

END-OF-LIFE MODE OF FAILURE OF A ZINC SULPHIDE CONCENTRATE FLUIDISED BED ROASTER AND ITS REBUILDING

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ABSTRACT

Zincor operates four Lurgi fluidised-bed roasters at its roast-leach-electrowin refinery in Springs, South Africa. In 2006, Zincor's four roasters had reached ages ranging between 26 and 38 years, while the expected life of this type of roaster is generally 20 to 25 years. Based on its condition, Roaster 3 was the first to be rebuilt in 2006. Roaster 4 is being rebuilt in 2007 and the last two roasters will be rebuilt over the next few years as necessary.

The main damage to Roaster 3 was caused by buckling of the roaster steel shell. This caused the freeboard and dome areas to shift, resulting in cracks in the dome brick lining and crumbling of the bricks lining the freeboard. The steel shell buckled due to the combined effects of too-high operating temperatures and corrosion caused by the following two main factors:

- Thicker external insulation was installed during a previous maintenance shut which resulted in an increased steel shell temperature and exacerbated the normal metal fatigue;
- SO₂/SO₃ containing gas that had permeated through the brick lining, passed through its dew point during frequent planned and unplanned shuts over the life of the roaster. This caused acid formation between the refractory brick lining and steel shell, resulting in corrosion of the shell.

The initial plan was to replace only the damaged areas of Roaster 3, but upon dismantling more damage was found and the roaster was rebuilt from the tuyeres upwards. During the rebuild, the opportunity was taken to modify the design of some of the brickwork to extend its life and make future repairs easier. This paper discusses the mode of failure of Roaster 3 and the lessons learnt during its dismantling and rebuilding.

1 Zincor Roaster History

Zincor has two large and two small roasters with hearth areas of 35 m² and 18 m² each respectively. By current world standards these are relatively small roasters. Modern roasters are being built with capacities of up to four times the large roasters at Zincor. The largest Lurgi roasters now have hearth areas in excess of 120 m² [1].

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From global experience, the normal life of a fluidised-bed roaster is approximately 25 years, depending on the treatment and maintenance of the brickwork and shell ^[2]. The two small Zincor roasters were built in 1968, with the two large roasters following in 1978 and 1980. In 2006, the two largest roasters were the youngest, but were still old at 26 and 28 years respectively. The two small roasters were 38 years old. By world standards, all four roasters could already have needed replacement.

The small roasters are still in relatively good shape, most likely due to their smaller size providing a more robust structure. Unfortunately, the shell of Roaster 3 had started to buckle, with serious damage to the brick lining in the freeboard and dome. The decision was taken to initially carry out major repairs to this roaster first in 2006. Roaster 4 is scheduled for 2007, with the small roasters to follow in future years.

2 Lurgi Fluidised-Bed Roaster Construction and Operation

A Lurgi fluidised-bed roaster is made up of three major sections. At the bottom is a conical windbox covered by a plate fitted with approximately 3800 tuyeres across the entire area. Above the windbox is the hearth area. This section of the roaster houses the slinger and burner ports, the calcine overflow port, water injection point and the bed cooling coils. Above the hearth, the roaster widens into the freeboard which is capped by the dome. The roaster exit into the waste-heat boiler is at the top side of the freeboard. The waste-heat boiler, cyclones and an electrostatic precipitator complete the hot gas train attached to a roaster.

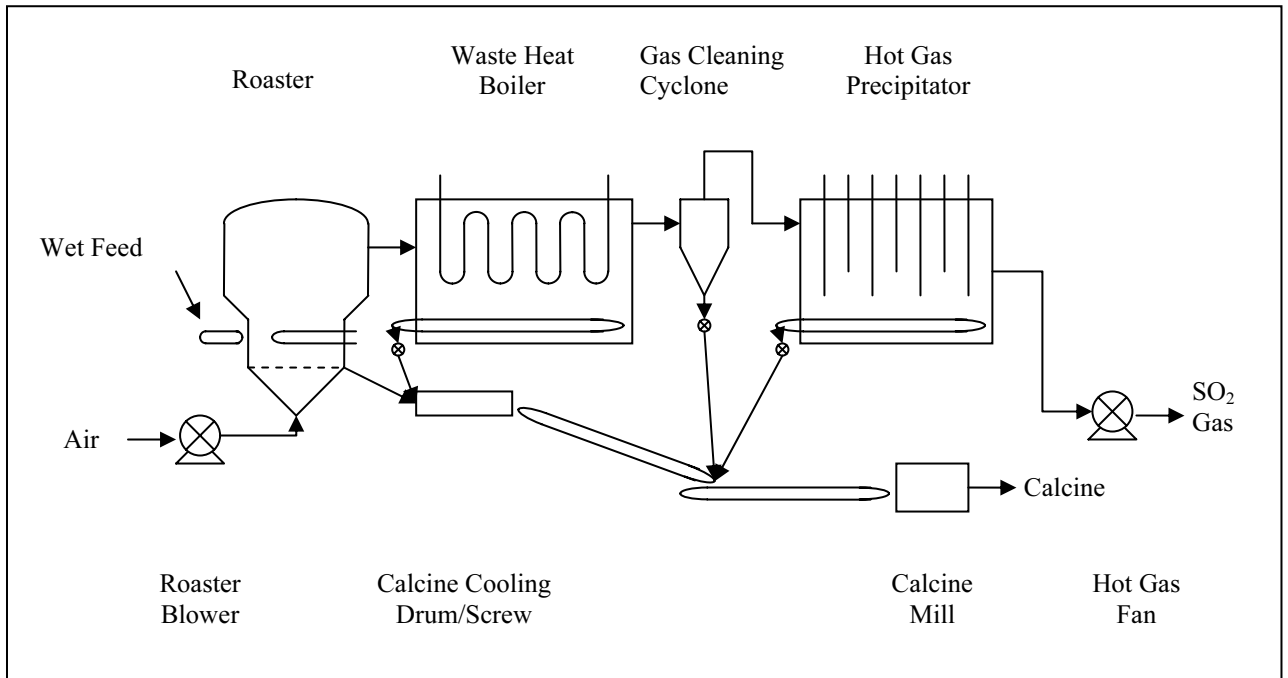
The shell of the roaster is made of steel, with an aluminium-clad insulation layer on the outside, and various layers of insulating materials and refractory brick on the inside. Annular steel bricking rings support the brickwork in the hearth and freeboard. The brickwork on the inside of the dome is inter-locking with a central key-stone type of plug and is thus self-supporting. Refractory cement is used for filling joints where required.

Sulphide concentrates are roasted to convert the metal sulphides to metal oxides (calcine) for leaching and the resulting SO₂ is converted to sulphuric acid. A blower forces air into the roaster windbox. If oxygen enrichment is practised, it is usually introduced into the blower duct into the windbox. This air passes through the tuyeres which provide an even distribution of air into the hearth area. A high-speed slinger belt throws the wet concentrate feed through the slinger port into the hearth where it starts to combust. Coarser particles will stay in the hearth area while finer material is carried up into the freeboard area.

An overflow port just above the tuyere plate allows coarse calcine in the bed to leave the roaster into a cooling drum or cooling screws. This flowrate is controlled by a plate regulating the height of the overflow. The fine calcine is swept with the gas through the top roaster exit into the waste heat boiler. These solids drop out in the boiler, cyclones and electrostatic precipitators and are collected in water- or air-jacketed chain- or screw-conveyors. The cooled calcine (100-120°C) then passes through a de-nodulising ball mill to break up any agglomerates that have been formed before it is pneumatically

conveyed to storage bins. The SO₂-containing gas is blown by a fan into the wet scrubbing system.

Figure 1 – Roaster and Gas Train Schematic Layout



3 Alternatives to Roasting

Currently, the production bottleneck at Zincor sits at the roasters. Ideally, the bottleneck should be moved to the cell house. To do this, alternative entry points for zinc raw materials have to be found. Before Roaster 3 was rebuilt, a quick study was done on alternatives to roasting, and whether there were any cost- and time-effective alternatives to roasting. Unfortunately, the time-scale to implement any of these alternatives, would take longer than it would to rebuild at least the big roasters. For the foreseeable future, Zincor will still be roasting concentrates.

Increasing the size of the large roasters was also rejected due to changes that would have been required to the gas train and civils and the associated increase in downtime and loss of production. This idea is still an option for when the two smaller roasters are replaced. Another alternative is to replace the two small roasters with one large one. The impact of increased roaster sizes on the contact sulphuric acid plants must still be investigated.

4 Acid Dew Point

“Dew point, or saturation temperature, is the temperature at which a given mixture of water vapour and air is saturated, i.e. the temperature at which water exerts a vapour pressure equal to the partial pressure of water vapour in the given mixture” [3]. This is effectively the saturation temperature of a water vapour/air mixture. The same principle applies to SO₂/SO₃/water vapour mixtures.

This effectively means that, for a given gas mixture, below a certain temperature, the SO₂/SO₃/water vapour mixture will be saturated and condense to form a mixture of sulphuric and sulphurous acid. For the roaster off-gases (approximately 8% SO₂, 0.1% SO₃, 5% O₂, 10% H₂O) at Zincor, this temperature is generally in the region of 180°C to 200°C [4].

During roaster operation, some gas can diffuse through the refractory lining, but any cracks in the refractory lining will allow this mixture direct access to the steel shell. Iron is suspected to catalyse the conversion of SO₂ to SO₃, so SO₂ in contact with the roaster steel shell could be converted to SO₃. Every time the roaster cools down below the dew point, a corrosive acid mixture forms in the refractory lining and against the shell. In-leakage of cool outside air through holes in equipment in the roaster gas train, can also cause a significant increase on the corrosion rate of any of these steel structures.

5 Roaster 3 Damage

Before Roaster 3 was taken off-line for rebuilding, an external temperature survey was done on the shell. The results showed most measurement points in excess of 450°C. Many points measured on the freeboard were in excess of 600°C. This significantly exceeded the maximum allowable temperature for the carbon steel shell, which should have been around 350°C.

When Roaster 3 was dismantled, the following damage was found:

- The steel shell had buckled and warped. This had been exacerbated by temperature excursions beyond what the steel was designed for. This was due to a previous increase in the external insulation from 25mm to 100mm in an attempt to increase steam production. The steel part of the dome had also started to sag due to temperature excursions.
- The buckling of the roaster shell had caused the dome to start moving. Combined with the dome sagging, radial cracks had formed in the dome refractory lining.
- The combination of the buckling shell and moving dome had damaged the refractory lining of the shell, causing crumbling of the bricks.
- Due to frequent shutdowns and poor roaster draft control, gas which had permeated through the brick lining and gaps had cooled and passed through the dewpoint, forming acid against the steel shell. This had corroded several parts of the shell.
- The bricking rings in the freeboard had been oxidised away, leaving little support for the shell refractory lining.

On previous major shutdowns, reinforcing bars had been welded to the outside of the shell in an attempt to halt the warping. The brickwork had also been patched where possible. The damage to the roaster was so extensive that a major rebuild from the tuyere plate upwards was required.

Pictures 1 to 4 – Roaster Damage



(clockwise from top left: buckled steel shell; deformed and corroded bricking ring; collapsing and damaged bricks in roaster dome; radial crack in roaster dome brickwork)

The following consequences of a catastrophic roaster collapse include:

- Collapse of a roaster could destroy the surrounding civil structure. Due to the proximity of the control room, a roaster falling onto it would be almost certainly result in fatalities.
- Steam pipes in and around the roaster would be ruptured, releasing steam at 34 bar pressure. Contact with this steam would result in serious injuries or fatalities.
- A large quantity of SO₂ would be released into the atmosphere around the roaster. This gas release could prove fatal to personnel in the surrounding area.
- If an oxygen supply line was ruptured, this would increase the intensity of any fire caused by the spillage of combusting concentrates.
- If the magnesium pre-leach plant was running at the time, rupture of the line feeding its waste gas to the roasters would result in the release of possibly toxic levels of H₂S in the vicinity of the roaster.
- Damage to process lines running past the roasters would disrupt operations at the zinc plant.

- Collateral damage to ancillary and neighbouring equipment could lengthen the period required to repair the damage.

6 Refractory Brick and Insulation Material Properties and Design

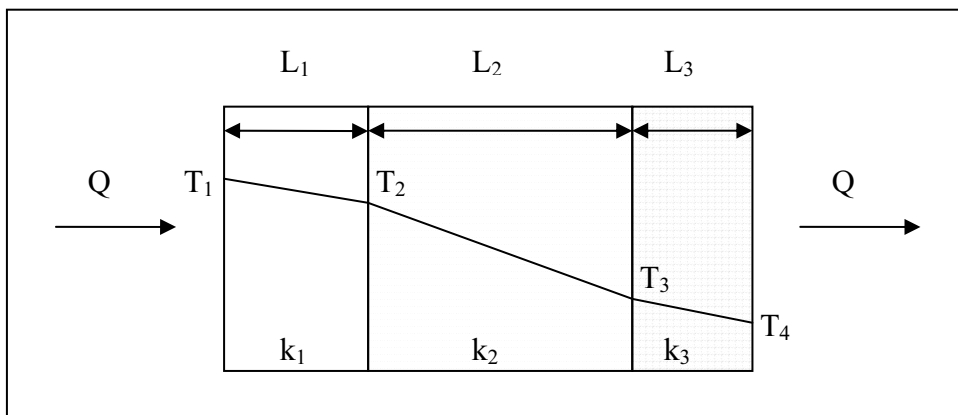
The use of the correct refractory and insulation materials is vital in roasters. Fourier's Law applies to one-dimensional conductive heat transfer through these materials:

$$Q = \frac{kA}{L}(T_1 - T_2) \text{ [5]}$$

where k is the coefficient of thermal conductivity, A is the surface area, L is the thickness of the material and $T_1 - T_2$ is the temperature drop. Better insulators have a lower coefficient of thermal conductivity and thus limit the heat transferred.

Knowing the dimensions and coefficient of thermal conductivity for an insulating material (or schedule of insulation materials), and the temperature difference across it, one can calculate the heat transfer. Once the total heat transferred has been calculated, the temperature at the interface between the individual layers in the roaster insulation can be calculated, and thus the steel shell temperature.

Figure 2 – Steady-State Heat Transfer Through a Composite Wall [6]



Refractory bricks are usually made from alumina- and silica-bearing materials in varying ratios, often with other additives (e.g. magnesium, chrome and zircon compounds). These bricks have two main functions: insulation and fire-resistant. The fire-brick is there to limit damage to the insulation brick, while the insulation brick limits the temperature experienced by the steel shell.

Insulating papers and boards generally have lower k values than refractory bricks, and the insulation wools have some of the lowest k values. This is why it is so critical to have to correct thicknesses of the various materials on either side of the steel shell to protect it.

7 Refractory Brickwork Design

While the roaster was running, the shell temperatures were well above the limits for carbon steel and were comfortably above the 200°C acid dew point. The critical part of the new refractory design was to have a steel temperature below the point where heat could damage it, but above the dew point to prevent corrosion during operation. The final freeboard insulation schedule is presented in Table 1 below, and the relevant temperatures can be seen there.

The final consideration in the bricking design was thermal expansion. The various types of brick and the steel shell all have different coefficients of thermal expansion. In the dome, the problem is solved by having an air gap between the bricks and the steel. In the shell, the solution is to have an intermediate insulating brick layer that is compressible.

One problem which occurred during rebuilding was the lack of V22 brick, which contains vermiculite. The vermiculite gives the brick very good compression characteristics, which makes it ideal for intermediate brick layers to absorb thermal expansion of other brick layers. There are no more reliable sources of vermiculite in South Africa, so the complete layer which was planned had to be substituted with V23 bricks in places. The normal way to compensate for the absence of vermiculite brick is to use expansion joints in the brick layers. In this case, compressible mortar was used in the joints. The ceramic fibre board used for insulation is also slightly compressible.

Table 1 – Comparison of Old and New Roaster Shell Insulation Schedule

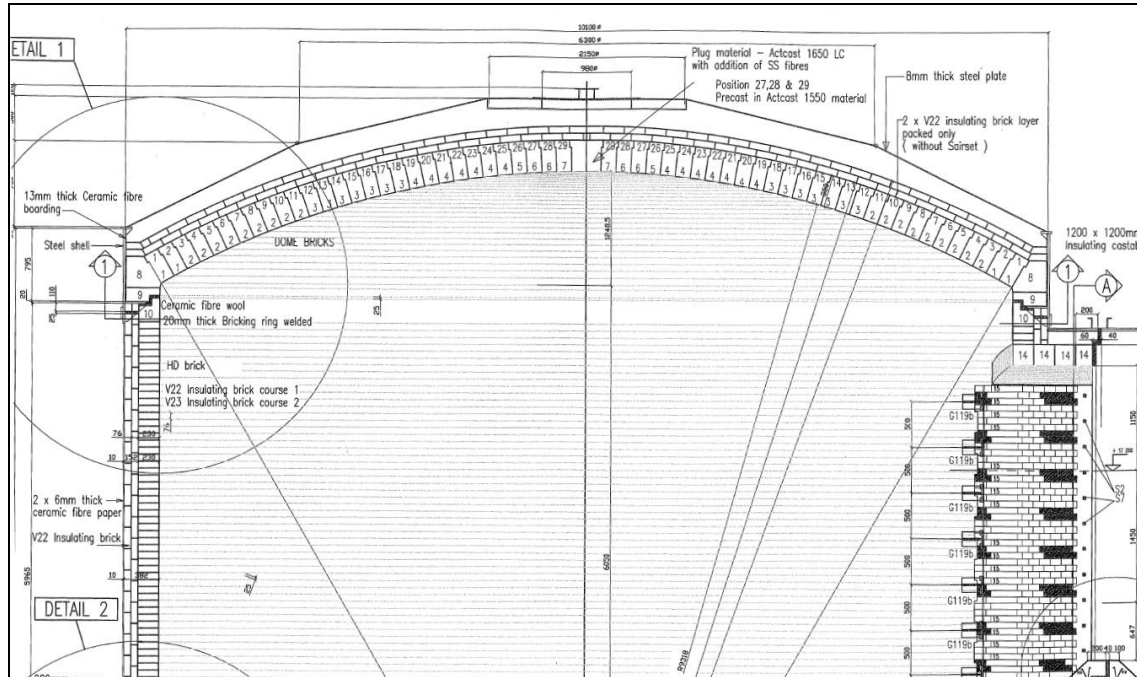
Layer	Old			New		
	Type	Thickness (mm)	Hot Side Temp (°C)	Type	Thickness (mm)	Hot Side Temp (°C)
Fire Brick	High duty	230	950	High duty	230	950
Insulation Brick 1	V22	76	838	V23	76	837
Insulation Brick 2	V22	76	730	V22	76	505
Board	None			Ceramic Fibre	2 x 6	382
Roaster Shell	Carbon Steel	10	617	430A Boilerplate	10	308
Lagging	Cerablanket 64	100	617	Insulfelt 80kg/m3	25	308
Cladding	Aluminium	0.6	78	Aluminium	0.6	79
Atmosphere			78			79

Measurements taken of the steel shell after commissioning showed an average temperature of 230°C, well below the predicted value of 308°C, but still above the acid dew point. The atmosphere temperature ranging from 71°C to 79°C was the temperature calculated to balance the conduction of heat through the shell with the

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convection and radiation of heat away from the surface of the roaster. The lagging on the roasters can be touched with a bare hand. All temperatures in the above table were calculated during the insulation design.

Figure 3 – Drawing of Roaster Shell and Dome Insulation [7]



8 Roaster Rebuilding Process

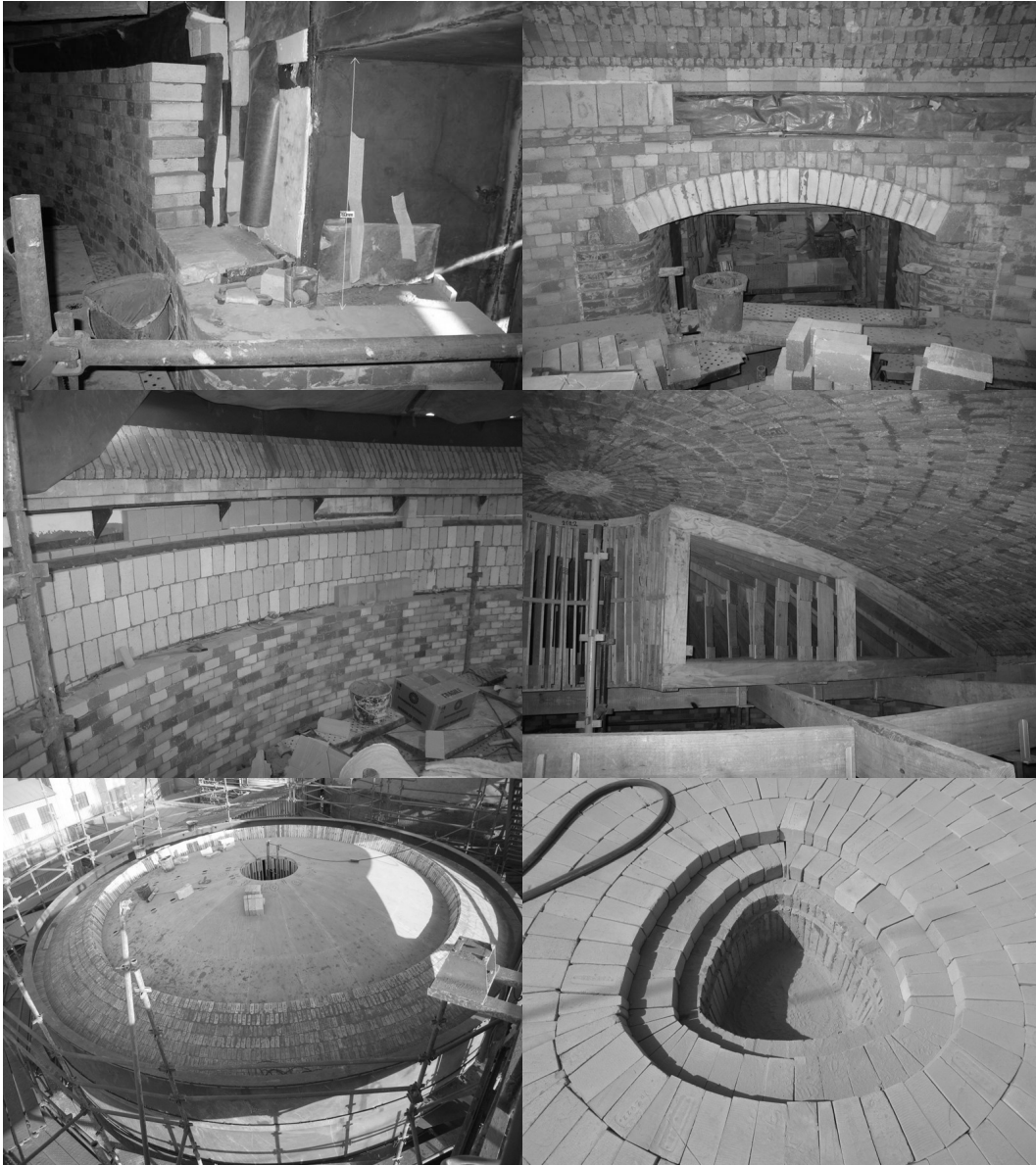
A few items were originally planned for improvement before the roaster rebuild took place. The first one was a re-design of the roaster overflow to incorporate air-cooling. This modification could not be fitted to Roaster 3 in time, but it will be retro-fitted at a later date. In the roaster exit, the bull-noses were changed from monolithic castings using conventional steel anchors, to pre-cast blocks using a tongue-and-groove anchor system. The fitment of the dogleg bricks protecting the dome steel bricking ring was changed from top-down, to bottom-up to make future replacement easier. The roaster shell material was changed from normal carbon steel to 430A boilerplate steel.

Table 2 – Roaster 3 and 4 Rebuild Project Plan

Project Phase	Time (days)	Activities
Pre-shut activities	7	Scaffolding is built around the roaster. The weather cladding is removed from the roaster. The tower crane support slab is cast and the crane is erected.
Cooling down and cleaning	4	The roaster is stopped and all ancillary equipment is isolated. The roaster lagging and the first two boiler bundles are removed. The roaster is cooled down and the bed material and bed cooling coils are removed. The internal scaffolding is built.
Roaster refractory demolition	18	A hole is cut in the dome roof and the plug is removed. The refractory lining is demolished from the top down.
Removal of roaster shell	8	The steel shell is cut away.
Rebuilding of roaster shell	20	The new steel shell is built, including the bricking rings.
Refractory installation	43	The new insulation and refractory lining and joint to the boiler are installed. The dome is installed and the refractory is dried out. Various external inspections are performed and the installation is certified.
Demobilisation	12	The ancillary equipment including steam coils and bundles are re-installed. The scaffolding is broken down and the contractors leave the site.
Total	112	

The total project cost for the Roaster 3 rebuild was R 17 045 240. In light of the damage to Roaster 3, the decision was taken to rebuild Roaster 4 completely as well. The projected cost for the Roaster 4 rebuild is R 23 654 000.

Pictures 5 to 10 – Roaster 3 Rebuilding



(clockwise from top left: wall insulation showing boards, paper and bricks; roaster exit into the boiler; removal of the dome former; top of the dome before the plug is cast; laying the dome bricks; brickwork at the top of the freeboard before the dome is installed)

9 Roaster Heat Balance

After the rebuild of Roaster 3 was completed, a heat balance across the roaster and its gas train was done using the METSIM modelling package. As can be seen from the table below, the heat loss through the shell is a minor portion of the total heat balance.

Table 3 – Typical Roaster Output Heat Balance (% Distribution)

Steam	Gas Train Calcine	Overflow Calcine	Roaster Shell	Gas to Wet Scrubbing	Total
75.8	19.8	1.8	2.0	0.7	100.0

The original idea of increasing steam production by installing thicker external insulation would not have made any significant difference. Roaster temperature control is mainly a balance between the calorific value of the roaster feed and steam production in the bed coils. Any additional cooling is accomplished by the direct injection of water into the hearth. This unfortunately generates steam in the gas train which later condenses and has to be removed.

10 Conclusion

The following lessons were learnt from the rebuilding of Roaster 3:

- Any changes to the insulation around a piece of equipment operating at high temperatures must be very carefully considered to determine all the effects of the change.
- Any changes to materials of construction must be documented so that no confusion exists when trying to determine causes of failures.
- Roasters must be operated continuously and properly for as long as possible between shutdowns to reduce the incidences of acid formation against the roaster shell due to gas passing through its dew point.

The Roaster 3 rebuild project went well and was completed on time and within budget. This was primarily due to the correct skills being available, but in a few years they might not be. Highly specialised masons and bricklayers are needed, along with very strict quality control at the refractory manufacturers and during the installation process.

11 Acknowledgement

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