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Modelling of a DR Shaft Operated with Pure Hydrogen Using a Physical-Chemical and CFD Approach

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Abstract

In an effort to develop breakthrough technologies which enable drastic reduction in CO_2 emissions from steel industry (ULCOS project), the reduction of iron ore by pure hydrogen in a Direct Reduction shaft furnace was investigated. After experimental and modelling studies, a 2D, axisymmetrical steady-state model called REDUCTOR was developed to simulate a counter-current moving bed reactor in which hematite pellets are reduced by pure hydrogen. This model is based on the numerical solution, by finite volume method, of the governing equations, including continuity and local mass, energy and momentum balances of the gas and solid species. A single-pellet sub-model was included in the furnace model to simulate the successive reactions ($Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$) involved in the process, using the concept of additive reaction times. The different steps of mass transport and possible iron sintering at the grain scale were accounted for. The kinetic parameters were derived from reduction experiments carried out in a thermobalance furnace, at different conditions, using small Fe_2O_3 cubes shaped from industrial pellets. The results were extrapolated to full-size pellets taking into account the size and shape effects. Solid characterizations (SEM, X-Ray diffraction, Mössbauer spectrometry, pycnometry and mercury porosimetry) were also carried out to further understand the microstrutural evolution. The current version of REDUCTOR is suited to the reduction with pure hydrogen, but an extension of the model to CO is planned so that it will also be adapted to the simulation and optimisation of the current DR processes. First results have shown that the use of hydrogen accelerates the reduction in comparison to CO reaction, making it possible to design a hydrogen-operated shaft reactor quite smaller than current MIDREX and HYL.

Keywords: Direct reduction, hydrogen, shaft furnace, kinetics, mathematical model.