MODELLING OF AN INDUSTRIAL SUBMERGED PLASMA ZINC FUMING PROCESS

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Introduction

Fayalite slags produced from secondary copper smelting contain a considerable amount of zinc oxide (ZnO). Valorising the ZnO is helpful in achieving a circular economy. To this purpose, the slags can be treated using slag fuming, where volatile metals such as zinc and lead are evaporated from the molten slag bath. The final slag with very low metal content becomes a valuable mineral product in cement industries, enabling true circular economy. A conventional zinc fuming process involves pressurised injection of pulverised coal and air into the reactor, which heats the molten slag bath, reduces ZnO and creates good mixing conditions.[1,2] But, this process uses a significant amount of fossil fuel, emitting a considerable amount of greenhouse gases. To face this challenge, new technology has been developed in which electrically powered plasma torches replace coal-fired jets. In this technology, compressed air is heated in a non-transferred arc plasma generator to produce air plasma. The air plasma is then mixed with natural gas to produce energy-dense reducing gas which is used in the endothermic reduction reaction of zinc oxide and in heating the slag bath. A solid reducing agent is added to enhance the fuming rate. The zinc fumes are combusted to produce zinc oxide precipitates in a post-combustion duct by drawing air from the surroundings. The gases and the precipitates are cooled in a spray cooler. Figure 1 shows a schematic of the plasma-driven zinc fuming process. A dynamic steady state thermodynamic process model of the submerged plasma zinc fuming process is developed in FactSage 7.0 based on the industrial scale fuming furnace at Metallo Belgium.

Model description

The thermodynamic process model of a submerged plasma slag fuming process describes the overall process as a sequence of five unit operations, namely production of air plasma in the plasma generator, mixing of air plasma with natural gas in the tuyere, fuming of zinc in the reactor, and post-combustion of offgas in a duct and cooling of offgas and zinc oxide precipitates in a spray cooler (Figure 2). Since the process is batch type, the conditions inside the reactor (temperature,

composition, *etc.*) change with time. In each unit operation, the chemical reactions, phase equilibria, and heat transfer are described simultaneously using Gibbs free energy minimisation. Each unit is connected by streams of heat and mass to the following units. Heat and mass transfer to the subsequent unit is assumed after attaining the thermodynamic equilibrium in the previous unit. The enthalpies supplied, generated and lost in each unit operation were also taken into account. The change in enthalpy of the system is associated with the changes in temperature and chemical composition.

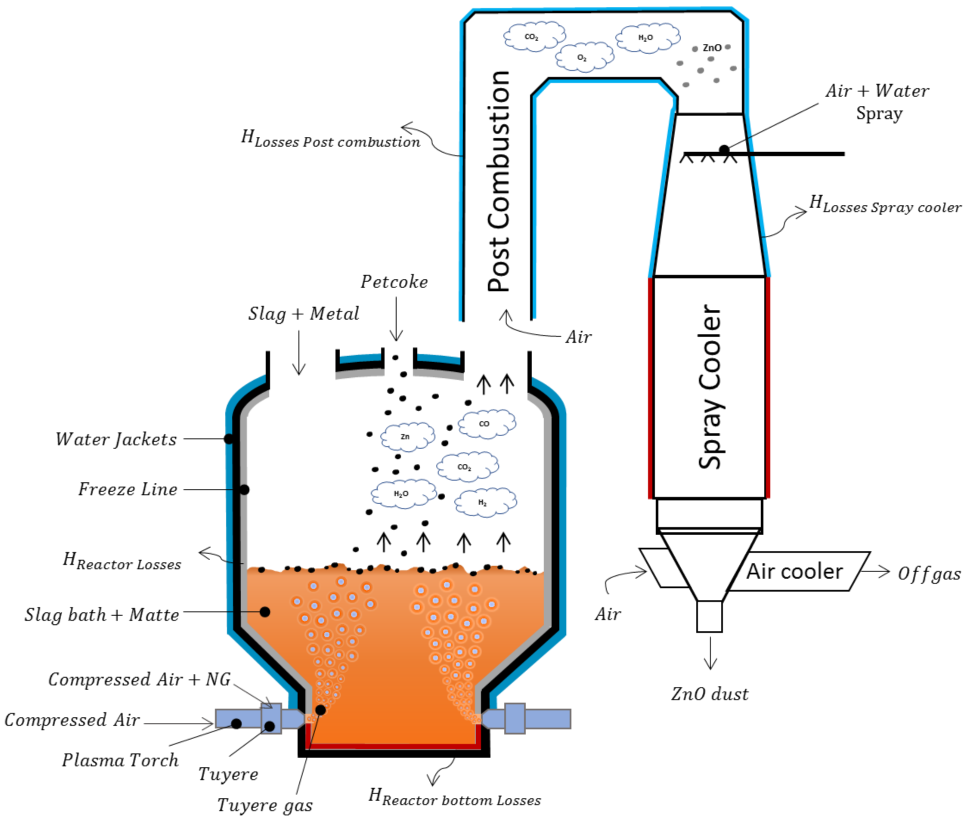

Figure 1: Slag fuming furnace

In the previous studies, it has been argued by many researchers that the zinc fuming process has rate limitations such as reaction kinetics, reactor specific factors including mixing, inhomogeneity, *etc.*[2-4] Despite these rate limitations, this model assumes that the reactions take place instantaneously and the slag bath is homogeneous. The fuming process is fully controlled by thermodynamics. The model described here presents the most efficient scenario of the zinc fuming process.

FactSage 7.0 databases FactPS, FToxid and FTmisc were used to calculate the thermodynamic equilibrium in every unit operation, and FactSage's macro processing was used to develop the flowsheet model. Microsoft Excel was used as a user interface to set up the initial conditions and record the results.

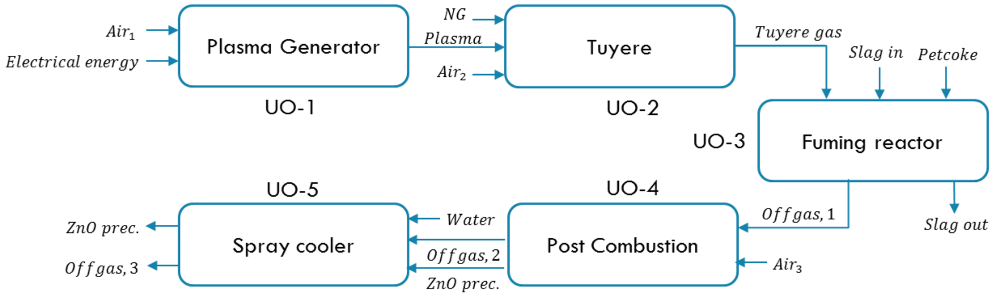

Figure 2: Flowsheet of the submerged plasma driven slag fuming process model

Case study

Seventy tons of molten secondary copper smelting slag containing 11.1 mol% zinc oxide is charged into the furnace, and its initial temperature is assumed to be 1150°C. The composition of slag is given in Table 1. 3000 Nm^3/h of compressed air (2 bar) is heated with 9000 kW in the plasma generator to produce a continuous stream of air plasma. The air plasma is mixed with 430 Nm^3/h of natural gas and blown into the reactor. Petcoke is fed into the reactor at a rate of 1 ton/h from the petcoke feed hole. The reactor is water cooled, and it is protected by a layer of freeze lining. The heat losses of the reactor ($\dot{q}_{slag\rightarrow FL}$) are calculated using Equation (1), where $h_{slag\rightarrow FL}$ is the heat transfer coefficient (W/m^2K), $T_{FL,\,H}$ is the temperature of the hot face of the freeze lining (K) which is the fayalite formation temperature calculated using FactSage, and T_{slag} is the temperature of the slag (K).

$$\dot{q}_{slag\rightarrow FL} = h_{slag\rightarrow FL}\left(T_{FL,\,H} - T_{slag}\right) \quad (1)$$

Table 1: Composition of secondary copper smelting slag (mol%)

FeO	SiO_2	Al_2O_3	CaO	ZnO	PbO	Cu_2O
44.8	34.1	5.3	3.8	11.1	0.12	0.69

Results and discussion

Figure 3 shows the evolution of zinc oxide and lead oxide with time (the scale on x-axis is omitted due to confidentiality) in the slag bath in the beginning of the process during a fuming operation predicted by the model in comparison with the reality. The model predicts faster fuming rates than measured one, and this suggests that the rate-limiting factors such as reaction kinetics, reactor specific factors such as mixing, inhomogeneity, *etc.* are involved which slow down the fuming process. The composition of the precipitates is 94% zinc oxide and 5% lead oxide which is very close to the reality.

The model was used to test the influence of reactor heat losses on the process output (simply put, the thermal efficiency of the fuming process), and it has been found that reactor heat losses have a significant influence on the fuming rate. When the reactor heat losses are low, a higher fuming rate was observed which implies that more energy is available for fuming and vice versa.

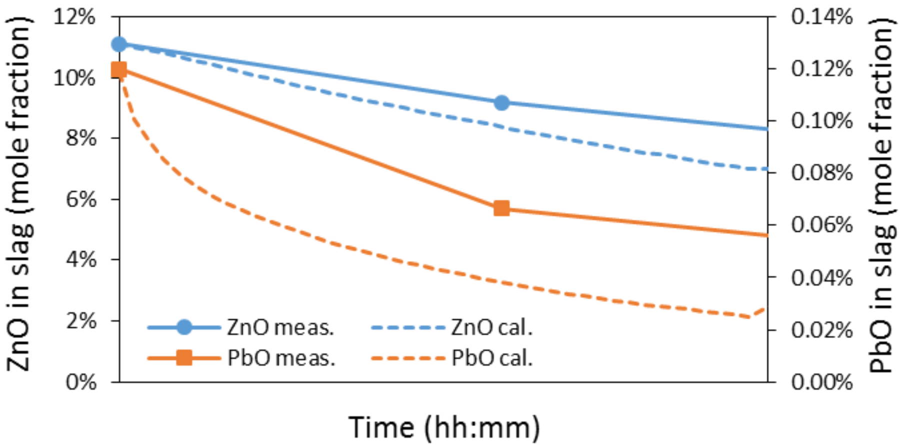

Figure 3: Evolution of zinc oxide and lead oxide in the slag bath with time

Conclusion

A dynamic steady state thermodynamic process model of the submerged plasma zinc fuming process is developed in FactSage 7.0 using FactSage's macro processing based on the industrial scale fuming furnace at Metallo Belgium. It has been found that the process has kinetic limitations. Reactor heat losses play an essential role in the efficiency of fuming.

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