Learning and Teaching using Process modelling and Simulation

Xiaowei Pan

Abstract**—**Depending on the way of teaching, teachers can make enormous difference in the quality of learning and teaching at university. This paper covers how to use process modelling and process simulation to help students to understand some of the complex industrious processes easier and better. Many industrious processes, such as the production of ferrochrome, are extremely complicated and often those processes are interacted and involve many physicochemical reactions that happen simultaneously. When there is any change in one of the inputs, it usually requires to understand the potential effects on the production processes and then decide what actions should be taken to accommodate the change of the mentioned input, in order to manage the production processes to achieve the desired target. Due to the complexity of the production, it takes many hours to complete a charge calculation, which involves with the calculation of mass and energy for the entire furnace. Using process simulation built with process models, it is possible to carry out many what-if scenario exercises in classroom, resulting in easier and better understanding of the cause-effect relationship existing in the production of ferroalloy.

Keywords**—**learning, teaching, process simulation, ferrochrome production

I. INTRODUCTION

FErrochrome production is one of the subjects lectured at the Department of metallurgy, University of Johannesburg. Ferrochrome, an alloy used to make stainless steel and especial steels, is mainly produced by carbothermic reduction of chrome ore in a submerged arc furnace or in a DC plasma furnace. The raw material, consisting of chromite ores, fluxes and reductants, are batched and mixed before being fed into the furnaces. In the furnace, the chromite ore (consisting mainly of iron oxides, chromium oxide, magnesium oxide, and aluminum oxide) are reduced with carbon to for the alloy. The reduction is highly endothermic and the production process is energy intensive, and consumes approximately 3,300-3,800 kWh per ton of metal produced. The energy is generally supplied in the form of electrical energy through carbon electrodes.

Dr Xiaowei Pan is with the Department of Metallurgy, University of Johannesburg, PO Box 17011 Doornfontein, 2028 Johannesburg, South Africa, phone: +27 11 559 6371; fax: +27 11 559 6194 ; e-mail: xpan@uj.ac.za

As MgO and Al2O3 are oxides with high liquidus temperature, fluxes like limestone, dolomite and quartz are loaded to form liquid slag phase so that it can be tapped out of the furnace. Alloy and slag are tapped through the taphole into ladles in a cascade arrangement, with the alloy being trapped in the first ladle, and the slag overflowing to the next ladles or into a pit, see in figure 1.

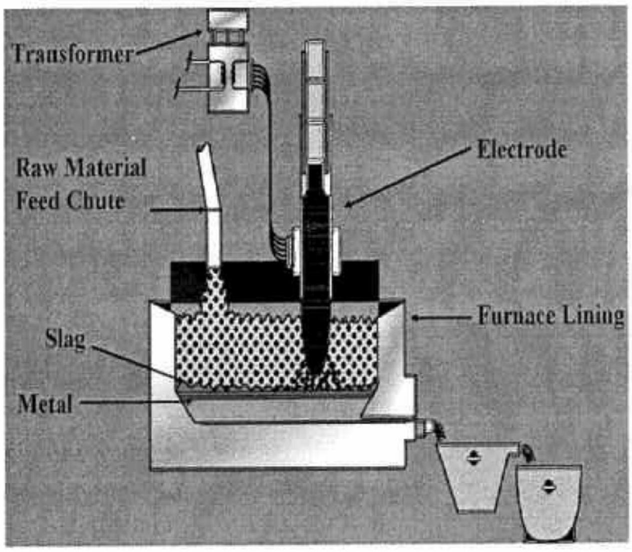

Figure 1. Schematic representation of a submerged arc furnace used to produce ferrochrome, including furnace, raw material, slag, metal, electrode, taphole, and ladles.

South Africa, with 80% of world chrome or reserves, is one of the major producers of ferrochrome, and its production accounts for about 34% of the total production in the world. With an increased challenge from other major producers, such as China, India, the ferrochrome producers in South Africa are exploring options to reduce the production cost.

The cost of electricity counts for about 35-40% of total production cost. Due to the shortage of power supply in South Africa, the cost of electricity has more than doubled since 2008, and a plan has been tabled to increase the electricity price by 16% every year from 2013 to 2018.

With a sharp increase in electricity cost, it is imperative to look for any alternatives that can use less electricity. A simulation of ferrochrome production, with no doubt, can be used to investigate various alternatives in a virtual environment, including the effect of various chrome ores on the electrical energy consumption (X Pan, 2014).

To help students apply the principles to the production processes, particularly to understand the pragmatic challenges facing the industry, simulation makes the learning easier and faster in classroom.

II. PROCESS MODELLING AND SIMULATION

Process modelling, in general is the process of producing a model, which is a presentation of the process of interest. A process model is similar to but simpler than the process it represents. The main purpose of a model is to enable us to understand, analyze and predict the effect of changes to the process. A process model intended for a simulation study can be classified as a first principle model or knowledge-base model. A first principle model is developed using mathematics conjunction with science like physics and chemistry. When a process is very complex and is ill-understood, the process cannot be simplified in any kind of mathematics. With enough experience or experiments, large amount of data can be used to generate a rule based model, like fuzzy logic, decision tree, and neural networks model.

On the one hand, a process model should be a close approximation to the real process and incorporate most of its salient features and functions, including, process inputs, outputs, and disturbances. On the other hand, a process model should not be so complex that it is impossible to understand and experiment with it. A good model is a judicious tradeoff between realism and simplicity. "All models are bad, it maters how useful they are. It is a good model if it is useful." quoted by X Pan at International Heavy Mineral Conference in Durban 1998.

III. SIMULATION OF FERROCHROME PRODUCTION

An excel-based simulation, called Ferroalloy Simulation (Ferroalloy-Sim), is used to help learners to understand the effect of different chrome ores on the electricity consumption used to produce high carbon ferrochrome (HCFeCr) in submerged are furnace (SAF).

The Ferrochrome Simulation is developed using the principles of mass balance and energy balance, the interface can be seen in Fig. 2. The simulation requires three inputs and generates the results of charge recipe, mass and composition for slag, metal, and off gas, with the energy consumption associated with the production process.

Lumpy chrome ores from six different locations of the Bushveld Igneous Complex are used. Quartzite is added as flux, and coke is used as reductant. The names of different chromite ores produced in South Africa are listed in Table I with other process parameters used to produce one ton of ferrochrome.

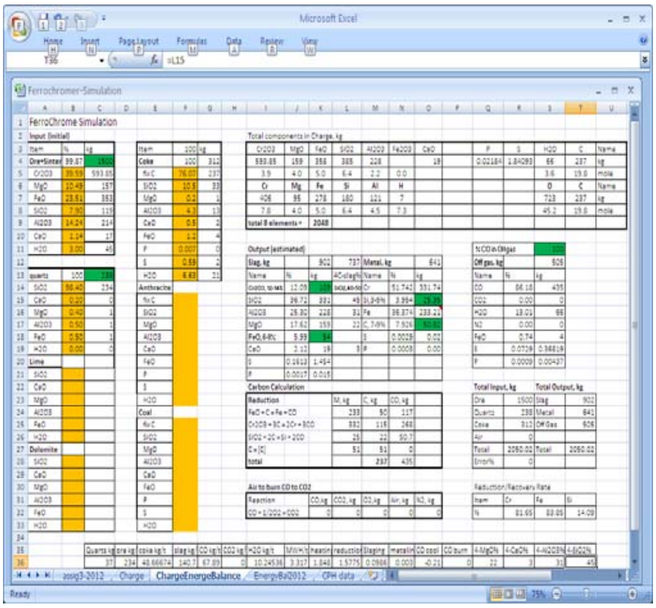

Fig. 2 Ferroalloy simulation used to calculate charge and electricity consumption of ferrochrome production in a submerged arc furnace

Based on the production of ferrochrome in South Africa, the following conditions are used as major smelting parameters:

- 6% FeO in slag
- 12% Cr_2O_3 in slag
- 45% SiO_2 in the 3-component slag of SiO_2-MgO-Al_2O_3
- 8% carbon in metal
- 4% silicon in metal
- Slag temperature 1700 ^{o}C
- Metal temperature 1600 ^{o}C

TABLE I
MAJOR SMELTING PARAMETERS USED TO PRODUCE ONE TON OF HCFeCr IN SAF USING DIFFERENT SA CHROME LUMP ORES

ore names	ore kg/t	quartzite kg/t	coke kg/t	slag kg/t	CO kg/t	MWH/t
Steelpoort	2202.02	455.73	490.86	1350.10	684.61	3.33
Lannex	2265.62	413.24	488.43	1369.81	680.29	3.31
Elandsdrift	2338.73	371.27	486.67	1405.82	678.95	3.32
Mooinooi	2339.57	372.90	487.49	1423.85	678.63	3.33
Millsell	2460.79	338.00	489.06	1563.55	679.01	3.41
Tweefontein	3196.63	164.69	483.11	2017.23	670.50	3.63

IV. SIMULATION AND DISCUSSION

A. Smelting Parameters

The main parameters, used to produce high carbon ferrochrome in a submerged arc furnace, are selected and listed in Table III, including raw material consumption, energy consumption, mass of metal, slag and offgas. They are expressed in terms of kilogram per ton of produced metal (kg/t):

- Ore consumption, ore-kg/t
- Flux, quartzite consumption, quartzite-kg/t
- Reductant, coke consumption, coke-kg/t
- Electric energy consumption, MWh/t
- Metal produced, t
- Slag produced, slag-kg/t
- Offgas produced, offgas-kg/t

B. Composition of SA Chrome Lumpy Ores

The selected chrome lumpy ores contains mainly Cr2O3, FeO, SiO2, MgO, Al2O3 and small amount of CaO. The range of chemical composition is 29-43% of Cr2O3, 20-24% of FeO, 4-20% of SiO2, 11-17% of MgO, 10-14% of Al2O3, 1-2% of CaO, see in Fig. 3.

The contents of MgO, Al2O3 and CaO have small changes in all selected chrome ores, particularly CaO with a range of only 1-2%. The major changes of the chrome ores appear in the contents of SiO2, Cr2O3 and FeO. The content of SiO2% increases from 4% of Steelpoort ore to 19% of Tweefontein ore, and the contents of Cr2O3%, FeO% decreases from 43 to 38, and 24 to 23 respectively, as shown in Fig. 4. The total content of Cr2O3 and FeO decreases from 67% to 50%, from Steelpoort ore to Tweefontein ore.

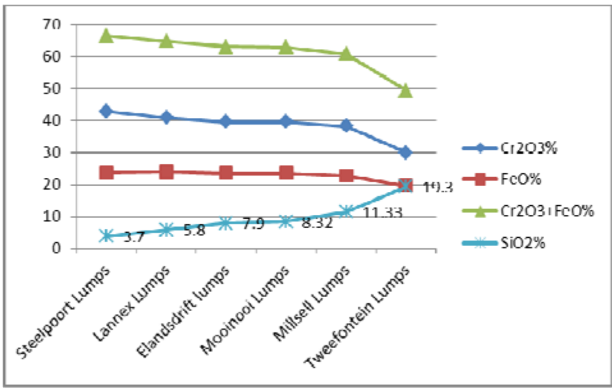

Fig. 4 Chemical composition of chrome lumpy ores, with increase of SiO2% and decrease of Cr and Fe oxides from Steelpoort ore to Tweefontein ore

C. Raw Material Consumption

The consumption of ores, flux quartzite, reductant coke, and the produced mass of slag and CO gas are shown in Fig. 5, with left axis in terms of kg per ton of metal (kg/t). The electric energy consumption is also shown the same figure with right axis in mega watt hour per ton of metal (MWh/t).

When producing one ton of high carbon ferrochrome in SAF, the Tweefontein lump ore has the highest ore consumption at 3200 kg/t, 22% and more than 30% higher than the consumption of Millsell and other ores. At the same time, the Tweefontein lump ore requires the lowest quartzite consumption at 160 kg/t. It is 205%-225% lower than the quartzite consumption comparing the ores of Millsell, Elandsdrift, and Mooinooi, and it is 277%-251% lower when comparing the ore of Steelpoort and Lannex, see in Fig. 6.

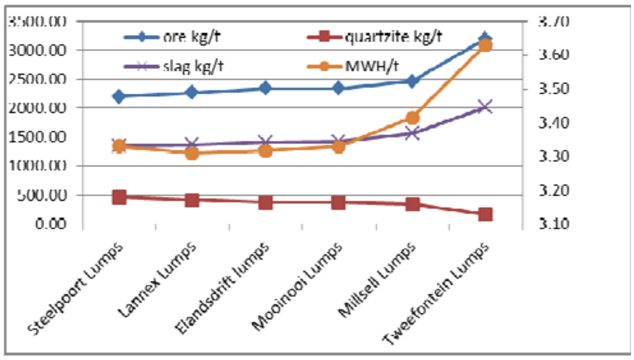

Fig. 5 Raw material consumption, when producing one ton of high carbon ferrochrome using different chrome lumpy ores of South Africa, with left axis for kg/t, and right axis for MWh/t

With the combination of high ore consumption and low quartzite consumptions when using lump ore from Tweefontein, the production process generates the most slag, about 2000 kg/t. it is 22% more than that of Millsell ore, and 29-33% more than the others.

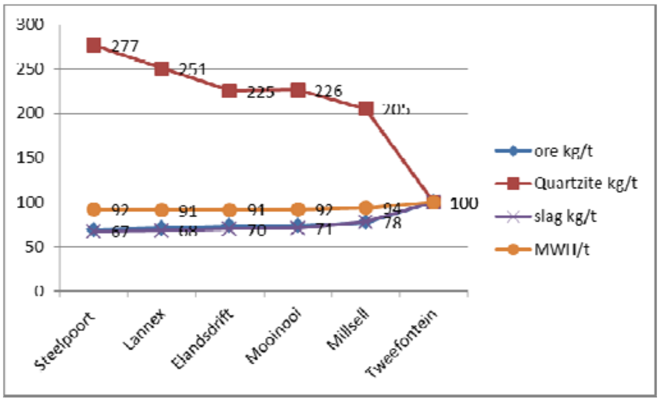

Fig. 6 Consumption of ore, quartzite, energy and production of slag when producing one ton of high carbon ferrochrome, compared with Tweefontein chrome lump ore

D. Electric Energy Consumption

The electric energy consumption ranges from 3.31 to 3.63 MWh per ton metal produced (MWh/t), when using the selected 6 different chrome lumpy ores. Tweefontein lumpy chrome ore requires the highest electric energy, with amount

3.63 MWh/t, as shown in Fig. 7. Millsell lumpy ore requires the second highest energy at 3.41 MWh/t, and the rest of 4 chrome ores consumes similar amount electric energy from 3.31 to 3.33 MWh/t.

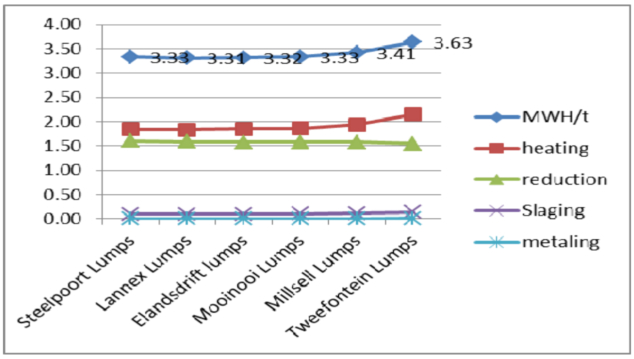

Fig. 7 Electric energy used for heating, reduction of oxides and forming of molten slag and metal, when using different chrome lumpy ores produced in South Africa.

V.CONCLUSION

Chrome lumpy ores are selected from 6 different locations across the Bushveld Igneous Complex, from Rustenburg on the north-west side, to Steelpoort on the South-East side of the complex.

The electric energy consumption is highly related to the SiO2 content of chrome ores, ranging from 4 to 20%. The lowest electric consumption of 3.31 MWh is required to produce one ton of high carbon ferrochrome, when the SiO2% of chrome ore is 6%. The required electric energy consumption increases when SiO2 content increases from 6% to 19% in the ores. Furthermore the energy consumption increases, when SiO2 content decreases from 6% to 4%.

The current investigation is mainly focused on the effect of ore compositions on the electric energy consumption. The effects of other factors will be carried out separately.

REFERENCE

1. X Pan, Model based control system for ferroalloy plant, International Heavy Mineral Conference 1998, Durban, pp212-224
2. X Pan, Effect of SA Chrome ores on ferrochrome production, Chrome ores on ferrochrome smelting, Proceedings of the 3rd International Conference on Mechanical, Electronics and Mechatronics Engineering (ICMEME 2014), Abu Dhabi, UAE, 19-20 March 2014, pp45-49
3. Masibulele P. Zintwana; R. Grant Cawthorn ; Lewis D. Ashwal, “Mercury in the Bushveld Complex, South Africa, and the Skaergaard Intrusion, Greenland”, Chemical Geology, Volumes 320–321, 6 August 2012, Pages 147–155
4. Gajana Kapure, Chandrakala Kari, S Mohan Rao and K. S Raju, “Use of chemical energy in submerged arc furnace to produce ferrochrome: Prospocts and limitations”, INFACON XI, 2007, pp165-170
5. M.H Farjadi and J. Azari, “Effect of chrome ore quality on ferrochrome production efficiency”, INFACON X, Cape Town, 2004 pp103-107
6. L. Hu, “Selection of chromite ores in HC FeCr production”, Ferroalloys, No6, 1990, pp21-28
7. P. C Hayes, “Aspects of SAF smelting of ferrochrome”, INFACON X, Cape Town, 2004, pp1-14
8. O. Naiker and T. Riley, “Xstrata Alloys in Profile”, Southern African Pyrometallurgy 2006, Johannesburg, pp297-305