Chemical Engineering Dissertation Defense

Modeling and Simulation of Ironmaking using Hydrogen on Laboratory Scale, Pilot Scale, and Industrial Scale

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Abstract

The ironmaking process involves the removal of oxygen atoms from the iron oxides to produce iron. Currently, the coal/coke-based blast furnace process dominates the industry with a 71% share of global steel production, making it responsible for 25% of total global industrial CO_2 emissions. Several processes have been commercialized to reduce these CO_2 emissions such as the direct reduction process which utilizes natural gas for energy and reducing agent. In the last few decades, H_2 has been identified as an alternative reducing agent in place of coal and reformed natural gas for decarbonizing the ironmaking process.

To commercialize the H_2 direct reduction (H2DR) process, it is necessary to study this process on a laboratory, pilot, and industrial scale to identify and address the roadblocks in the path of commercialization. Based on the literature review performed in this dissertation, four knowledge gaps were identified, and hypotheses were formulated to address the same.

First, a numerical model was developed for a single iron ore pellet reduction process with a dynamic porosity function, and it was validated using experiments.

Second, the equation of the radius of pellet was derived as a function of the degree of reduction using experimental data to account for the shrinking and swelling.

Third, a numerical model was developed for a pilot scale H2DR reactor and was validated for average metallization of the pellets at the reactor outlet and the internal temperature profile in the reduction zone.

Fourth, the numerical model for the pilot scale H2DR reactor showed a gradient of metallization at the outlet boundary which was validated by experimental metallization analysis of 31 randomly selected pellet samples one by one.

At the end of the dissertation, the pilot scale model of the H2DR reactor was scaled up to an industrial scale with a DRI production capacity of 2.38 million tons/year approximately. The mass balance obtained from the industrial scale model was used to perform the techno-economic analysis to determine the economic implications of shifting from a 100% natural gas operation to a 100% H_2 operation on an industrial scale.

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