A predictive mass and energy balance model for SiMn production in Submerged Arc Furnaces

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INTRODUCTION

Silicomanganese (SiMn) serves as an alloying element for steel and it is added to most steel grades to influence the strength, hardness, and toughness [1]. SiMn is produced in electric submerged arc furnaces (SAFs) around the world and is energy intensive [2]. There are currently two routes to produce SiMn and the main difference is 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 [2]. In South Africa only the ore-based route is used where ore is fed together with quartz, reductant and other materials to produce SiMn.

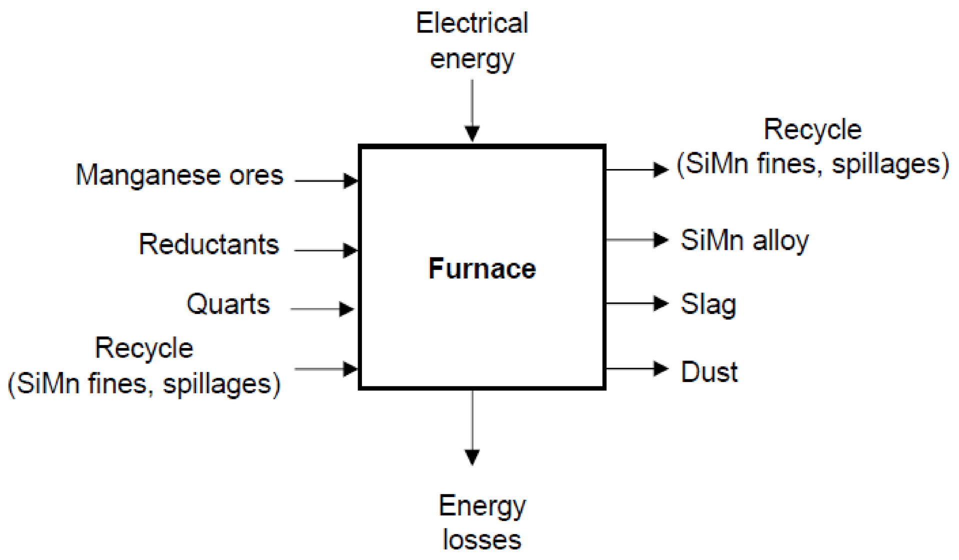

Figure 1. A mass balance schematic for SAF operations at Transalloys [4]

This study entails a model the SiMn process. The model is a combination of a first principle mass and energy balance tuned with industrial 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 for use with a techno-economic model to assess the feasibility using slag from high carbon ferromanganese processes in South Africa to produce SiMn.

MODELLING APPROACH

The model was constructed from historical operational data from industrial furnaces as well as first principles. The first step was to test the data for consistency. In this context data consistency refers to checking whether material input and output streams balance and chemical analyses are consistent.

The second step was to use relationships pertaining Mn and Fe recovery between from the industrial data to tune the model from first principles with, such that the model would reflect real furnace operations when calculations were done.

The model was implemented in Microsoft Excel, but in parallel also in Python. Both models yield the same answers, but the Python version of the model allows for running bulk simulations when required.

MODEL PARAMETERS

The model takes the following inputs: Composition of the manganese sources, reductants and fluxes. Furthermore the Fe recovery (as a %FeO in the slag), required slag basicity as expressed by the ratio (%CaO+%MgO)/%SiO2, %C and %Si needs to be specified. The slag, metal and off-gas temperature is also specified, along with an estimate of the energy loss for the particular furnace involved.

The mass balance is solved iteratively to calculate the amount of pure carbon and SiO2 required to satisfy the specified conditions as well as the metal, slag and gas composition. As per the approach by Broekman [5], a correlation was drawn from 409 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. Further refinement of the model will be made by predicting the equilibrium MnO content of the slag using FactSage in the next phase of the project, since the activity of MnO in the slag is a function of both temperature and basicity [6].

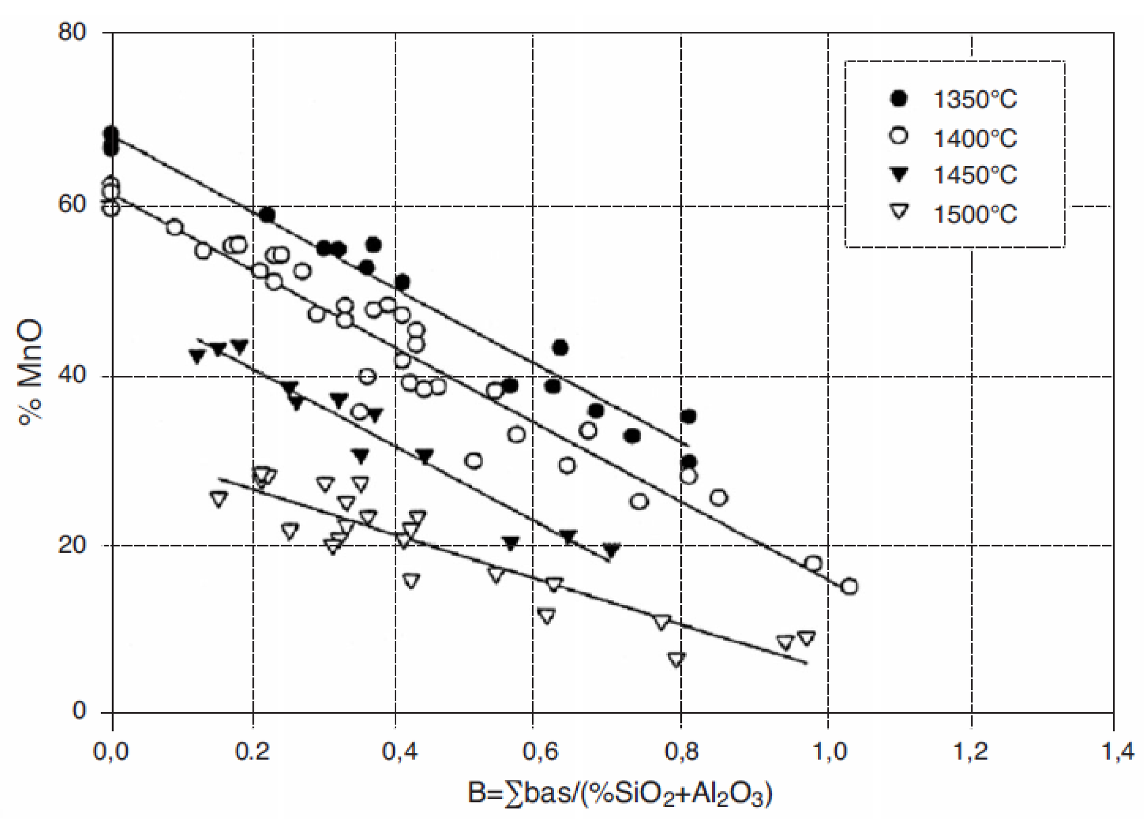

Figure 2. MnO content in multicomponent slags in equilibrium with FeMn (as per reference [6])

To ensure that the energy balance is as accurate as possible and that the carbon requirement was calculated correctly, the raw material analysis for the manganese source was recalculated to a mineral composition. The ore feed was assumed to be predominantly UMK and Wessels lumpy ore, though a small fraction of briquettes along with other inputs are added. The recycle streams were not considered along with the dust, these streams will be incorporated later into the model. The reductant was assumed to be pure carbon and the quartz pure Silicon dioxide, though discrepancies will arise they will be corrected for later. Sulphur and phosphorous was 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). 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). Lastly, 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%.

MODEL RESULTS

To test whether the model agrees with the actual furnace data, the average output masses, slag and metal chemistry and energy consumption was compared to the output from the model.

Table 1: Comparison between model result and actual plat data (for one furnace)

Parameter	Model Result	Actual (Ave ± Std Dev)
Amount of C / t ore	237	223.8 ± 28.2
Amount of SiO2 / t ore	284	296.6 ± 23.6
Energy Consumption (MWh/t SiMn)	4.39	4.0 ± 0.3
Slag/Metal Ratio	0.7	0.8 ± 0.1
% Mn Recovery	82.2	80.8 ± 10.3
Metal Chemistry		
% Mn	68.0	66.4 ± 1.3
% Fe	13.7	14.7 ± 0.9
% C	1.8	1.8 ± 0.2
% Si	16.5	16.3 ± 0.6
Slag Chemistry		
% MnO	17.7	12.9 ± 1.7
% FeO	0.3	0.3 ± 0.02
% SiO2	50.4	46.3 ± 1.5
% Al2O3	3.3	4.7 ± 0.6
% CaO	27.7	25.0 ± 1.6
% MgO	5.6	5.7 ± 0.7

CONCLUSIONS AND FURTHER WORK

A model has been successfully constructed for SiMn production in Submerged Arc Furaces for use in a techno-economic evaluation of the process. Further work will include developing a model where the effect of temperature on the recovery of manganese is fully described on a fundamental basis.

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FOR FURTHER INFORMATION

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