Mathematical Modelling of Converter and Ladle Processes

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Introduction
As the steel producers are striving for shorter lead-times, higher productivity and higher agility of production, the requirements for the operating practices of unit processes have increased. With the help of modern reaction models, the amount of experimental work required to design new production practices can be decreased.

The focus of this work was to develop phenomena-based simulators for the Argon-Oxygen Decarburization (AOD) and Composition Adjustment by Sealed argon blowing (CAS-OB) processes. Here, an approach based on the Law of Mass Action was employed for thermodynamically consistent treatment of parallel mass transfer controlled reactions [1]. The reaction rates (kg/m²) are described as follows:

\[ \dot{R} = k_a \left( \sum_{i=1}^{n} N_i^a - \sum_{i=1}^{n} N_i^b \right) \]

where \( k_a \), \( a \), and \( K \) denote the forward reaction rate coefficient, the activity and the equilibrium constant, respectively. The value of the forward reaction rate coefficient is adjusted so that it forces the reaction interface into mass transfer controlled thermodynamic equilibrium. The accuracy of the method can be controlled by permitting a predefined small error either in the Gibbs free energy (residual affinity method) [1] or in the reaction quotient (reaction quotient method) [2].

CAS-OB Simulator
The CAS-OB process is the most common process for refining of stainless steel. Modern vessels employ both top- and side-injection of gases (Figure 1). The aim of this work was to create a fast phenomena-based simulator, which can predict the dynamic changes in the compositions and temperatures of the steel, slag and gas phases.

The simulator detects the simulated process stages automatically and chooses the required modules as shown in Figure 2. The mathematical model for side-blowing assumes that the reactions take place in the gas plume, which is modelled as a three-phase plug flow reactor [3,4]. Reactions between the top-blown gas jet and the steel bath are assumed to take place simultaneously on the cavity caused by the dynamic pressure of the gas jet and on the metal droplets caused by the shear force of the gas jet [2,5]. An example of the prediction accuracy of the top-blowing model is shown in Figure 3. The mathematical description of the reduction stage is based on the assumption that the reactions take place between steel bath and slag droplets [6]. Also this model has been validated with good results [7].

CAS-OB process simulator is currently divided into two parts: the heating stage model [8] and the reduction stage model [9]. In heating stage, the steel bath is heated chemically by oxidising aluminium with pure oxygen jet inside a bell structure [3,8]. The heat and mass transfer coefficients of the jet were determined by Computational Fluid Dynamics (CFD) simulations [9]. A CFD simulation case is presented in Figure 4. Chemical reactions are solved inside the bell, heat and mass transfer also in the ladle. Computational nodes are presented in Figure 5. Validation and refinement of the heating model are in progress; preliminary results for heat-up are shown in Figure 6.

The reduction stage model considers reactions and heat transfer during slag reduction which is carried out after the heating stage [9]. The construction of the reduction stage model was preceded by the development of the CFD model for the generation of slag droplets during bottom blowing [11]. Validation results of the model and heat consumption predicted by the model are presented in Figures 7 and 8, respectively.

References