A predictive mass and energy model for SiMn production in submerged arc furnaces

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INTRODUCTION

Silicomanganese (SiMn) serves as an alloying element for steel and is added to most steel grades to improve the strength, hardness, and toughness (Olsen and Tangstad, 2004). SiMn is produced in electric submerged arc furnaces (SAFs), and the process is energy-intensive (Jipnang *et al*., 2013). There are currently two routes for producing SiMn, the main difference between them being the primary source of manganese raw materials used. One route uses ore to provide manganese, while the duplex process uses ferromanganese process slag as a manganese source (Jipnang *et al*., 2013). In South Africa, only the ore-based route is used, where ore is fed together with quartz, reductant, and other materials to produce SiMn.

The mass balance allows for the accounting of all elements in the system and is based on the law of conservation of mass. The energy balance relies on the accuracy of the mass balance and enthalpy data for different species in their respective states. The accuracy of the ore analysis plays a crucial part in the challenges experienced when modelling the SiMn system (Heay, 1990).

In this study South African ore compositions were used to model the SiMn process. The model is based on first-principle mass and energy balances, along with industrial operational data. The aim of this mass and energy balance is to predict operational values such as the ore blend, reductant requirement, and energy consumption as accurately as possible. The model will also be used in future to evaluate the techno-economic feasibility of using ferromanganese process slag from South African operations to produce SiMn.

BACKGROUND TO THE SiMn PROCESS

The literature study formed a basis for the assumptions that were made about how the system behaves, and the operational data provided guidance on the validity of the assumptions. There are gaps in the knowledge of the process, both from literature and the operational data, and further assumptions were made. A simple schematic of the SiMn system for a South African plant is shown in Figure 1.

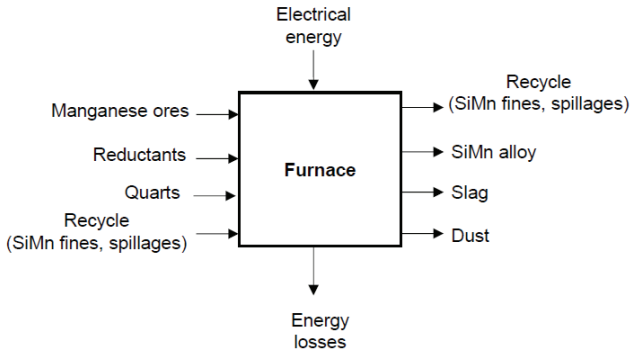

Figure 1. Mass balance over the SAF at Transalloys (Thobadi, 2016)

ASSUMPTIONS AND CALCULATION APPROACH

The data provided by Transalloys does not disclose full process details, but a number of important assumptions were made from the information available. The ore feed was assumed to be predominantly UMK and Wessels lumpy ore, though a small fraction of briquettes along with other inputs were added. The recycle streams and dust were not considered, and these streams will be incorporated later into the model. The reductant was assumed to be pure carbon and the quartz pure silicon dioxide; any discrepancies that arise will be corrected later. Sulphur and phosphorus were also excluded from the initial model.

The ore analysis was reworked to a mixture of ideal minerals based on XRD and EPMA analysis (in this case braunite, bixbyite, hausmannite, calcite, dolomite, quartz). This was done to ensure that the different amounts of oxygen associated with manganese could be captured for the mass balance and the correct enthalpy data could be used for the energy balance. The slag and metal temperature was assumed to be 1500°C and the off-gas temperature 350°C (a significant amount of CO_2 leaves the process compared with, for example, a ferrochromium process). The model was implemented (as a first pass) in Microsoft Excel®. The model inputs are the %FeO and (%CaO+%MgO)/%SiO_2 ratio in the slag as well as the %C and %Si in the metal. Furthermore, the %Mn lost to the off-gas was also an input, as well as the energy losses (in this case assumed to be 15%). The mass balance is solved iteratively to calculate the amount of pure carbon and SiO_2 required to satisfy the specified conditions, as well as the metal, slag, and gas compositions. As per the approach by Broekman and Ford (2004), a correlation was drawn from 490 taps of plant data to estimate the amount of MnO in the slag as a function of the other slag components. This correlation does not include temperature, hence the scatter observed in the actual fitted model, but gave reasonable results. The correlation was found to be %MnO = 46.89 – 1.03 (%CaO+%MgO) with a regression coefficient of 0.73. When data for temperature becomes available, further refinement will be made to the model, since the activity of MnO in the slag is a function of both temperature and basicity (Holappa and Xiao, 2004). Based on a mass balance on 410 data points for one furnace, the average loss of manganese to the off-gas was 9.03 mass%. The 95% confidence on the mean for this figure is 1.31%. For the energy balance, enthalpy data was sourced mainly from FactSage 7.0 (FactPS database for pure species and gas, FTOxid for the slag enthalpy, and SGTE solutions database for the enthalpy of SiMn metal).

PRELIMINARY RESULTS

To test whether the preliminary model data agrees with the actual furnace data, the average output masses, slag and metal chemistry, and energy consumption was compared to the model result (Table I).

Table I. Comparison of actual furnace data and model results

Parameter	**Model result**	**Actual** (av. ± std. dev)
Amount of C required per t ore	239	223.8 ± 28.2
Amount of SiO_2 required per t ore	298	296.6 ± 23.6
Energy consumption (MWh/t SiMn)	4.15	4.0 ± 0.3
Slag / metal ratio	0.60	0.8 ± 0.1
% Mn recovery	84.1	80.8 ± 10.3
Metal chemistry		
% Mn	68.5	66.4 ± 1.3
% Fe	13.2	14.7 ± 0.9
% C	1.8	1.8 ± 0.2
% Si	16.5	16.3 ± 0.6
Slag chemistry		
% MnO	10.4	12.9 ± 1.7
% FeO	**0.3**	**0.3 ± 0.02**
% SiO_2	**53.8**	**46.3 ± 1.5**
% Al_2O_3	**0.0**	**4.7 ± 0.6**
% CaO	29.6	25.0 ± 1.6
% MgO	5.9	5.7 ± 0.7

CONCLUSION

There is reasonably good agreement for all parameters, with the exception of the amount of SiO_2 and Al_2O_3 in the slag, which is attributed to the fact that the ash in coal and coke used as reductant is not included in the model (this will be added to the model in due course).

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