag resistance to the flow of current supplies energy to achieve and maintain smelting temperatures.

The charge is thermally treated, to melt it and bring about physical and chemical changes, which results in 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 and matte phase. The slag phase floats on top of the matte phase because of its lower relative density. The slag is tapped and granulated for disposal, while the matte is tapped at regular intervals for further processing in the converters.

Table III: Typical chemical analysis of furnace matte and slag, converter slag (mass %) and temperatures

Material	%Ni	%Cu	%Co	%S	%FeO	%Fe	%SiO_2	%MgO	T, ^{O}C
Furnace Matte	20.0	5.00	1.20	27.0		40.0			1260
Furnace Slag	0.30	0.11	0.23	0.77	35.20		43.30	14.90	1460
Converter Slag	0.93	0.42	0.93		65.50		29.00		

Converting Process

The converters are basically horizontal steel cylinders, lined with chrome-magnetite bricks. Each converter has an opening at the top, and the cylinder can rotate about its horizontal axis. Air for oxidation 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, and the temperature control is by doping with reverts. After most of the iron has been slagged, skimmed off, and recycled back to the furnace, more matte is added and the process is repeated until a sufficiently large volume of white metal is obtained in the converter. After the removal of the last slag, during the clean-off period, the second blowing stage (leach blow) reduces the sulphur levels from 26 to 6.5%. During this stage, doping is by leach alloy scrap.

The final matte is granulated with water sprays and is dispatched to the refinery for further processing.

Table IV: Typical chemical analysis of leach alloy and converter slag, mass %

	%Ni	%Cu	%Co	%S	%Fe
Leach Alloy	70.5	14.8	0.98	5.72	0.40
Leach Alloy Scrap	70.5	14.8	0.98	5.72	0.40
Converter Slag	0.93	0.41	0.92		65.5
Ni Scrap	99.0				

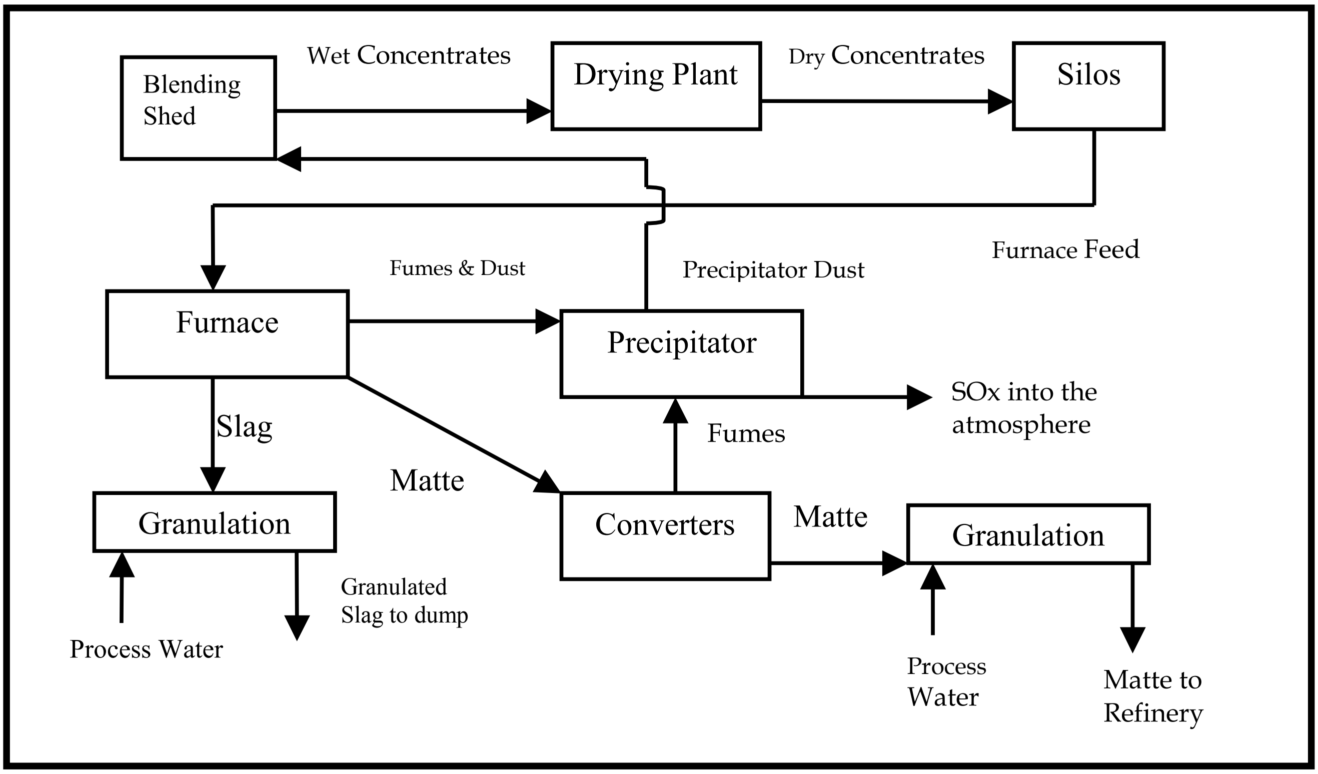


Figure 1: Smelter Flow Sheet

Factors leading to the shutdown

In the years leading to 2008, the local business environment was marred by unfavourable macro-economic conditions, caused by the adverse socio-economic environment and characterized by hyperinflation, unfavourable exchange rates, along with a restrictive supply chain. This led to low productivity, low capacity utilization, high costs of production, and skills migration. The onset of the global economic recession towards the end of 2008 resulted in a collapse of metal prices, resulting in BNC making a decision to put its operations on Care and Maintenance. By the end of November 2008, BNC mining operations had come to a halt, while the smelter continued for four months, to deplete all concentrate stockpiles.

SMELTER DECOMMISSIONING

Prior to the decommissioning, detailed shutdown procedures were reviewed, with the assistance of internal and external consultants, to ensure a safe and effective shutdown schedule. The following procedures were instituted as a result of the review.

Drier

Concentrate stocks were depleted on 6 February 2009. Recycled materials and concentrate sweepings were then run through the drier, before its eventual shutdown four days later. The whole dryer system, including hoppers, conveyor belts, a scrubber, and silos, were cleaned out via the furnace, before shutting down the coal-fired, hot gas generator.

Furnace

The furnace was operated on low power, averaging 8 MW during the depletion of concentrate stocks and sweepings. The furnace charge was averaging 150 t per day in the last three months of production, against a target of 600 t. The small quantities of matte generated were treated as normal at the converters until 11 February 2009, when the last amounts of commercial matte were tapped from the furnace, while a holding bath of slag was maintained. The furnace was then put on holding power, averaging 5 MW, for fourteen days, followed by a two-day furnace burn-down (applying power without concentrate feed) to remove build-up. Slag temperatures were raised to 1540°C, compared to the normal 1460°C, in order to melt-down side-wall build-up, the false-bottom, and the hearth build-up (the latter having been noted in the period leading up to the shutdown). Due to this red-top operation, furnace structures became visibly red-hot and water-leaks were experienced on the cooling system of the electrode contact pads. Compressed-air hoses were used to cool down the furnace fume-extraction ducting, and the furnace power had to be temporarily shut down.

The slag bath was tapped and the furnace power was finally switched off on 26 February 2009, and the six electrodes were raised out of the bath to a holding position.

Converters

The converters received limited quantities of furnace matte during the decommissioning period, and preheating using diesel-fired burners was used to help maintain adequate temperatures before converting. The last converter charge was produced and the matte granulated on 11 February 2010. All the converters were then turned down in preparation for a future start up.

Furnace Monitoring Plan

Furnace monitoring started immediately after switching the power off, with the objective of maintaining the furnace integrity during its cooling-down phase. Furnace monitoring of each shift started on 27 February, and continued until 16 March, followed by daily monitoring until 30 April 2009. Brick temperatures, furnace movements, and spring tensional forces were measured, the latter by a hydraulic jack, with the results reported as tonnes. The resultant values were compared to the pre- burn-down measurements.

Table V: Furnace monitoring schedule

Lateral, longitudinal, roof, & tonnage checks	Immediately after draining the furnace
Contraction & refractory monitoring	2 hour intervals
Spring lengths measurement	2 hour intervals
Spring adjustments	When spring changes beyond 3 mm
Spring tonnage measurements	Daily
Furnace movement monitoring report	Daily
Cooling water furnace system isolation	After stabilization of the furnace

Refractory Temperatures

All of the furnace refractory temperatures decreased as expected during the furnace-monitoring period, as shown in Table VI.

Table VI: Summary of furnace thermocouple temperatures during the monitoring period

Furnace Wall	Thermocouples	Average Thermocouple Temperature, °C		
		Day 1	Day 64	Δ°C
Side-walls	T1 to T12	359	24	335
End-walls	T23 & T13 to T16	215	22	193
Hearth	T17 to T22	488	35	453

- On the side-walls, the greatest decrease in temperature was on thermocouple T3, revealing the melt dynamics during shutdown.
- For the end-wall thermocouples, the matte-end placed thermocouple T23 dropped the most, due to the furnace burn-down that aimed at removing the build-up in the furnace.
- The matte-end hearth thermocouple T18 dropped the most due to the furnace burn-down.

The rate of temperature fall during the monitoring period is shown in Figure 2 below for the above noted temperature drops.

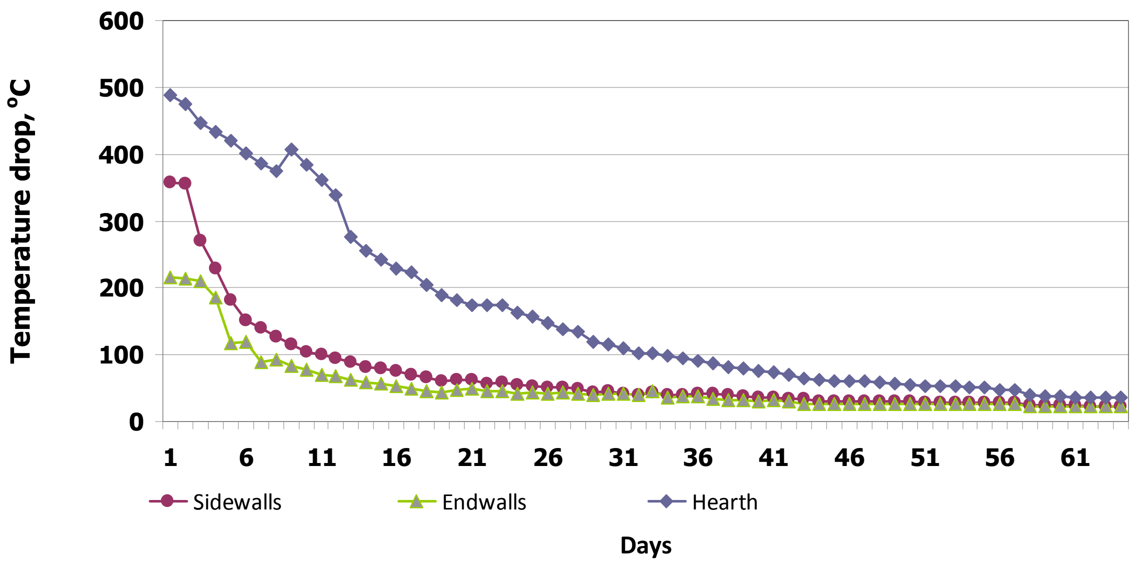


Figure 2: Refractory temperature drops during decommissioning

After switching the furnace power off, the temperature drop resulted in the contraction of refractory, and subsequently the furnace structure. A sharp increase in the hearth temperature occurred on Day 9, after switching off the hearth cooling fans, and this resulted in a rise in the hearth temperature (see Figure 2) as more energy was conducted from the hot hearth build-up through the refractory bricks.

Roof Movements
The furnace roof is suspended on the skew-back beam which is mounted on the furnace buckstays. As the furnace walls contract, the buckstays move inwards and the surface area of the furnace top reduces, thereby forcing the roof arc to move upwards. Under normal operating conditions, the roof was designed to allow for a movement of ±50 mm.

The furnace roof moved upwards right from switching off, as a result of the drop in the temperature of the refractory bricks and their subsequent contraction. Of the four panels, panels 2 and 3 had the greatest movement, much higher than the normal 50 mm. Roof movements were then controlled by limiting the tonnage decrease on top cross springs to 17 t (normal working tonnage) and top long spring to 15 t (maximum working tonnage) from 9 March.

Table VII: Roof movements

Panel	**1**	**2**	**3**	**4**
Movement (mm) (24.02.09)	-44	-35	-27	-10
Movement (mm) (09.03.09)	-17	22	22	28
Movement (mm) (30.04.09)	-27	30	31	39
Change (mm)	17	65	58	49

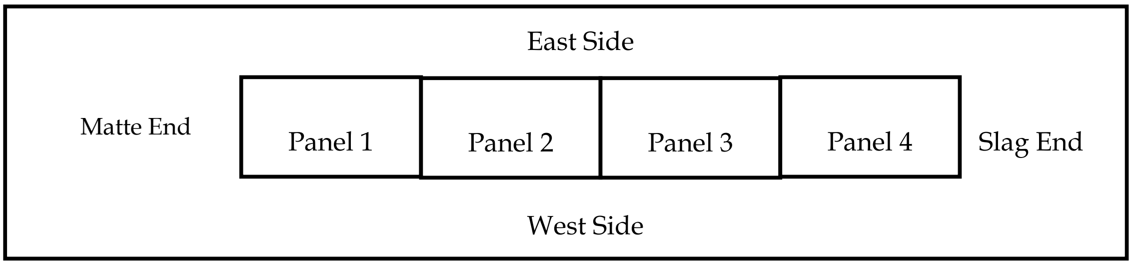


Figure 3: Furnace roof panels arrangement

Lateral Movements
The furnace top and bottom contracted on all its end- and side-walls due to the drop in refractory temperatures, as seen in Figures 4 and 5.

Furnace Top: Contraction on the end-walls was relatively uniform, although the eastern matte-end side contracted the most by 45 mm. The side-walls contracted the most at the centre, where panels 4 and 5 contracted by 42 mm, as shown in Figure 4.

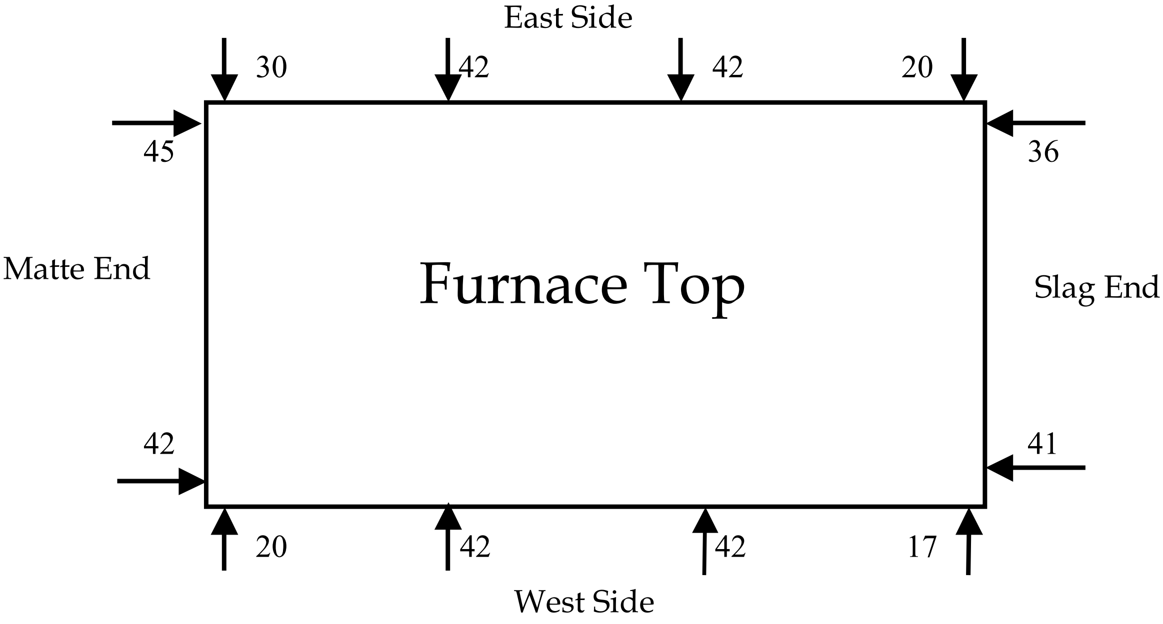


Figure 4: Lateral movements at the Furnace Top (upper section) in mm

Furnace Bottom or Hearth-end: The furnace contracted more at the slag-end than at the matte–end. The furnace bottom (hearth) had the least contraction on the side-walls, with a maximum of 9 mm, indicating the relative stability of the hearth during the furnace cooling period, as shown in Figure 5.

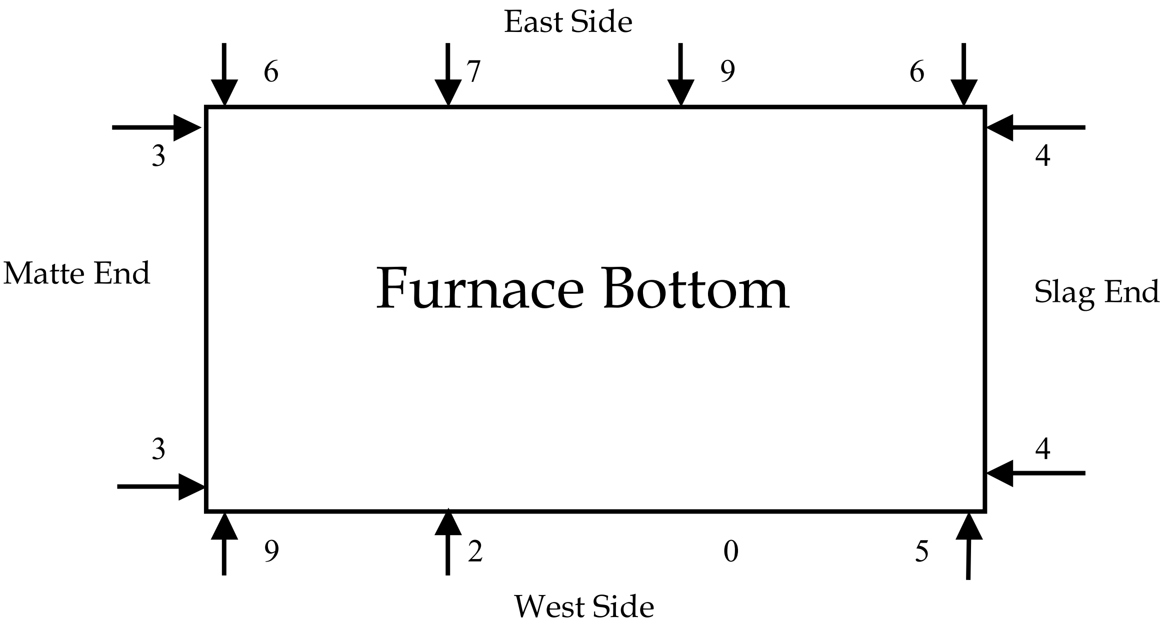


Figure 5: Furnace Bottom lateral movements (bottom section) in mm

Spring Tensional Forces

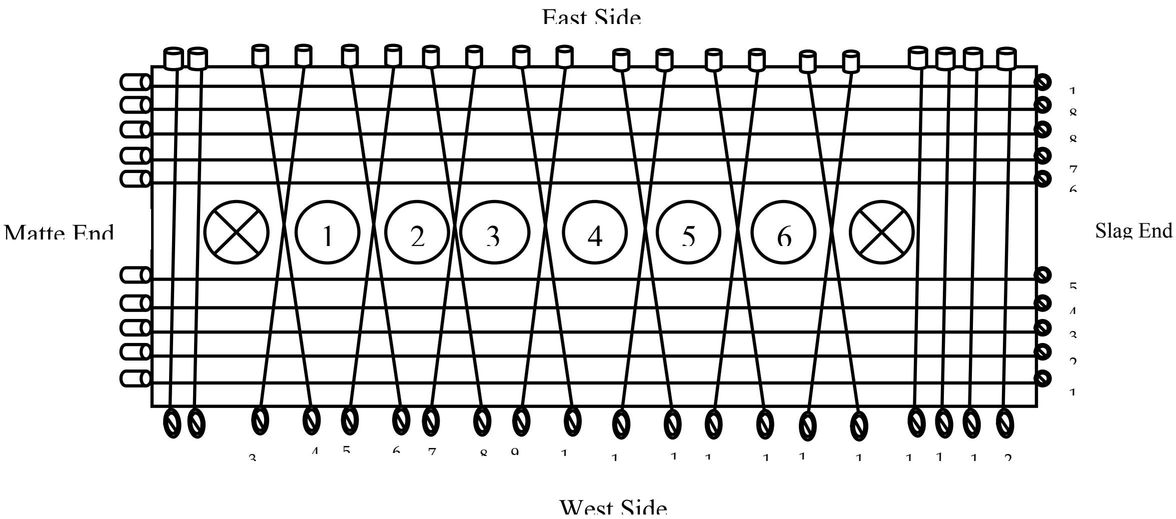
During normal furnace operations, all the top springs had their tensional forces maintained above the maximum working load to avoid a roof collapse. These were the forces that were maintained daily from 27.02.09 up to 09.03.09, after which they were allowed to drop to the working load to avoid roof popping during furnace contraction. However, the low refractory temperatures led only to a small drop in forces. When the furnace monitoring was finally stopped on 30.04.09, the top cross springs had tensional forces within their working load limits, while the top cross springs tensional forces were above their maximum working load.

The safe working loads for all the furnace springs are shown in Table VIII.

Table VIII: Typical Working Tensional forces for Furnace Springs

Working Tonnage	Top Cross	Top Long	Bottom Cross	Bottom Long
Minimum	14 t	9.6 t	24 t	28 t
Normal	17 t	12.0 t	30 t	35 t
Maximum	20 t	14.4 t	36 t	42 t

Most of the bottom springs had their tensional forces within the working range limit before the burn-down. During furnace monitoring, spring tensional forces were controlled at those used in normal practice. They continued to decrease, due to the drop in temperatures, but were adjusted back to their original tonnages before decommissioning.



Key

Fume extraction ducting

Electrodes, 1 – 6

Spring

Nut

Tie Rod with spring and nut

Figure 6: Furnace top springs aerial view arrangement

Top Cross Springs: Major decreases in tensional forces were recorded on springs 11 and 20, which decreased by 4 t each at 21 t, as shown in Figure 8.

Top Long Springs: The biggest drops were on springs 1, 2, 3, 5, and 9, which dropped by 5 t each.

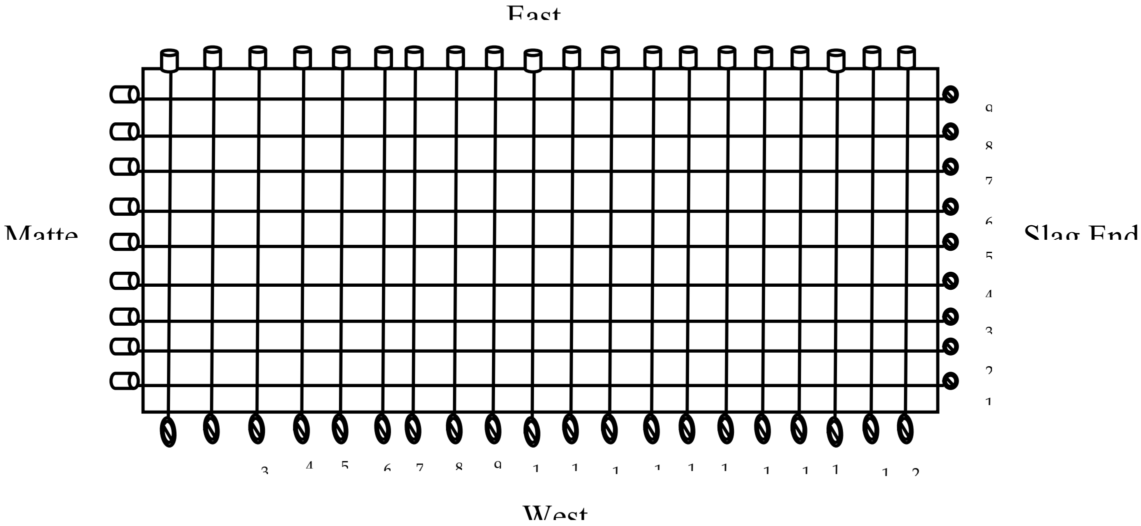


Figure 7: Furnace bottom springs aerial view arrangement

Bottom Cross Springs: At the end of the monitoring period, most of the springs were 2 t above the normal operating tensional forces, which was within measurement error.

Bottom Long Springs: At the end of the monitoring period, most of the springs were 1 t above the normal operating tensional forces, which was also within measurement error.

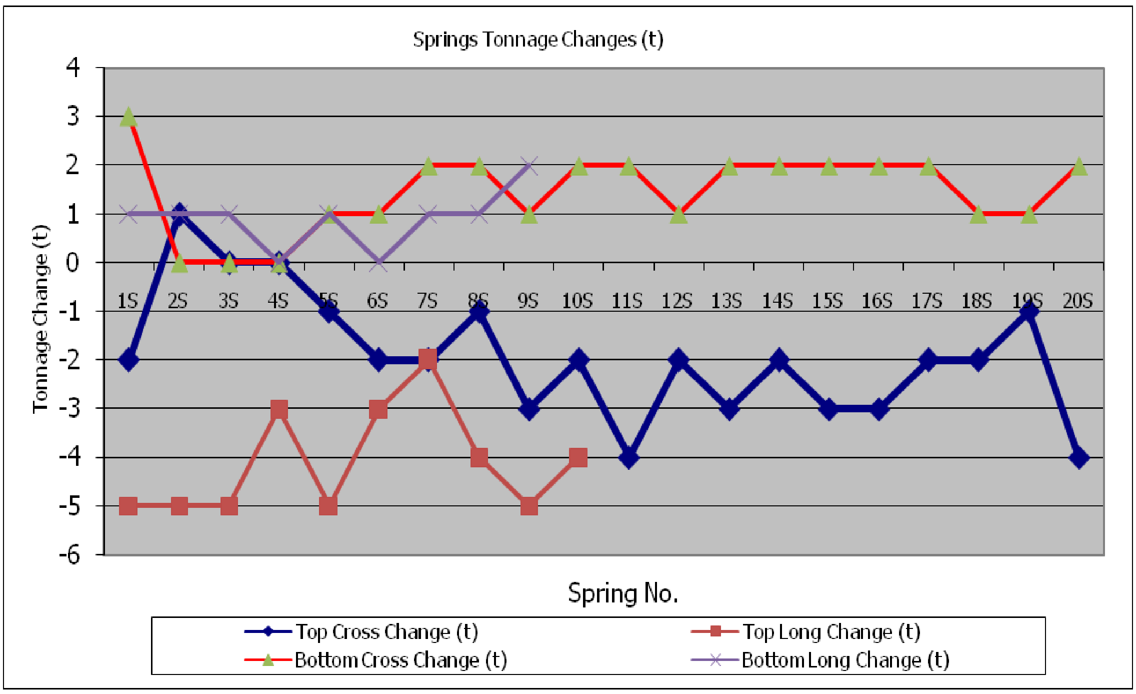


Figure 8. Tensional force changes for individual springs

It is quite evident from the spring tensional monitoring that the furnace integrity was well maintained throughout the cooling duration.

CARE AND MAINTENANCE

The Care and Maintenance (C & M) plan was developed to maintain the physical integrity of the smelter, at the lowest cost in line with the limited company financial resources. Measures were taken to stabilize the costs, while ensuring that assets were maintained in readiness to resume operations after normalisation of the economic environment. Such measures included power and water shedding at the workplace and mine villages, resting labour, and stringent controls over stores costs during C & M.

After the completion of the daily monitoring phase, the furnace was left in a condition ready for start-up at some future date. During the care and maintenance period, monthly furnace monitoring was instituted for temperature, spring tensional forces, and movements on the roof and the furnace.

Since the beginning of the care and maintenance period, the furnace has remained stable, and no movements or major spring tensional forces have been observed.

Furnace Inspection during the Care and Maintenance Period

Furnace build-up was dug out, and subsequent inspection revealed the following observations.

1. There was a lot of concentrate build-up on the all the furnace upper side-walls.
2. The build-up on the hearth was approximately 800 mm thick and this was dug out. Mineralogical examination showed the presence of high occurrence of olivine, with hematite, chrome spinel, pyrrhotite, magnetite, and pyrite as minor constituents.
3. There was slight wear of the side-walls just below the slag-matte interface.
4. The slag end wall bricks below the tap-holes had been extensively damaged, with infusion of bricks with melt.
5. The expansion gap between the roof and the side-walls had been significantly sealed.
6. The skew-back beam was damaged by intense furnace heat due to limited feed rates during the last months of production.
7. The bricks from the rabbling doors up to the roof level were extensively eroded.
8. Most of the rabbling doors were damaged by heat and needed replacement.
9. All of the roof panels were in good condition, despite a small portion of western-end of the matte-end panel that seemed to have moved downwards.

These observations were critical as regards the formulation of the furnace re-start plan, of which the key aspects are noted below.

1. De-brick all of the six roof panels.
2. De-brick the slag end-wall.
3. De-brick side-wall panels and the matte end-wall to two courses below the rabbling doors.
4. Remove the rabbling doors.
5. Level the walls with a castable.
6. Install rabbling doors.
7. Re-brick all the walls, and level above the rabbling doors with a castable.
8. Replace skew-back beam.
9. Install roof formers in the furnace.
10. Re-brick the six roof panels.

CHALLENGES AND LESSONS LEARNT

- Batch processing operations are not healthy for the furnace, as evidenced by the build-up in the furnace, which reduces the operating volume of the furnace.
- Both batch processing and low feed rate operations led to the damage on the skew-back beam, which adversely affects the furnace integrity.
- The furnace dig-out was slowed down by relatively hard materials comprising slag and matte phases as well as un-reacted sulphides. The latter could have been from occasions of massive sulphide ore addition into the furnace during normal operation.
- One of the furnace springs broke, probably from fatigue and regular compression of springs during furnace monitoring.
- The burn-down was not as efficient as expected – this was evidenced by a false bottom of approximately 800 mm that was observed during the furnace inspection.
- The burn-down resulted in a superheated slag – which could have resulted in molten material breakthroughs on the side and end-walls.
- The red top during the burn-down caused thermal radiation to the furnace structures which resulted in tie rods and fume extraction ducting becoming very hot and this could have affected their integrity.

SMELTER RE-START PLANS

Refurbishment

The smelter re-start plan includes plant refurbishment to restore its capability, with the cost estimated at US $11 million, and the work to be carried out over a period of 8 months.

The major expenditure is on masonry repairs to the furnace and converters, refurbishment of the furnace off-gas ducting and electrostatic precipitator, and general furnace and plant refurbishment. The major refurbishment areas are summarised in the table below.

Table IX. Re-start plans for Bindura smelter

AREA	OBJECTIVE	KEY AREAS
MASONRY REPAIRS	To refurbish the furnace, two converters and ancillaries.	Castables, mortars, tie-rod covers, converter bricks, chrome-mag bricks for both furnace walls, and super-duty bricks for furnace walls, roof, ladles, and tapping launders.
OFF-GAS HANDLING SYSTEM	To refurbish the furnace ducting and the ESP.	Replace furnace ducting, stainless steel bellows for furnace and converter. Refurbish ESP and access platforms.
ELECTRIC FURNACE	To restore matte smelting capabilities on the furnace area.	Structural repairs and refurbishment of electrode ancillaries, furnace instrumentation, fume extraction ducting, and power supply.
CONVERTERS	To restore matte conversion capabilities on the converter area.	Structural rehabilitation. Refurbish instruments and 30 t cranes. Refurbish converters' water jackets, flexible hoses, and liners. Procure girth gear and pinion.
MATERIALS HANDLING	To refurbish materials receipts and storage plant.	Procure grab cranes and weighing software. Refurbish sheds and plant civils.
TAP-HOLE MANAGEMENT	To refurbish matte and slag tap-holes and both matte and slag granulation stations	Refurbish tapping blocks, launders, scraper winch, and pumps.
BLOWERHOUSE	To refurbish compressors, switchgear, air reticulation, and cooling water pipe-work	Refurbish compressors, cooling water piping, and air regulation. Refurbish transformers, switch-gear, cooling water system, and air flow regulation.
CHARGE PREPARATION	To restore charge preparation capacity.	Refurbish conveyors, stoker, dust recovery system.

PROCESS IMPROVEMENTS

The smelter also plans to improve process efficiency through the installation of:

(a) Flash Drier to improve furnace capacity and dust losses from 0.5% to 0.1%;
(b) Pneumatic Conveyance to reduce dust losses from 1.5% to 0.1%;
(c) Furnace Enclosure to reduce energy and dust losses.

The total cost of the smelter refurbishment, including process improvements, is estimated to be US $30 million.

CONCLUSION

The decommissioning of the Bindura smelter was a success. The furnace is now awaiting repairs and then start-up. Proper planning and commitment on the part of the decommissioning team enabled decommissioning to be successful.

It is also important that in future the furnace must run at steady conditions, avoiding situations of low feed rates or operating in batch processing mode. In the months preceding the BSR shutdown, the furnace build-up, estimated to be about a metre, had shifted the furnace bottom upwards and hence reduced the furnace capacity. As a consequence, lancing for matte was being done through the build-up layer, leading to tapping challenges and matte-loss to slag.

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