Ignition Characteristics of individual Pulverized Coal Particles in N₂ & CO₂ environments - Comparison with Predictions from a Flame Sheet Model

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1. Objectives & Approach

Oxy-Fuel combustion technology is considered as an appealing option for CO₂ sequestration and storage [1]. A complete understanding on coal combustion is necessary to determine and delineate the real impact of replacing N₂ with CO₂ on coal ignition and burning during oxy-fuel condition. This requires fundamental study on oxy-combustion that provides data essential for modelling oxy burners and is also necessary for a better understanding and successful commercialization of this new combustion technology. As conceptualized from the review of existing literature, this study is based on the hypothesis that, the behaviour of coal particle ignition and combustion in O₂/CO₂ environment are significantly different from the behaviour in O₂/N₂ atmosphere. The objective of this study is to compare the combustion behavior of single coal particles in N₂ and CO₂ to quantify the impact of CO₂ when substituted for N₂.

The present study involves an experimental and numerical study to characterize single coal particle burning in air and oxy-fuel environments and are detailed elsewhere [2]. Burning of a bituminous and a lignite coal in simulated air (O₂/N₂) and oxy-fuel (O₂/CO₂) conditions was examined 1800K with oxygen concentration varying from 10 to 50% by volume. The parameters like devolatilization and char combustion times of single coal particles were obtained experimentally and compared against prediction. The mechanistic explanations for the observed differences in the behaviour were explained with the help of the single particle combustion model.

2. Results and Discussion

2.1 Intensity pattern

The burnout time and particle temperature information during volatile and char particle burning can be interpreted from the statistical analysis of the intensity traces. The intensity traces obtained showed single and double peaks for both the coals depending on the operating conditions. The proportion of single peaks follows an increasing trend with oxygen concentration for both the coals and is shown in Figure 1. This can be explained by; at higher oxygen concentrations, the volatile flame sheet stays closer to the particle surface as the stoichiometry can be achieved closer to the particle. Greater access of oxygen to the char surface causes both volatile and char combustion to take place simultaneously resulting in single peak. As can be seen from the figure, the proportion of single peak is higher than double for lignite even at lower oxygen concentration which has higher volatile fraction.
2.2 Burnout times

The volatile and char burnout times for the two coals at different conditions are shown in Figure 3. The burnout times show a decreasing trend with oxygen concentration and are longer in the presence of CO₂ compared to N₂ for both the coals. The observed oxygen effect can be explained by; at higher oxygen concentration, the stoichiometry for volatile combustion can be attained closer to the particle and hence flame sheet stays closer (see Figure 2) and burns hotter imparting higher energy feedback enhancing devolatilization rate thus reducing burning time. The higher flame temperature at higher oxygen concentration increases the char burning rate through higher particle temperature. The longer devolatilization time in the presence of CO₂ is due to the lower volatile flame sheet temperature that causes lower energy feedback from the flame sheet to the particle. The lower volatile flame sheet temperature is due to higher molar heat capacity of CO₂ that has a cooling effect on the combustion heat released. Also, the oxygen diffusivity in CO₂ is lower than in N₂ mixtures. This causes higher flame stand off and also slows down the consumption rate of volatiles compared to a N₂ atmosphere. However, the durations as in air combustion can be achieved by increasing the O₂ level in the ambient gas.
2.3 Particle temperature

The effect of oxygen concentration on the burning temperature of particles can be explained by the enhanced particle heat up and increasing volatile flame sheet temperature at higher oxygen concentrations. At higher oxygen concentration, more volatiles can be burnt at once increasing the temperature and heat release. As mentioned before, lower volatile flame sheet temperature due to higher molar heat capacity and lower mass diffusivity in CO\(_2\) causes the volatile and char to burn at temperature lower than in N\(_2\). Burning temperature as in air case can be attained by increasing O\(_2\) level in CO\(_2\) mixtures as can be seen from the figures. The predicted volatile flame sheet temperature as shown in Error! Reference source not found. is the adiabatic flame temperature of model volatile methane calculated using FACTSAGE.

![Volatile flame temperature](image1)

![Char burning temperature](image2)

2.4 Comparison of measured data against predicted data

The comparison of the measured mean burnout times and the predicted data are shown in Error! Reference source not found. and Figure 4, both following the same trend of decreasing volatile combustion times with increasing oxygen concentration in the ambient gas and longer burnout times in the presence of CO\(_2\). However, the burnout times are over predicted and the difference is significant at lower oxygen concentrations. The possible reasons could be the non-spherical geometry of the particle and flame sheet, potential slip between the particle and gas, choice of model volatiles, assumption regarding the flame sheet physics, wide particle size distribution (due to inhomogeneities and uncertainties in the rate coefficients. However, the predicted trends are in good agreement with the measured trends.

3. Conclusions

The ignition behaviour of a bituminous and a lignite coal were studied under simulated air (O\(_2\)/N\(_2\)) and oxy-fuel (O\(_2\)/CO\(_2\)) environments in an optical entrained flow reactor. The volatile and char burnout times at same oxygen levels, are longer with lower particle temperature in the presence of CO\(_2\) for both the coals. The measured delay in burnout times and lowered temperature under oxy-fuel conditions is attributed to the higher specific heat capacity of CO\(_2\) and lower mass diffusivity (O\(_2\)) in CO\(_2\) mixtures. The experimental results showed that the combustion times as in air can be achieved by increasing the oxygen concentration above 21% in an O\(_2)/CO_2\) atmosphere. The single particle model based on volatiles burning in a flame sheet also predicted longer volatile and char combustion times in oxy-fuel conditions compared to air combustion. The model in its present form overestimates the combustion times and volatile flame temperatures compared to those observed in the current experimental study. However, the predicted trends are in agreement with the measured data.

References