Reaction Kinetics Modeling on Hydrogen Co-firing in Natural Gas Horizontal Firetube Boilers for Steelmaking Industry Applications

Kwangkook Jeong[1], Jaedal Lee[2], Michele Vachon[3], Roy McCann[4]

[1] Mechanical Engineering, Arkansas State University, Jonesboro, AR, USA

[2] POSCO Research Institute of Industrial Science & Technology, Pohang, South Korea

[3] Big River Steel, Osceola, AR, USA

[4] Electrical Engineering, University of Arkansas, Fayetteville, AR, USA

Abstract:

The steelmaking industries have used hydrogen gas, natural gas, and by-product fuel gas in their combustion boilers for their redox cleaning, galvanizing, and batch annealing furnace processes, etc. As a baseline, a 2,200 hp horizontal firetube boiler burning natural gas at 4,053 lb/hr exhausts the combustion flue gas at 78,000 lb/hr at stack containing 13 wt% CO_2 at the full boiler load. As scaling up the estimation to the total production lines within the proximity, the annual direct CO_2 emission from the process is approximately estimated at 0.04 tons of CO_2 per ton of steel production from the cold mill process, which is responsible for up to 5.4 % of overall CO_2 emission at 0.74 metric tons of CO_2 per ton of steel production in the Unites States. Co-firing and replacement of natural gas with hydrogen gas will enable to reduce the direct CO_2 emission, and also benefit the natural gas combustion in terms of flammability and stabilization since it has wider flammability limit (3-70 % H_2 in air mixture) and higher flame speed (210 cm/s), which is five times faster than the methane's at 40 cm/s. In the full replacement case, the hydrogen demands from the proximity would be reached at least 2,127 ton per year. Moving forwards to further considerations, a modeling for the chemical reactions of co-firing hydrogen and natural gas in the combustion chamber have been carried out to investigate the chemical reaction kinetics and products, and its impact on the predictive performance and control of the facilities. The fundamental studies for the co-firing modeling have been completed in terms of combustion and thermochemistry including the first/second thermodynamic laws, stoichiometric chemical reaction equations, equilibrium products, adiabatic flame temperature, and flue gas recirculation, etc. After the model validations with the baseline boiler design data, a few cases have been attempted with variations of the hydrogen co-firing ratio and flue gas recirculation ratio to look into its impact on overall reaction and combustion performance. The modeling results are analyzed from the viewpoint of on-site steelmaking processes. A discussion of the feasibility of controlling hydrogen gas combustion using wireless sensor networks to optimize the operational conditions is provided.

Correspondence to: kjeong@astate.edu