AN EFFECTIVE EQUILIBRIUM REACTION MODEL FOR THE SUBMERGED PLASMA FUMING PROCESS USING CHEMAPP

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Introduction

Use of the plasma fuming process in process metallurgy opens up new horizons for the treatment of lead and zinc blast furnace slags. This technology shows excellent performance in recovering valuable metals and producing a metal-cleaned slag. Previously, the zinc slag fuming process has been studied extensively based on mathematical simulation and experiments.[1-2] A representative approach of modelling is to use a thermodynamic database and indirectly incorporate the database in reaction kinetics, such as the Equivalent Equilibrium Reaction Zone (EERZ) model.[3] The model assumes that an effective reaction volume exists at the gas slag interface, and the reaction kinetics are described by the change in the size of the transient reaction zone over time. It is not needed to directly solve the governing equations of the complicated multiphase flow and heat transfer in the process, therefore it is considered to be an efficient and flexible model. The EERZ model was widely used to predict the kinetics of steelmaking.[3] Yan *et al.*[4] has extended this model to predict the gas-slag interaction in the plasma process of re-fusing the derived fuel. Their work reported the effect of the gas-slag interaction level on the reaction products. The submerged plasma fuming technology is an upgrade to the traditional (coal-fired) slag fuming technology in terms of process intensification. However, very few reports on the modelling of this process can be found. The fuming kinetics of the plasma driven process is unclear.

The purpose of this paper is to develop an effective equilibrium reaction zone model to describe the fuming kinetics of the plasma driven process. This is a thermodynamic based transient model where ChemApp will be used to design and implement the modelling.

Model development

In this model, the submerged plasma fuming process was divided into 11 reaction zones, where R0 refers to the start slag melting, R1 the plasma generation, R2 the

natural gas combustion, R3 the raw material feeding and melting, R4 the coal and slag reaction, R5 the slag mixing, R6 the gas and slag reaction, R7 the equilibrated slag homogenisation, R8 the off gas removal to the gas phase, R9 the power input and R10 the heat loss by the freeze lining and off gas, as shown in Figure 1a. Among these reaction zones, R2 can describe the oxygen potential of the gas mixture by calculating the combustion degree of reductants. R9 and R10 can be used to calculate the heat balance in the fuming process.

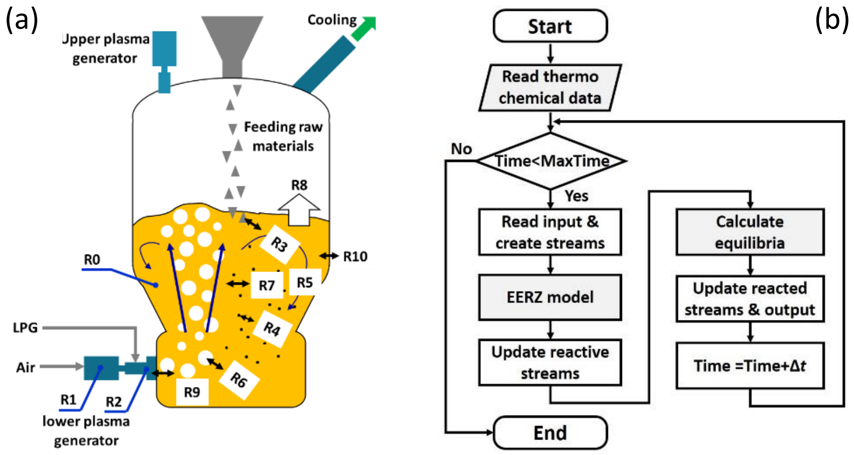

Figure 1: Schematic illustration of (a) reaction zones inside the plasma fuming reactor, and (b) the structure of the ChemApp-based model

For the gas-slag reaction R6, a thermodynamic equilibrium is assumed at the interface. For a given time step, the equilibrium would be calculated between a certain amount of slags and reductants, followed by equilibrium homogenisation in the slag phase (between equilibrated slag and bulk slag) and in the gas phase (between equilibrated gas and bulk gases). The amount of reactive slags was calculated according to the first order mass transfer equation. The amount of equilibrated products was calculated based on the FactSage database. Kinetics of reaction was taken into account by varying the amount of reactive phase. This is the concept of the Effective Equilibrium Reaction Zone model. More details about the model may be found shortly in our future papers.

In order to implement the thermodynamic-based transient model, ChemApp (GTT technologies, Herzogenrath, Germany) was used in conjunction with the thermodynamic databases FactPS and FToxid. ChemApp allows using of the thermochemical database to design and implement FactSage calculations flexibly. Figure 1b highlights the computational flow diagram for zinc reduction in the slag fuming process. A stream concept is used, and the stream is defined as a mixture of the non-reacted matter at constant temperature and pressure. For a new time step, the input data which mainly consists of the equilibrated products from the last time

step, the new gas mixture read from the data files directly and the reaction conditions (temperature, pressure, *etc.*), are first set as streams. And then the update reactive fraction model is called to determine the gas-slag reactive level. The streams calculated by the model are then transferred to reaction zones where equilibrium calculations are implemented. After that, the equilibrated products can be separated into different phases. Off gas will flow out of the reactor, and the equilibrated slag will mix with the rest of the bulk slag uniformly, forming the initial input slag for the next calculation time step. This loop continues until the fuming time runs out.

Modelling case

This ChemApp model was applied to predict the plasma fuming behaviour in a pilot trial. The testing campaign was divided into three stages, namely, I-start slag melting, II-raw material feeding and III-metal fuming. The operation parameters are shown in Figure 2. The initial contents of zinc and lead are 7.46 wt% and 2.60 wt%, respectively. Sampling was conducted at specific intervals throughout the trial. The measurements were compared with predictions to verify and improve the model.

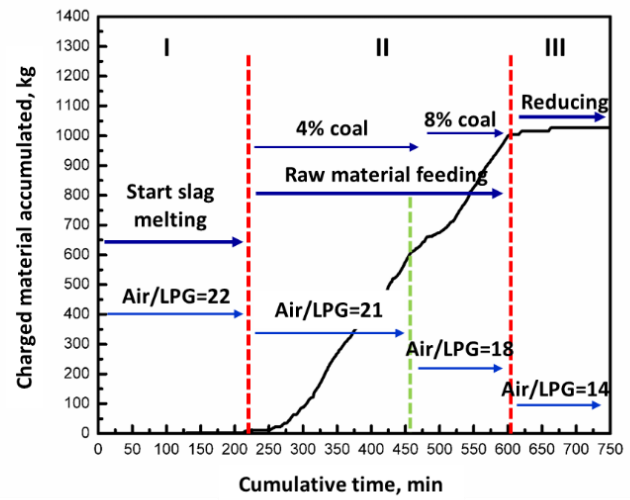

Figure 2: The operation parameters and fuming stages for the modelling case

Results and discussion

Figure 3 shows the comparison between the simulation results and the experimental data. In general, the model performs very well in predicting the remaining contents of Zn (Figure 3a) and other components (Figure 3b) in the slag as a function of process time. However, the remaining content of Pb slightly deviates from the measurements, which is probably due to a different fuming mechanism of Pb from Zn. Further work will be conducted to understand the Pb fuming behaviour. In the feed stage, the content of FeO slightly increases with the accumulation of raw

materials as shown in Figure 3b. That is because the feedstock contains a higher concentration of FeO than that in the start slag. ZnO content in the slag continues to increase until the reduction stage, while PbO concentration remains at a relatively low level as shown in Figure 3a. In the reduction stage, ZnO concentration in the slag rapidly decreases with the fuming time, and eventually levels off at 0.58 wt%. The PbO concentration has reached a relatively low level (0.14 wt%) before the reduction stage.

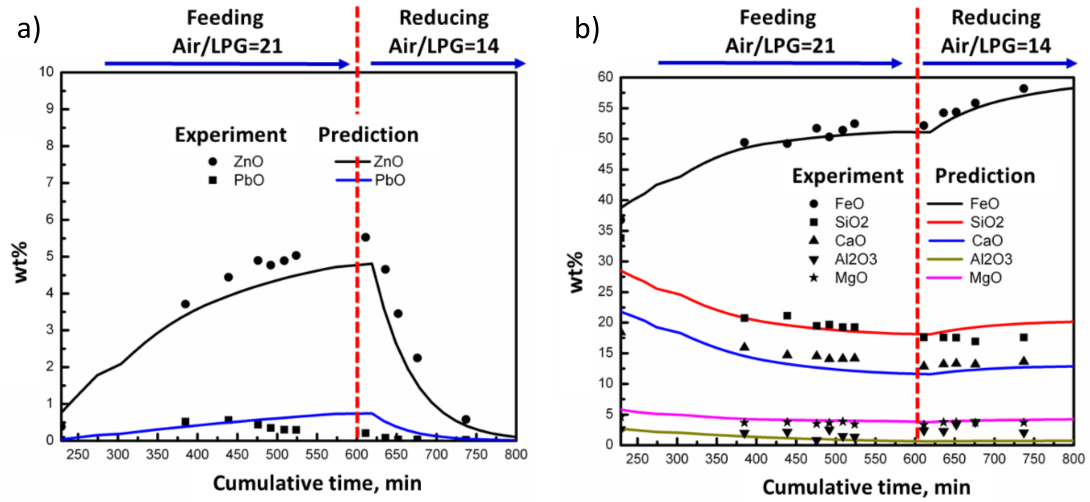

Figure 3: Comparison between the simulation results and the experimental data for the concentration profiles of (a) ZnO and PbO and (b) other components

Conclusion

An effective equilibrium reaction zone model has been developed to understand fuming kinetics of zinc and lead in the plasma driven process. ChemApp was applied in this model, to design the model and implement the simulation. The prediction shows a good agreement with the experimental data. This model can be further extended to investigate the influence of process parameters on the fuming efficiency.

References

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