Furnace tapping practice at Tronox Namakwa Sands

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Tronox Namakwa Sands operates two ilmenite smelters for the production of high-titania slag and low-manganese pig iron. Slag or metal is tapped from one of two product-specific, bi-level tap-holes. In this paper the refractory design specific to the tap-hole refractory layout is described, as well as practices for slag and metal tapping and refractory maintenance. Further developments planned are briefly described.

Keywords: tapping; best practice; DC arc furnace; slag; iron; mickey; refractory; tap-hole; V-down.

Introduction

Tronox Namakwa Sands produces high-titania slag for the TiO₂ pigment industry and low-manganese pig iron for foundries producing castings for the automotive and engineering components industry. The smelting process at Tronox Namakwa Sands comprises of the carbonaceous reduction of ilmenite to produce slag containing 87% TiO₂ on average, pig iron containing 2.5%C, and off-gas containing 75% CO. The CO-rich off-gas is cleaned and subsequently utilized as fuel elsewhere on the plant. Two direct current (DC) electric arc furnaces are installed, with power inputs of 25 MW and 35 MW. The 25 MW furnace (Furnace 1) was commissioned in June 1995 and the 35 MW furnace (Furnace 2) in February 1999. Figure 1 is a schematic diagram of the DC arc furnaces at Tronox Namakwa Sands.

![Figure 1. Schematic diagram of a DC arc furnace at Tronox Namakwa Sands (Gous, 2006)](image)

This paper reports on general tapping practice followed at Namakwa Sands. It concludes with the challenges faced by Namakwa Sands, which could potentially be addressed through research or by tap-hole design changes. Aspects regarding refractory design, with special emphasis on tap-hole design, slag and metal tapping practices, and refractory maintenance practices are also addressed.
Refractory design

The two DC furnaces are circular in shape with basic dimensions as indicated in Table I. Each furnace is continuously fed with ilmenite (ore) and anthracite (reductant) and operated on a freeze-lining principle where a layer of slag is frozen onto the sidewall refractory at all times (Zietsman and Pistorius, 2006). Iron and slag are tapped at regular intervals through bi-level iron and slag tap-holes. Each furnace has two iron tap-holes and two slag tap-holes. Furnace design aspects related to the tap-hole are summarized in Table I. The actual tap-hole refractory layout combines a number of refractories: MgO bricks, alumina-silica blocks, alumina-silica ramming, and some chrome-alumina blocks—depending on whether slag or metal is being tapped. While the brick surrounding the tap-holes is MgO brick, the slag tap-hole consists of alumina-silica tapblocks and alumina-silica ramming. For the iron tap-holes, the tapblock consists of a combination of high-alumina-silica blocks, some chrome-alumina blocks, and alumina-silica ramming with the ‘dog-house’ shaped copper block on the very outer cold face as indicated in Figures 2 and 3. Chrome-alumina blocks were still in the trial phase on the cold face section of iron tap-holes.

Table I. Summary of furnace design

<table>
<thead>
<tr>
<th></th>
<th>Furnace 1</th>
<th>Furnace 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace diameter (mm) *</td>
<td>9 000</td>
<td>11 600</td>
</tr>
<tr>
<td>Furnace height (mm) *</td>
<td>4 800</td>
<td>6 366</td>
</tr>
<tr>
<td>Tap-hole elevation (mm) †</td>
<td>Metal: 1 200</td>
<td>Metal: 1 400</td>
</tr>
<tr>
<td></td>
<td>Slag: 2 200</td>
<td>Slag: 2 400</td>
</tr>
<tr>
<td>Number of tap-holes</td>
<td>2 iron and 2 slag tap-holes</td>
<td></td>
</tr>
<tr>
<td>Tap-hole refractory</td>
<td>Alumina-silica/ copper cooler</td>
<td></td>
</tr>
</tbody>
</table>

* Inside steel shell
† Centre-line top of hearth refractory

Figure 2. Plan view of the iron and slag tap-holes

The length of the iron tap-holes is 1550 mm consisting of 10 high-alumina tapblocks (see Figure 3). The dog-house shaped, water-cooled copper block is installed on the outside segment of the tap-hole, covering only the outer two tapblocks. Iron tap-holes are located 35° away from centre line of the furnace. Five thermocouples, strategically installed around the copper block, monitor water-cooling and any anomalies potentially associated with iron penetration. Above the tap-hole copper blocks, a set of three thermocouples monitors the integrity of the refractory wall. Typical composition of the refractory materials used for tapblocks is shown in Table II.
Table II. Typical composition of refractory materials

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Composition, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO₂</td>
</tr>
<tr>
<td>Alumino-silicate bricks</td>
<td>1.4</td>
</tr>
<tr>
<td>Alumino-silicate ramming</td>
<td>3.7</td>
</tr>
<tr>
<td>MgO brick</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The length of the slag tap-holes is 1350 mm consisting of a high-magnesia refractory brick on the hot face and 4-high alumina tapblocks on the cold face. High-alumina refractory is rammed into the gap between the tap-blocks and the refractory wall. Slag tap-holes are located 10° away from centre line of the furnace. There are neither specific thermocouples nor copper blocks for monitoring the slag tap-holes; only the general refractory sidewall thermocouples located along the slag tapping plane used to monitor the freeze lining integrity. The plan layout and location of the tap-holes along the sidewall is depicted in Figure 2, while the elevation view of the iron and slag tap-holes are depicted in Figure 3 and Figure 4 respectively.

As the iron tap-hole is the high-wear area in the ilmenite smelter, several studies were conducted to extend the refractory campaign life. These include basic modifications to complex tap-hole refractory design, as well as modifications to clay guns, as indicated below:

- **Iron and slag tap-hole design changes**: removal of the Jack Arch and the lintels on the iron tap-hole. Retain slag Jack Arch but with design modification to include either smaller bricks or tongue-and-grooved bricks
- **Reduction in the size of the copper cooler block**: the size of the copper cooler block currently in use is one-third that of the copper cooler blocks used prior to 2010
- **Improved temperature monitoring around the tap-hole**: through installation of additional refractory thermocouples at strategic points. These would be incorporated into the heat-loss model that monitors refractory wear. This, in turn, will provide critical information indicating end of tap-hole campaign life on an iron taphole
- **Installation of flow meters in the hydraulic circuit of clay guns**: used for advanced tap-hole monitoring. The ultimate goal being to accurately measure drill depth when opening the iron tap-hole, and to reasonable measure the volume of clay extruded from a clay gun to effect a solid plug. A secondary benefit would be user-friendly troubleshooting on the clay guns by the operations team
- **Clay trials**: conducted to find suitable clay with reconstructive properties to assist in prolonging tap-hole campaign life.
The original problem is described in more detail in the section on refractory maintenance practices, as well as the reasons that the revised design is regarded as an improvement.

**Slag and metal tapping practices**

Typical slag composition is stated in Table III and metal composition in Table IV. Typical slag and metal tap temperatures are included.

**Table III. Typical slag composition and tap temperature**

<table>
<thead>
<tr>
<th>TiO₂</th>
<th>FeO</th>
<th>MgO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MnO</th>
<th>ZrO₂</th>
<th>Tap temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>87.00</td>
<td>8.50</td>
<td>0.75</td>
<td>2.20</td>
<td>1.40</td>
<td>0.21</td>
<td>2.20</td>
<td>0.20</td>
<td>1660–1700</td>
</tr>
</tbody>
</table>

**Table IV. Typical metal composition and tap temperature**

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Ti</th>
<th>Tap temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00</td>
<td>0.05</td>
<td>0.01</td>
<td>0.04</td>
<td>0.10</td>
<td>0.04</td>
<td>1550–1600</td>
</tr>
</tbody>
</table>

The development of tapping practices stemmed from the philosophy of operating furnaces for their full refractory campaign lives. As the iron tap-hole is the high-wear area in the furnace, tapping practices place much emphasis on iron tap-hole management to achieve the desired refractory campaign life.

Originally, iron tapping into 32 t ladles was carried out through one tap-hole for a period of 3 months, after which five cold-face tapblocks were replaced. The practice was later changed to six-monthly tapping periods, after which two cold-face tapblocks were replaced. In recent years the practice was changed to replacing five cold-face tapblocks, while still maintaining six-monthly tapping periods. Typically 30 000 t were tapped from the 25 MW furnace and 35 000 t from the 35 MW furnace in a 6-month period. At the end of 6 months, partial repair from outside the furnace was carried out on the spent tap-hole and iron tapping was then continued on the second tap-hole for the same period. This practice has since changed, and the aim currently is to tap 90 000 t of iron through a tap-hole (regardless of the furnace) before a partial repair.

The iron tap-hole is drilled open using a hydraulically operated drill. A mild steel drill shaft with a diameter of 38 mm and a length 2400 mm is fitted onto the drill carriage of the clay gun for drilling. Once drilling is completed and the drill carriage removed, iron starts to flow. In the event of poor iron flow the taphole is prodded with a mild steel reaming rod to improve the flow rate. Oxygen lancing of iron tap-holes is kept to a minimum, but has increased in recent campaigns. An iron tap-hole campaign is defined as the period between total tap-hole rebuilds. Total iron tap-hole rebuilds are carried out at relines and every two years (during an internal V-down) before the next reline. Later sections provide a detailed discussion on iron tap-hole campaigns, focusing on refractory maintenance practices.

Figure 5 depicts iron tapping campaign data showing that the use of the drill to open the tap-hole has decreased because of increased lancing during taps. It is believed that an alternative tap clay with satisfactory reconstructive properties, proper monitoring of the amount of clay plugged by the clay gun, and application of best practice behaviour will result in minimization and subsequent elimination of iron tap-hole lancing.

![Figure 5(a). Furnace 1 iron tap-hole open mechanism (% drill open)](image1)

![Figure 5(b). Furnace 2 iron tap-hole open mechanism (% drill open)](image2)
Figure 6 depicts a normal iron tap-hole in operation and Figure 7 a tap-hole undergoing a partial external repair, where the ‘Mickey’ refers to the very outer tapblock on the cold face.

Slag tapping is carried out by alternating the two slag tap-holes. Slag is tapped through one tap-hole into 25 t ‘t-cups’ in 25 t or 50 t increments until 2000 t is tapped. This takes approximately 1 week to achieve, depending on the production rate of the furnace. At the end of the tap cycle, partial repair is carried out on the spent tap-hole by replacing one or two tapblocks on the cold face, depending on the severity of the wear on the tapblocks. Slag tapping is switched over to the second tap-hole. The partial repair may be carried out before 2000 t has been tapped if anomalies like large tap-hole diameter, ‘spalling’ etc. are observed, rendering the tapping practice unsafe.

Typical campaign periods for alternating slag tap-holes are summarized in Figures 8 and 9.

The slag tap-hole is drilled open using the same hydraulically operated drill used to open the metal tap-holes. A mild steel drill shaft with a diameter of 64 mm by 2400 mm is fitted onto the drill carriage of the clay gun for drilling. Tap-hole drilling involves drilling a short distance of 300 to 500 mm and then lancing open with oxygen. Due to the high melting point of slag, further lancing is required during the progress of the tap to maintain a steady flow of slag. A comparison of wear patterns between a slag tap-hole in operation and the one undergoing a partial repair, with outer tapblock already removed, is depicted in Figure 10 and Figure 11 respectively.
At the completion of either a metal or slag tap, the tap-hole is plugged with high-alumina-silica resin and tar-bonded clay using the clay gun. Approximately 20 to 30 litres of clay is extruded for every plug. Once the launder has cooled, housekeeping duties include cleaning and maintaining the tap launder and ensuring the tap-floor is in a safe state.

Sampling of molten tapped products for control analysis and temperature measurements of both iron and slag tapped forms an integral part of the tapping practice. Specific prescribed personal protective equipment for tap-floor operations must be worn at all times during tapping.

Table V summarises the tap cycles for iron and slag tapping.

### Table V. Summary of tapping cycles

<table>
<thead>
<tr>
<th></th>
<th>Iron tapping</th>
<th>Slag tapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap-to-tap cycle</td>
<td>3 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Duration of tap</td>
<td>30 min</td>
<td>15 min</td>
</tr>
<tr>
<td>Number of taps per day</td>
<td>12 taps</td>
<td>22 taps</td>
</tr>
<tr>
<td>Size of tap</td>
<td>32 t</td>
<td>25 or 50 t</td>
</tr>
<tr>
<td>Desired tap-hole length</td>
<td>1000 mm</td>
<td>Not measured</td>
</tr>
</tbody>
</table>

**Refractory maintenance practices**

Full refractory relines of the furnaces typically occur every 6 years. Tap-hole maintenance between full relines consists of several planned events. Typical campaign data for the life of tapholes at Namakwa Sands, indicating the improvements that have been achieved, is depicted in Figure 12 and Figure 13. The data was compiled for the period 2004 to 2014, with campaigns 6 and 7 in 2010 and 2012 respectively on Furnace 1 achieving more than 80 000 t on the south iron tap-hole. Furnace 2 also achieved this record during campaign 6 in 2011 on the north iron tap-hole.
The slag tap-hole is maintained by replacing the cold-face tapblock after every 2000 t of slag tapped. After 6 months, when about 24 000 t have been tapped out a tap-hole of operation, four blocks are replaced.

The iron tap-hole is maintained by replacing the five cold-face high-alumina monolithic blocks after 80 000 t of iron has been tapped. Extreme care is taken not to damage the copper block covering the tapblocks. Earlier replacement of the very outer high-alumina tap block, often referred to as a ‘mickey’, may be done, depending on the physical condition i.e. abnormal uneven wear patterns and spalling, rendering the tap-hole unsafe for operation.

One of the factors taken into account when deciding how many tapblocks to replace includes the extent of loss of the ‘mushroom effect’. When the tap-hole is plugged with tap-hole clay, a mushroom-shaped block must develop inside the furnace to protect the walls inside as they are particularly stressed by the intense tapping. This is termed the ‘mushroom effect’ (Dash, 2009). When the loss of this ‘mushroom effect’ takes place, it leads to increased ‘trumpeting effect’ on the hot face, i.e. likely to cause an uncontrolled iron or slag runout’ through the taphole.

The monitoring of the iron tap-holes is based on a number of parameters, including:

- Tap-hole rotation history
- Tap-hole refractory thermocouple temperatures
- Refractory wall thermocouple temperatures
- Tap-hole plug lengths
- Iron flow rate during tapping
- Iron temperature measured during tapping
- Quality consistency of the type of clay used for plugging
- Physical condition around the taphole, launder, and the clay guns observed during physical inspections.

Iron tap-hole rotation was originally 3 months with replacement of five tapblocks. Over the years, it has improved to rotation being practiced on a six-monthly basis during a campaign life. However, this practice may be abandoned when severe wear pattern deterioration is experienced, i.e. spalling of the very outer high-alumina block, uneven wear pattern etc. Tap-hole refractory thermocouples provide an indication of increased iron bath level in the furnace, resulting in to higher heat losses through the area. An increased iron bath level in the furnace may also lead to higher iron flow rates. A plug length of 1000 mm is maintained on the iron tap-holes. Tapped iron temperature is a function of furnace chemistry control, and while it is not a direct monitoring parameter, it may exacerbate a condition where a shorter plug length is experienced (consistently shorter than 700 mm). Regular physical inspection of the tap-hole face area, iron launder, and the clay guns plays a crucial role in observation of any physical wear or damage to the tap-hole area.

After 2 years in operation, both iron tap-holes are replaced using a V-down technique. The aim of a V-down is replacement of the tapping area refractory, including both slag and iron tap-holes within a reline campaign. V-downs essentially entail a 21-day shutdown to replace both iron tap-holes and both slag tap-holes. After tapping down the furnace to the iron tap-hole level, the front wall (at the 135° to 225° area) is broken down from the roof in a V manner to end at the base of the iron tap-holes. Breakdown is facilitated by means of a Brokk machine and the waste refractory is removed via the shell openings for iron tap-holes. Once the reline or a V-down is complete, all new tap-holes are manually plugged with tap-hole clay prior to the furnace heat-up. The extend of sidewall refractory removal during a V-down breakdown is indicated in Figure 14.
After a V-down, the refractory lining is cured and preheated according to the refractory supplier’s curing curve. The electrical system of the furnace is used as a source of energy input during curing and preheating. Energy input is monitored using both permanent and sacrificial thermocouples strategically installed at various locations around the furnace.

Further developments

Challenges experienced by Tronox Namakwa Sands include:
- Controlling the tap-hole wear pattern and wear rate
- Finding suitable and economical tapblocks that ensure safe tapping practices for extended periods
- Finding suitable tap-hole clays that, with best practice, will contribute to extended tap-hole campaigns and therefore furnace reline campaigns
- Finding suitable reconstructive tap-hole clays to use intermittently that ensure extended tap-hole campaigns
- Continuous training of tap-floor personnel on tapping and refractory best practices.

Projects currently underway include finding a suitable tap-hole clay and upgrading of tapping equipment. Namakwa Sands has embarked on trialling a number of environmentally friendly tap-hole clays on both iron and slag tap-holes. Tapping equipment (drill and clay gun) is being evaluated for improved monitoring and ability to close and open tap-holes under abnormal conditions.

Conclusions

At the ilmenite smelters operated by Tronox Namakwa Sands the iron tap-hole is the high-wear area in the refractory design, requiring extensive maintenance, and therefore downtime, in the form of partial or full lining repairs.

There is an ongoing effort to extend refractory lining life and develop best practices for safer operation of tap-holes and a more efficient and reliable usage of clay guns. The quality of the tap-hole clay being used for plugging the tap-holes is of importance as, with best practice, the clay will contribute to extended iron tap-hole campaigns and therefore furnace lining life.

Specific projects underway include finding suitable tap-hole clays and upgrading tapping equipment.

Acknowledgements

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References


The Author

Siyabonga Gabriel Mgenge, Metallurgist (furnaces), Tronox Namakwa Sands

I obtained a BTech degree in Extraction Metallurgy from Witwatersrand Technikon (now University of Johannesburg) in 2002, and have acquired all my experience in heavy minerals metallurgy, most of which has been pyrometallurgical in ilmenite smelting. I have also completed Management Development Programme (MDP) at UNISA in 2011. My experience includes the six in line (solid) electrode AC furnaces at Richards Bay Minerals until middle of 2012; and later at single (hollow) electrode DC furnaces at Tronox Namakwa Sands.

Besides looking after the quality of furnace metallurgical control and process efficiency improvements, I work closely with the refractories handling of the plant, especially the tapping practices and tapfloor consumables. I have also acquired a strong project experience relating to the de-commissioning, whole rebuild, V-downs and commissioning of a furnace. It is the keen interest in the tapping methods and the need for Tronox Namakwa Sands to acquire tapfloor best practice that led me to partake in the tapping conference.