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Effects of Moisture Content and Particle Size on Flame Stability and Nitric Oxide Emissions during Coal/Biomass Combustion under Air-Fired and Oxy-Fuel Conditions

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1. Introduction

Oxy-coal combustion is a technology that will enable carbon capture and storage (CCS) through the use of pure oxygen. To control temperatures and to act as the primary fuel carrier, flue gas is recycled back to the combustion chamber. The high concentrations of CO₂ in the recycled flue gas can retard the ignition of the coal particles, but by increasing the oxygen concentration (> 21 vol.%), ignition can be accelerated. Improved flame stability, increased temperatures and thermal efficiencies, and reduced fuel consumption and pollutant emissions are potential benefits to the combustion of coal with increased oxygen concentrations. NO_x emissions can be significantly reduced through the exchange of N₂ in the combustion air with CO₂ and recycled NO_x can reduce NO_x formation from fuel-bound nitrogen in the near burner zone. Thus, oxy-coal plants have the potential to reduce NO_x emissions below regulation level without post-combustion capture technologies. But even with this incentive, future oxy-coal plants will not contribute to renewable energy targets for regions where coal is the dominant power source.

CCS technology when applied to biomass co-firing systems can remove atmospheric CO₂ and can also further reduce criteria pollutants such as NO_x and SO_x. The CO₂ removed by the biomass during growth is not released back to the atmosphere with this technology. When introducing biomass into a coal power plant boiler, the combustion characteristics and emissions can change depending not only on the type of biomass, but also on processing such as size reduction and drying. In this work, flame stability and the dependence of NO emissions on biomass co-firing ratio, moisture content, and particle size are investigated experimentally and numerically under

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both oxy-combustion and air-fired conditions. Numerical simulations are employed to provide a detailed analysis of the combustion zone and to better understand these effects.

2. Experiment

Experiments are performed in a 35 kW combustion facility, utilizing pulverized subbituminous coal and various biomass materials. Subbituminous Powder River Basin (PRB) coal and sawdust samples obtained from a sawmill were the fuels used in this study. Batches of sawdust were prepared with different size distributions, nitrogen and moisture content. A batch of bulk sawdust, referred to as A_{bulk} was prepared by removing only particles larger than 18 mesh (1 mm). A batch of smaller particle size was prepared by sieving samples through a 50 mesh (0.3 mm) screen, and this batch is referred to as $A_{<50\text{mesh}}$. The nitrogen content in the coal was 0.97 wt% and in the sawdust was 0.15 wt%. Batches of sawdust with other nitrogen and moisture contents were also considered.

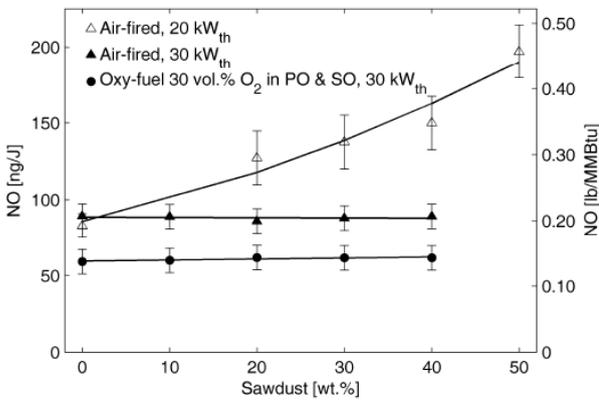


Figure 1. NO emissions vs. mass percentage of Sawdust A_{bulk} co-fired with coal, under air-fired and oxy-combustion conditions.

As shown in Figure 1, NO emissions do not scale with overall reduction in fuel-bound nitrogen. At 20 kW the co-fired flames were lifted and a subsequent increase in NO emissions is observed in Fig. 1 with increasing biomass. At 30 kW the cofired flames were stable and lift-off was not observed up to 50% sawdust. Figure 1 shows that NO emissions are relatively constant when cofiring up to 50% biomass. This indicates that nitrogen conversion to NO increases as the percentage of sawdust co-fired increases. A similar trend can be seen under oxy-combustion conditions. The overall NO emissions are seen to decrease 20%, presumably due to the lack of thermal NO.

To investigate the effects of biomass particle size on NO emissions the sieved batch of biomass $A_{<50\text{mesh}}$ was cofired with the coal and reduced NO

emissions were observed. Furthermore, studies with sawdust having a lower nitrogen content revealed that when co-firing sawdust with coal, NO formation is dependent on biomass particle size and nitrogen content. A 23% reduction in NO emissions was observed when cofiring with sieved sawdust that had an order of magnitude lower fuel-bound nitrogen than coal. No such reduction in NO emissions was observed under oxy-combustion conditions. Experiments and modeling are underway to explain this anomalous behavior.

3. Numerical

Preliminary computational fluid dynamic (CFD) results with ANSYS Fluent indicate that the relatively large size of the biomass particles is a key cause of the higher NO conversion rates when co-firing with sawdust. A slightly elongated high temperature zone is observed in the co-firing cases due to the large particle size of the biomass particles. Devolatilization and particle track behavior are also effected by the large biomass particles, which directly impact NO formation.

Biomass particles also have a high volatility, which creates a fuel-rich zone for NO destruction in the near burner zone, as shown in Figure 2. Nonetheless, for the large biomass particles that have a delayed release of volatiles these species form NO outside the fuel-rich zone and further downstream than for the case with coal only.

Numerical results also show that the particle size and moisture content of the biomass are affecting the NO formation pathways. When the characteristics of combustion for small and large sawdust particles are compared, it was found that the release of volatiles from the large particles is delayed. This delay can potentially cause the intermediate nitrogen-containing species to be released into areas of higher oxygen in the near burner region. The model also shows that larger sawdust particles, due to their high momentum, penetrate through the fuel-rich near burner zone creating a longer high temperature region. These findings explain the higher conversion rates observed under biomass cofiring conditions

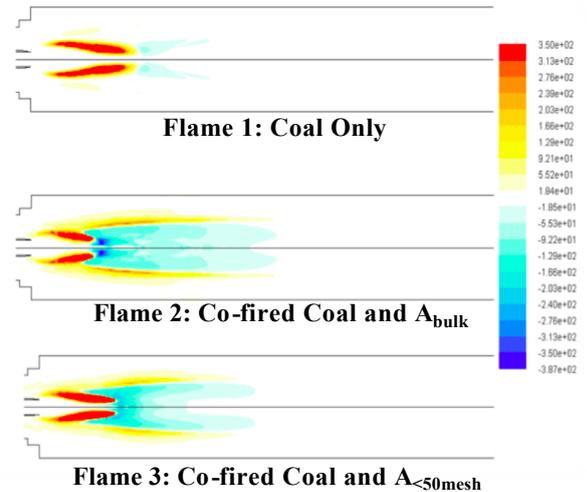


Figure 2. Rate of NO formation normalized by fuel-bound nitrogen for three flames: (1) coal only, (2) 50 wt% cofired Sawdust A_{bulk} and (3) 50 wt% cofired Sawdust $A_{<50\text{mesh}}$