MILD Combustion of Solid Fuels

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ABSTRACT

Moderate or Intense Low-oxygen Dilution (MILD) combustion has been identified as an innovative technology that offers ultra-low pollutant emissions, high thermal efficiency, enhanced combustion stability, thermal field uniformity, and broad fuel flexibility. MILD combustion of solid fuels has received much less attention than gaseous fuels and its burning characteristics are not well understood. As solid fuels, in particular pulverised coal, form the majority of available fuel sources, there is a need to extend understanding of the application of MILD combustion to pulverised coals. The current research seeks to investigate the MILD combustion characteristics of pulverised coals via experimental and computational approaches.

In the first stage of this work, an experimental campaign was conducted to investigate the MILD combustion characteristics of pulverised coal in a laboratory-scale self-recuperative furnace. High volatile Kingston brown coal and low volatile Bowen basin black coal with a particle size in the range of 38-180 μm were injected into the furnace using either CO_2 or N_2 as a carrier gas. The results point to major differences between the resulting 'flames' of the two coals and minor differences associated with the carrier gas in respect to pollutant emissions. Ash content analysis showed that black coal was not burnt effectively, which is thought to be due to the particle residence times being insufficient for complete combustion in the furnace.

In the next stage of this research, a comprehensive numerical investigation, using Computational Fluid Dynamics (CFD) modelling, was conducted to understand the influence of three devolatilisation models on the prediction accuracy of pulverised coal MILD combustion. It was found that the advanced chemical percolation devolatilization (CPD) devolatilization model with a three-step global kinetic mechanism gives, as expected, the best agreement with the experimental measurements for the Kingston brown coal case. While all models produced similar results for the Bowen basin black coal case.

A new vertical co-flow furnace was also designed and built for this project. The furnace contained an insulated and water-cooled central jet surrounded by a hot and

diluted co-flow. The furnace walls, as well as co-flow temperature and local oxygen concentrations, are controlled by a secondary swirling burner using non-premixed natural gas combustion. Loy-Yang brown coal from the Latrobe Valley, Victoria, Australia, with particle sizes in the range of 53-125 μm and 250-355 μm, is injected into the furnace using CO_2 as a carrier gas. The bulk jet Reynolds number was varied from Re_{jet} = 5,527 to Re_{jet} = 20,000. In-furnace temperatures and chemical species were measured together with visual observations and CH chemiluminescence (CH^*) imaging at the bottom, middle and top parts of the furnace. The CH^* signal intensity is found to be significantly lower at the top part of the furnace which is an indication of the slow rate of heterogeneous combustion of char particles. The largest amount of CO concentrations are measured for the highest jet velocity (i.e., R_{jet} = 20,000) case which implies that with increasing turbulence there is a better mixing and a broad devolatilisation zone is formed which produces more CO. The measured NO emission for any case was less than 125 ppmv (db at 3% O_2) which provide evidence to the potential benefits of MILD Combustion application to Victorian brown coal towards reducing NO emission.

Complementary CFD modelling study helped in shedding light on the flow field, turbulence intensity, volatiles' release rate, combustion of volatile matters, and overall carbon consumption inside the furnace for all cases. It was found that increasing the jet Reynolds number increases the volatiles release rates and decrease the rate of overall carbon consumption. It was also found that, for both particles' size cases, stable MILD combustion is established with a similar large recirculation vortex around the centre of the furnace. Devolatilisation starts earlier for the smaller particles' case and is completed at the end of the recirculation vortex while for the larger particles' case the devolatilisation happened post the recirculation vortex. The difference is related to the particle dispersion within the jet and differences in Stokes number.

This study provided valuable systematic data for the fundamental understanding of the MILD combustion of solid fuels. The outcomes of this research are a step forward to allow the industry to have better confidence in utilising the MILD combustion technology.

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