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THE POLOKWANE SMELTER MATTE TAPPING CHANNEL MODEL

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ABSTRACT

The 68 MW Anglo Platinum smelter has been designed with adequate transformer capacity and copper waffle coolers to allow for deep electrode immersion and higher heat fluxes to be able to treat concentrates with a chrome content of 4%. Nelson *et al. 2005*

With this high furnace intensity, matte temperatures of 1500°C and higher with the degree of superheat of about 650°C, can often be experienced due to various furnace conditions like uneven concentrate feeding and electrode immersion for example. These high matte temperatures cause severe erosion of the tapping modules (bricks) and can also be a critical safety factor if not properly managed.

The original tap block design consisted of the copper block with two water circuits for the cooling and 5 (230 x 230 x 114) mag-chrome tapping modules with magnesia surround bricks. After testing different materials, this design was then changed to a tap block with 3 water circuits and alumina-chrome tapping modules.

A 'bull nose' consisting of an extra water cooled copper block which extends outside the furnace wall was added and the complete tap channel now contains a total of 8 tapping modules. A CFD model for this complete unit has therefore been developed showing the thermal profiles in each section of the copper and refractory as well as the heating of the water. This model is used in conjunction with the 'Safeway' system currently being tested in the tapping channel and works like a thermocouple except it will measure the highest temperature over an area in the block and not just at one point.

These two measures provide excellent monitoring and management of the tapping channel and can assist in decision making around brick replacements and testing of different materials as well as a training tool to operators showing the impact of the different tapping conditions on the tap block.

BACKGROUND

The six-in-line furnace of Hatch design at Polokwane smelter is the largest capacity furnace in the platinum industry and as is rated at 68 MW (168 MVA). The electrical supply to the furnace is via six Soderberg 1.6m diameter electrodes and three single-phase 56 MVA transformers. Electrode currents are in the region of 35-45 KA, and operating resistances of 8-12 mΩ with the electrode immersion depths between 20% and 40%. Hundermark *et al. 2006*

These operating conditions result in high operating temperatures with slag normally between 1600 and 1700°C and matte between 1450 and 1550°C. Matte is tapped from the furnace through the brick-lined, water-cooled copper tap block. Due to these operating temperatures and often experienced high tap rates, the corrosive/erosive factor is high and greatly affects the availability of the tap holes due to replacements of the very costly tapping bricks.

The original tap block design only consisted of one copper block and a copper faceplate at the front with two water circuits and 6 tapping bricks. A third water circuit was later added. This design was then changed and the 'bull nose' which is an extra copper block with a top that can be taken off was added and the faceplate was split into two units, a faceplate and a copper insert.

Figure 1 show the tap channel.

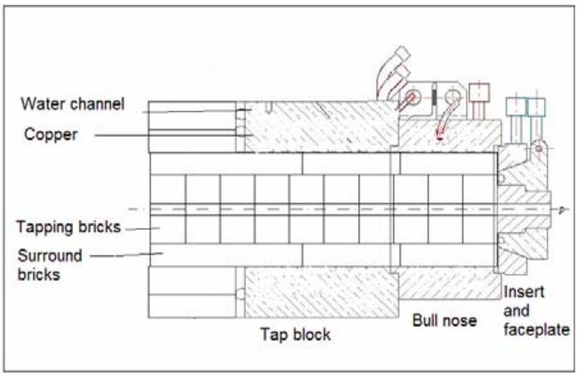

Figure 1: The tap block design

The CFD model using Fluent as CFD package was then used to evaluate the efficiency of the new design and determine the effect of the tap block on the matte flow as well as the effect of the matte flow on the refractory and copper units of the tap block. The tap rate is also of critical importance as it becomes difficult to close the tap hole at high tap rates, and the factors affecting the tap rate was therefore studied.

TAPPING BRICKS

As the repair and maintenance of the tapping bricks are the major cause for the unavailability on the tap channel as well as a major cost contributor, various tapping bricks were tested to find the optimum tapping brick.

Two types of bricks, Alumina-Chrome and Mag-chrome bricks were tested from two different suppliers. It was found that the Alumina-Chrome refractory performed better than the Mag-chrome refractory and comparing the bricks from the first supplier with the second supplier bricks, the second supplier bricks lasted on average for 210 taps before a full repair compared to 150 taps. The reason can mainly be contributed to the star cracking shape occurring in the bricks from the first supplier where matte could penetrate. The bricks from the second supplier contain zirconium which prevents the cracking. However, the Mag-chrome bricks from the first supplier out-performed the Mag-chrome bricks from the second supplier.

Silicone-carbide bricks were also tested but found to be inferior. The quality of the silicon-carbide bricks was questionable and the mode of failure was again thermal cracking.

GRAPHITE TAPPING BRICKS

Three tests were done using a graphite brick. In the first test, only one graphite brick was used as first brick in the tap channel. The first brick was replaced after 29 taps and only had one crack but with the tap hole still in good condition. (Figure 2). For the second test, the first and second bricks were graphite bricks but after twenty taps the tap hole was very much enlarged and was replaced immediately. The third test showed the same results after only one day's tapping. However no matte penetration was visible. (Figure 3)

Figure 2: Graphite brick during the first test after 29 taps

Figure 3: Graphite brick during the second and third test showing a very enlarged tap hole

Two lumps of the brick (sample 1 and 2) were submitted for chemical analysis. Estimated matte penetration, from these results, for sample 1 is 54 mass %, and for sample 2 it is 15 mass %. The apparent values are raised due to the large differences in the relative densities of carbon, refractories, and matte – by volume, matte penetration is 38 % (sample 1) and 7 % (sample 2). The analysis showed that a refractory phase was also present which puts a question mark at the sampling method of the brick as the original brick consisted only of carbon. Andrews *2005*

BULL NOSE

The main reason for the installation of the bull nose was to reduce the rate of erosion on tapping modules closer to the furnace and to extend the period prior to the eight block repair. See Figure 1.

The previous design only consisted of one copper tap block and a faceplate and contained only 6 (the sixth brick is halfway in the furnace) bricks. The schedule for replacing bricks was as follows:

- At 40 taps, the first two bricks were replaced,
- At 80 taps the first 4 bricks were replaced
- At 160 taps, six bricks were replaced.

After the installation of the bull nose, the schedule changed as follows:

- At 45 taps, the first three modules are replaced
- At 90 taps , the first six bricks are replaced
- At 190 taps, all 8 bricks are replaced

The amount of bricks changed during the previous design was 13 bricks compared to the 20 bricks with the bull nose. An extra 30 taps of 33 ton/tap or 990 ton more matte are tapped with the added bull nose before a major repair. This schedule is still in the process of optimization and can be extended.

CFD MODEL

The CFD model assumes that the heat generation in the model are only from the matte flowing through the channel at steady state.

It was assumed in this model that the water inlet conditions are the same and a general matte flow rate and temperature for the matte inlet was assumed as shown in Table 1 and 2. The k-ε turbulence model was used to model the matte and water. The Fluent user's guide was used as reference for the turbulence model.

Boundary	Temperature (K)	Flow rate (m^3/hr)	Flow Rate (ton/min)
Water inlet	313	6	0.1
Matte inlet	1743	14	1

Table 1: Inlet conditions for the tap block model

	Boundary Condition	Reynolds number	Condition
Water flow	No-slip	83419	Turbulent
Matte flow	No-slip	235105	Turbulent
Outer walls	Adiabatic		

Table 2: Boundary Conditions for the tap block model

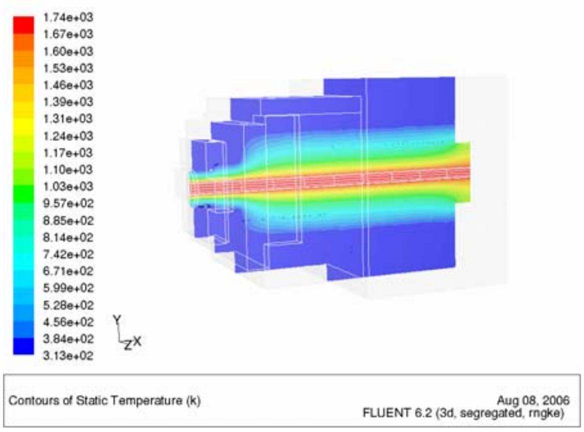

Figure 4: A cross section of the tap block showing the thermal profile in the block while tapping

Figure 4 show the thermal cross cut through the model. The main temperature drop occurs in the refractory. The reason for the decrease in the temperature rate change from the front of the tap channel towards the back is due to the copper being closer to the matte channel and the refractory at the front part are therefore less than at the back.

From Figure 5, it can also be seen that the heat fluxes in this front section of the block is higher than at the back.

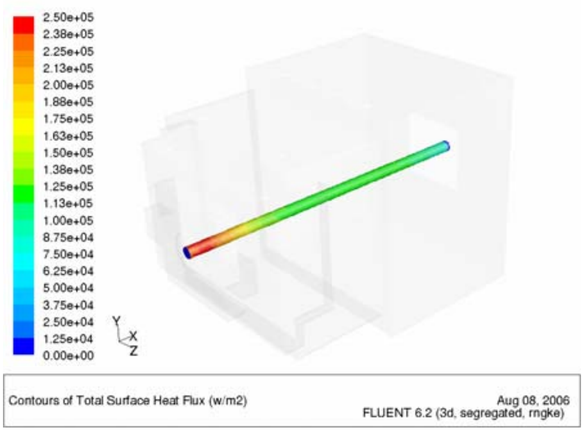

Figure 5: Heat flux distribution from the matte. Largest heat fluxes occurring around the front of the tap channel where the copper is closer to the matte.

It is therefore expected that the copper insert will show the highest copper temperatures of the tap block as it is the closest to the matte channel with the highest heat fluxes occurring in this region.

The water cooling of the copper is still very effective though as can be seen from the temperature profiles through the copper insert. The copper stays below 77°C as is shown in Figure 6.

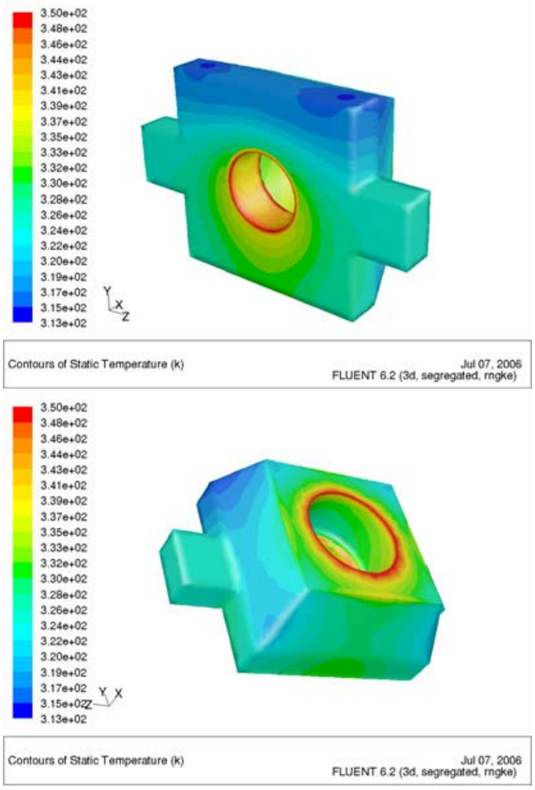

Figure 6: Thermal profile through the copper insert. Maximum temperature 77°C.

The difference in temperature between the first and the seventh tapping brick are shown in Figure 7.

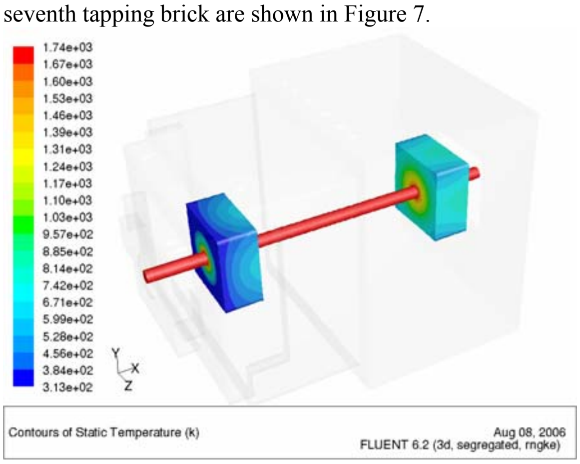

Figure 7: The first (left) and seventh tapping bricks thermal profiles showing the seventh tapping module at a much higher overall temperature.

The cooling of the matte as it flows through the channel can be seen in Figure 8. It is however seen that the cooling effect on the matte is very little and the average drop in temperature is only 2°C. Figure 8 show the temperature profile of the matte at the outlet with the temperature being at 1739K at the surface but still at 1743K at the centre. The matte inlet temperature was specified 1743K.

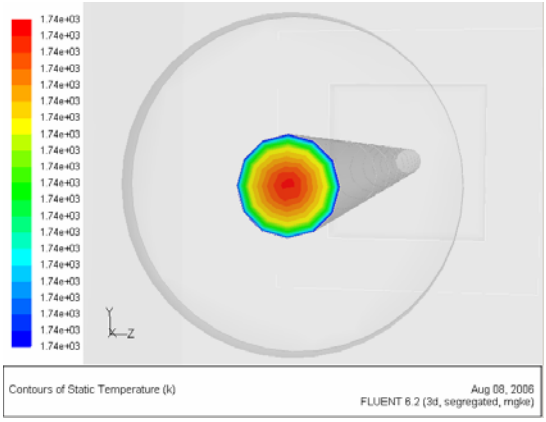

Figure 8: Temperature profiles of matte in the tap channel at the outlet.

TAPPING RATES

High matte flow rates are often the reason why brick replacements are done as high tap rates are often caused by the bricks being in a poor condition such as an increased tap hole diameter. It is therefore important to understand all the factors affecting the matte flow rate such as bath temperature, tap hole diameter and the hydrostatic head. The perception also exists at Polokwane Smelter that high matte temperatures are a reason for high tapping rates due to the changes in viscosity and density with temperature.

Based on the results from the previous CFD model, a simplified CFD model was used to simulate the flow through the tap channel to determine the effect of furnace bath levels (pressure) and the temperature of the matte on the tapping rate. The slight decrease in temperature shown in Figure 8 was assumed to be insignificant and the matte temperature was modelled as constant in the determination of the tapping rates.

The CFD model was specifically used instead of Torricelli's law, which states that the speed, *v*, of a liquid flowing under the force of gravity out of an opening in a tank is proportional jointly to the square root of the vertical distance, *h*, between the liquid surface and the centre of the opening and to the square root of twice the acceleration caused by gravity.

$$v = (2gh)^{1/2} \qquad (1)$$

This doesn't take the viscosity and density differences of the fluid into account, whereas the CFD model does.

The data for viscosity and density for matte were taken from reference 4, who compiled these properties from various literature sources to ensure it reflects the Polokwane smelter matte properties. See figure 15 and 16 in the appendix. Hadley *et al. 2006*

Figure 9 show that there is no significant relationship between the tap rate (ton/min) and matte temperature. The matte viscosity does decrease with temperature which makes the matte more fluid and the speed of the matte therefore does increase with temperature but as the density also decreases with temperature, the pressure at the inlet decreases as well and the mass flow rate in ton/min therefore remain constant. The hole diameter does have an significant impact on the matte flow rate however. However there is no relationship between slag temperature and tapping rates as per Figure 10.

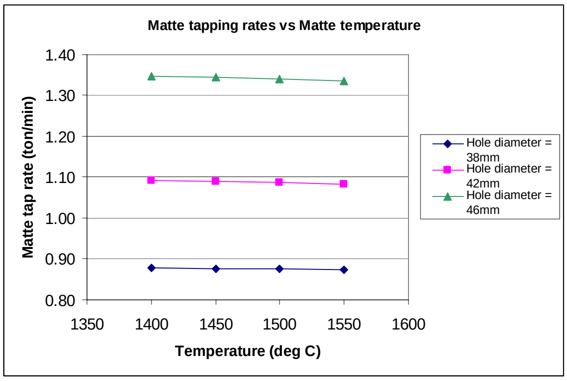

Figure 9: Matte tapping rate vs Matte temperature. Matte level – 60cm,
Slag level - 110cm, slag temperature - 1650°C

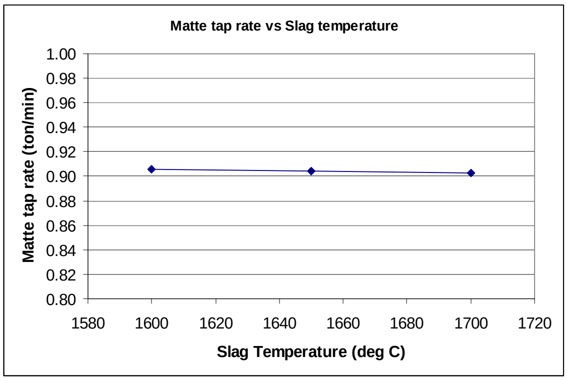

Figure 10: Matte tapping rate vs Slag temperature. Matte level – 65cm,
Slag level - 110cm, Matte temperature - 1450°C

The effect of the matte and slag levels can be seen in Figure 11 and 12. Because of the increase in pressure, the matte tapping rate increases with increasing bath levels.

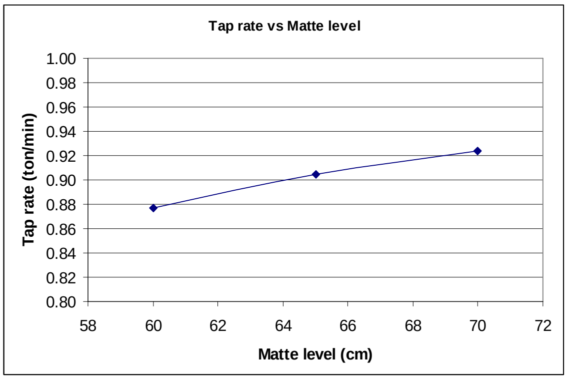

Figure 11: Matte tapping rate vs matte levels. Slag level -110cm, Matte temperature - 1450°C, Slag temperature - 1650°C.

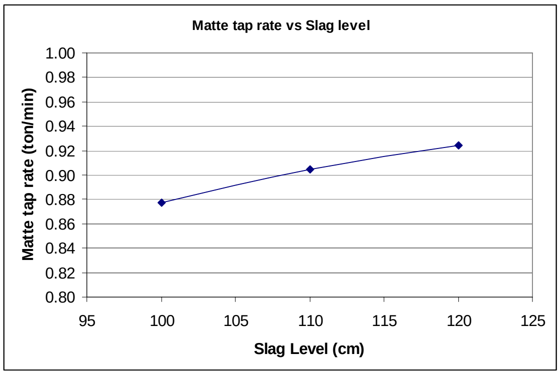

Figure 12: Matte tapping rate vs Slag level. Matte level - 65cm, Matte temperature - 1450°C, Slag temperature - 1650°C.

To verify these numbers, data from the plant was taken to see if a correlation between matte temperature and tap rate exists. The data are for a constant bath level reading between 180 and 182 cm. The data are for the same tap hole and the bath level reading are from the sounding bar closest to the tap hole. However, the data does not take the tap hole diameter into consideration which as we have seen from Figure 9 is a major contributor. No correlation could be found.

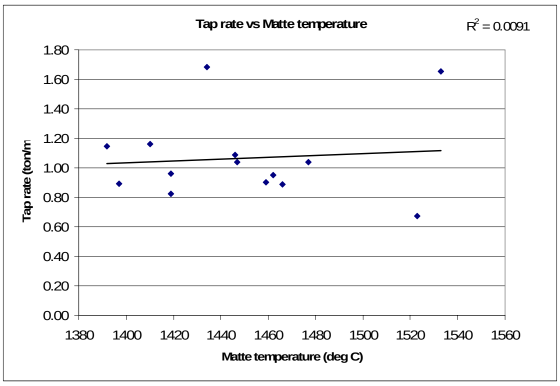

Figure 13: Tap rate vs matte temperature determined from plant data. Bath levels are constant between 180cm and 182 cm. No significant correlation exists.

CONCLUSION

High matte temperatures in the region of 1500°C are often experienced at Polokwane Smelter (improvements have been made). This causes severe corrosion/erosion on the matte tap bricks in the tapping channel. In order to optimize the life of the bricks several tests were done to determine the brick which will be able to withstand these conditions. It was found that the alumina chrome with zirconium brick is giving the best results and the longest life. The tap block was extended and a bull nose was added to the front of the tap block which caused the erosion of the tapping bricks closer to furnace to be less and the time between brick replacements were increased. The CFD model shows the thermal profiles in the copper and refractories as well as the heat fluxes at the different sections of the tap channel due to the matte flow. It shows that virtually no cooling of the matte takes place in the in the tap channel and it can therefore be concluded that the matte significantly influences the tap block by significantly increasing the temperature of the various parts, but that the tap block has no effect on the matte flow.

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APPENDIX

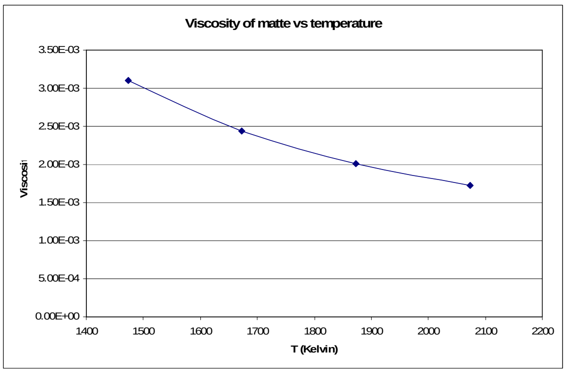

Figure 14: Viscosity vs temperature for matte. (Hadley *et al.* 2006)

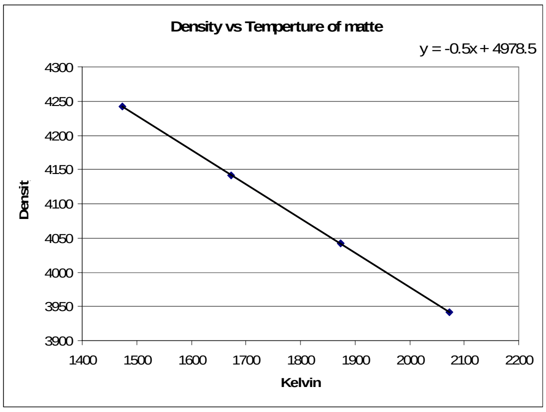

Figure 15: Density vs temperature for matte (Hadley *et al.* 2006)

	Density (kg/m^3)	**Cp (J/kgK)**	**Thermal Conductivity (W/mK)**
Tapping bricks	2900	1090	4
Surround bricks	2900	1090	2.8

Table 3: Refractory properties