Current state and ongoing development of a dynamic EAF process model

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INTRODUCTION

Steelmaking in the electric arc furnace (EAF) is one of the two main sources of crude steel and the main recycling route for scrap. Therefore, there is significant interest in optimization of the EAF process with regard to energy and resource efficiency, tap-to-tap time, emission control and other aspects. To gain a better understanding of the process and identify possible potential for optimization, simulation models are used.

The presented process model is based on the approach published by Logar, Dovzan and Škrjanc.[7-11] It was developed further by Meier, who implemented the electrode as a separate zone and changed the gas phase and thermal radiation models.[12] The model is analytical in nature and based on fundamental thermodynamic and physical principals. However, some empirical parameters remain necessary to describe simplified or insufficiently documented relationships. In the current implementation, the model uses data from an industrial EAF as input and for validation of the simulation results.

It is planned to attain operational data from at least two more EAF to use as model input to further validate its applicability to industrial furnace operation. Furthermore, the thermochemical calculation will be improved by including additional elements and improving the equilibrium calculation the chemical reaction rates are based on. To accelerate and ease parameterization when applying the model to different furnaces and operating conditions, an optimization algorithm is being developed and tested, that adjusts the necessary parameters.

Thermochemical Model

In the current model the equilibrium concentrations used when calculating reaction rates are based on equilibria of different oxide species in the slag and the concentrations of metal in the melt. CaO, MgO, Al_2O_3, SiO_2, MnO, P_2O_5 and FeO are considered in the slag, while Si, Mn, P, C and Fe are included in the melt. The reaction rates for injected C and O_2 are based on the same equilibrium concentrations. The concentration and reactions of Oxygen dissolved in the melt are not considered.

In combination with the temperature, the composition of the melt is one of the main target value for the EAF process. Since the oxidation of metals releases significant amounts of energy, the thermochemical calculation has a strong influence on both the melt's temperature and composition. To better model this aspect of the EAF process it is planned to consider Al and S in addition to the currently implemented elements and improve the calculation of the equilibrium concentrations. The oxygen concentration within the melt will be calculated. Slag and melt compositions will then be determined by the equilibrium reactions of each element with oxygen in the melt and it's oxide in the slag, with the exception of Sulphur which forms an additional anion in the slag and is treated as such.

For this purpose the regular solution model as published by Ban-Ya [1], Gaye's model [3-6] and an approach using stored equilibrium data calculated by Factsage are considered. Activities of species in the melt are calculated using the interaction parameters suggested by Sigworth and Elliot.[14]

The calculation suggested by Ban-Ya is sufficiently simplified to be executed for each step of the simulation and most of the necessary interaction parameters can be found in literature. However, the model has been criticized for being oversimplified and only accurate for narrow composition ranges.[2, 13]

While based on a similar approach of describing multi-component slags with binary interaction parameters, Gaye's model is more complex and considered to give better results.[2, 13] Depending on the execution speed for the necessary equations in Matlab it may however be too complex to be evaluated for each iteration. As with Ban-Ya's model both the necessary equations and most interaction parameters can be accessed through literature.

Both models will be implemented and compared to equilibria calculated using Factsage for the composition ranges relevant for the EAF model. Apart from accuracy, the execution speed within the model will have to be evaluated.

Another approach under consideration is storing equilibrium data for the necessary ranges of composition and temperature. This data would then be accessed from within the simulation without the need to execute the calculation for each iteration. This would allow for a more time-consuming method to be used for calculating the equilibrium conditions. To store and access the pre-calculated thermochemical data without the need for excessive storage capacity and time the

system suggested by Zietsman could potentially be applied.[15] In its current state the published system for storing and evaluating the equilibrium data through graphic representation has only been applied to ternary systems. However it is planned to further develop the method and potentially apply it to the presented EAF model.

Parameter Optimization

The process of readjusting model parameters when applying the model to different furnaces or operating conditions, or after changes to the model have been made, can be quite time consuming and requires extensive knowledge about the model. To reduce both time and necessary knowledge, an algorithm that will automatically adjust parameters and evaluate the simulation results in comparison to plant data has been developed.

After selecting the parameters to be adjusted and the allowed range for each parameter, a combination of a genetic algorithm and local optimization is used to search for the optimal set of parameters within the given range. The quality of a solution is rated by the mean squared error between selected results calculated by the model and plant data. The genetic algorithm generates new sets of parameters in different areas of the search-space, retaining and modifying the best solutions from the previous generation, while the local optimization allows for efficient and directional searches in the vicinity of a promising solution generated by the genetic algorithm.

While the model with its non-linear behaviour and the large number of necessary parameters have proven to be too complex for global optimization, the algorithm has been useful in optimizing isolated aspects of the model and finding inconsistencies in the implementation and the use of certain parameters. Currently its use still requires significant knowledge of both the model and the algorithm. Therefore, further development is necessary, but there may be potential to accelerate the process of parameterization.

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