



A mechanistic model to predict matte temperatures during the smelting of UG2-rich blends of platinum group metal concentrates

J.J. Eksteen *

Lonmin (Western Platinum Ltd.), Private Bag X508, Marikana 0284, South Africa

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ABSTRACT

High matte temperatures can be related to numerous catastrophic furnace failures in the platinum group metal (PGM) industry where chromite-rich upper group 2 (UG2) concentrates are smelted. Chromite rich concentrates require high slag temperatures as well as sufficient mixing to suspend the chromite spinel particles in the slag and prevent settling in a so-called “mushy” layer consisting of a three phase emulsion of slag, matte and chromite particles. To achieve sufficient bath mixing and to melt and suspend chromite spinel build-up, high hearth power densities are utilised. However, high hearth power densities in conjunction with a heat-insulating concentrate layer, leads to high side wall heat fluxes which motivated the use of intensive cooling in the furnace side wall so that a slag freeze lining can be formed. If matte temperatures are above the slag liquidus temperature, any matte that comes into contact with the freeze lining can destroy the freeze lining. Moreover, if the matte temperature exceeds ca. 1500 °C, chemical thermodynamics indicate that matte has the ability to sulfidise $\text{MgO-Fe}_x\text{O-Cr}_2\text{O}_3$ refractories, leading to rapid wear of refractories exposed to high temperature flowing matte. Models are derived for the concentrate-to-matte and slag-to-matte droplet heat transfer. Calculations using the derived models, physical properties and furnace operating conditions give realistic matte temperatures and show that matte temperatures rapidly increase as the concentrate bed becomes matte drainage rate limiting. It is shown that for each concentrate blend mean particle size and mineralogy, there is a maximum smelting rate above which the concentrate bed becomes rate limiting with regards matte drainage, thereby significantly contributing to matte preheating, prior to further heat absorption from the slag layer.

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1. Introduction

Matte temperatures, while not normally problematic during the smelting of traditional Ni–Cu sulphide concentrates, have been experienced to be problematically high when UG2-rich blends of PGM concentrates are smelted in high intensity electric furnaces. This problem is particularly endemic to some South African PGM smelters where the chromite rich UG2 ores are smelted in high ratios to Merensky or Platreef based concentrates, such as at Anglo Platinum’s Polokwane smelter and at Lonmin’s Western Platinum smelter in Marikana. The industry practice to date has been to not micro-agglomerate the concentrates prior to smelting, a factor that will be explored in more detail in this research. Pelletizing to fairly coarse sizes (larger than 1 mm) were used in the past, but has caused furnace blow-backs due to moist pellet-cores. It is foreseen that high matte temperatures will become an increasing problem in the future when more of the smaller PGM producers on the

Eastern Limb of the Bushveld Igneous Complex (BIC) smelt their ores or deliver it for toll smelting elsewhere.

UG2 concentrates are characterised by relatively high chromite contents, low base metal contents (relative to Merensky and Platreef concentrates) and are particularly rich in hydroxylated ultra-fine soft minerals such as talc. Modal analyses of concentrate mineralogy based on QEMScan analyses of Western Platinum concentrates and a typical repulped revert recycle stream, are presented in Table 1.

Repulped and/or floated reverts which may make up 15–30% of the overall feed of a furnace. UG2 concentrate blends are smelted in circular, 3-electrode, or rectangular, 6-in-line alternating current electrical furnaces. When the Cr_2O_3 content in the concentrate feed is above its solubility limit in slag at 1450–1650 °C (about 1.8% Cr_2O_3 in a non-reducing environment), the chromite spinel minerals will not dissolve and needs to be tapped out at the same rate as they enter the furnace to prevent accumulation which leads to chromite build-up in the hearth, in front of tap holes, or in a three-phase “mushy” layer suspension at the slag–matte interface. Suspension of solids is achieved through sufficient mixing which, in turn, is obtained through sufficiently deep electrode immersion and operating at hearth power densities in excess of 160 kW/m².

* Address: Department of Process Engineering, Stellenbosch University, South Africa. Tel.: +27 823766055; fax: +27 115161310.

E-mail address: Jacques.Eksteen@lonmin.com

Table 1
Sulphide and gangue mineralogy of Merensky and UG2 concentrates.

Mineral	Eastern UG2 concentrate	Western UG2 concentrate	Western Merensky concentrate	Repulped reverts and slag plant conc. ^a
Pentlandite (or Heazlewoodite for reverts ^a)	2.0	3.6	15.1	9.8
Chalcopyrite (or Chalcocite for reverts ^a)	1.1	1.7	9.1	6.4
Pyrrhotite	0.4	0.8	16.7	3.7
Pyrite	0.9	0.9	0.9	–
Other sulphides	0.3	0.3	0.8	2.1
Orthopyroxene	51.0	50.3	35.4	22.2
Clinopyroxene	4.6	6.1	6.1	–
Olivine (or amorphous glass for reverts)	0.2	0.2	0.1	42.6
Plagioclase/Anorthite	9.9	5.4	4.6	–
Amphibole/Tremolite/Actinolite	2.5	2.3	4.1	–
Talc	11.0	16.7	2.7	–
Serpentine	2.1	2.6	0.1	–
Chlorite	1.9	1.7	0.4	–
Biotite/Phlogopite	0.8	0.8	0.5	–
Quartz	0.7	0.4	0.5	–
Chromite spinel	8.2	4.1	0.6	2.5
Magnetite spinel	0.1	0.3	0.2	1.1
Carbonates and other minor minerals ^a	0.1	0.4	0.3	9.3

As the slag at the operating temperature of 1550–1680 °C would rapidly dissolve the furnace side-wall refractories, a slag freeze lining is utilised to protect the refractories. This freeze lining is formed using deep cooled copper waffle or copper plate coolers which can sustain high side-wall heat fluxes. The principal weakness of most furnaces is the slag–matte tidal zone (interface zone) where the slag–matte interface moves up and down along the refractory contact zone due to the intermittent nature of matte tapping and matte accumulation between taps. When the matte temperature is higher than the liquidus temperature of the slag freeze lining, flowing matte will transfer heat to the freeze lining at a higher rate than the copper coolers can remove it and effectively destroy the freeze lining. The high heat transfer rate is due to high matte superheats and the fact that matte has a much higher thermal conductivity, lower viscosity and higher density than slag.

The phase transition of a typical slag freeze lining (of slag chemistry as seen at Western Platinum's smelter) in the presence and absence of matte is illustrated in Fig. 1. The phase transition is as modelled using the thermodynamic modelling software FactSage[®]. The one case presents the equilibrium liquid melt of a typical smelter slag in the absence of matte. Another curve is presented

of a slag in equilibrium with a matte of equal area (or volume with unit thickness). As the slag has some ability to dissolve sulphur as sulphide and matte has the ability to dissolve some oxygen, the speciation of the melt and solid phases are slightly shifted. Matte appears to cause a slight lowering of the solidus, while not significantly affecting the liquidus.

From Fig. 1 it is clear that the slag starts melting between 1050 and 1100 °C depending if matte is present or not and has essentially completed melting by 1450 °C when all (95%) slag based freeze line has melted, except for the chromite spinel mineral that does not completely dissolve/melt until a temperature of close to 1800 °C is reached. Therefore, matte at temperatures greater than 1450 °C will destroy a slag freeze lining completely.

Moreover, matte at temperatures above 1500 °C also becomes chemically aggressive to refractory bricks. Lonmin uses a RHI Radex H60 brick in its furnace hearth with the composition: 58% MgO, 19% Cr₂O₃, 6.5% Al₂O₃, 14% Fe₂O₃, 1.4% CaO, 0.6% SiO₂. Above 1500 °C matte has a significant capacity to sulfidise MgO–Fe_xO–Cr₂O₃ refractories. Matte has a significant solubility for oxygen (shown in the discussion below) and can ferry oxygen between oxide bricks and slag at sufficiently high temperatures:

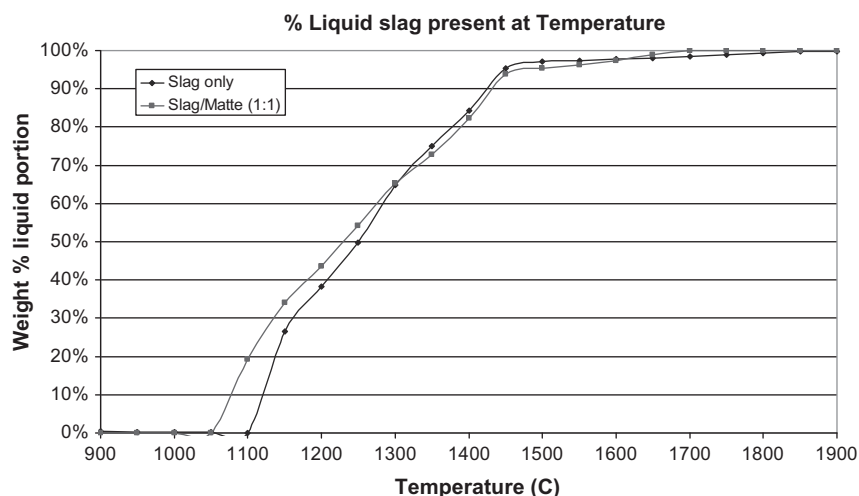


Fig. 1. Phase transition of a slag freeze lining in the absence and presence of matte.

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