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Radiative intensity, no emissions, and burnout for oxygen enriched biomass combustion

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Abstract

As concern over global climate change continues, the use of biomass as a substitute for coal is one method of reducing CO_2 emissions. One of the primary problems with utilizing biomass in boilers originally designed to burn coal is burnout. Biomass particles cannot be economically ground to the fine particle size typical of coal particles, creating a problem for particle burnout. The impact of oxygen injection in a swirl-stabilized burner on particle burnout and NO emissions was investigated by measuring NO and LOI, as well as flame characteristics, including flame imaging, flame intensity, and flame temperature. The results showed that when a low momentum flow of pure (>99%) oxygen is introduced into the center of a swirl stabilized biomass flame, an inverted diffusion flame is produced with oxygen in the center and volatiles on the outside of the flame. This high intensity center flame is surrounded by a lower intensity turbulent air/volatiles flame. This high temperature inner flame can heat incoming particles more rapidly than a conventional air flame improving burnout and flame stabilization without increasing effluent NO as long as the center flame does not extend into and disturb the fuel rich recirculation zone. Oxygen injection can therefore be used to improve burnout without increasing NO formation.

Keywords: Biomass; Oxy-enhanced combustion; NO_x; Burnout

1. Introduction

One of the most attractive solutions for reducing CO_2 emissions from coal-fired power plants is to replace a portion or all of the coal used in existing boilers with biomass. In addition to global environmental benefits, biomass is typically low in sulfur, potentially removing the need for a scrubber. Typically, biomass is used in existing boilers or co-fired with coal and therefore must be burned in the residence time of existing equipment.

There are several methods whereby oxygen has been utilized to assist in the combustion process of coal and/or biomass, which we will refer to as oxygen enhanced combustion. These include:

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oxygen added to the secondary air (oxygen assisted combustion); oxygen added to recycled flue gas (oxy-coal or oxy-fuel combustion), and; oxygen added to specific locations in and/or near the burner (oxygen enriched combustion). The focus of this work is on oxygen enriched combustion, where pure (>99%) oxygen is strategically added in relatively small fractions of the total oxidizer (25% or less) to locations in the near burner zone.

Fundamental combustion studies have been performed that provide information relevant to all types of oxygen enhanced combustion. When single coal particles are burned in elevated oxygen concentrations it has been shown that ignition temperature decreases, char oxidation temperature increases, apparent char reactivity increases, and particle burnout time decreases [1–3]. Similar results have been observed for wood particles burning in oxygen enhanced air environments where ignition delay was impacted more at lower ambient temperatures than at high temperature [4].

Most of the recent work on oxygen enhanced combustion is related to oxy-fuel combustion [5–7]. The primary objective of this form of combustion is to remove nitrogen from the product stream so that CO_2 may be captured and sequestered more easily. In oxy-fuel combustion, oxygen concentrations of 25–28% (molar) are required in retrofit applications in order to achieve similar heat flux profiles to coal combustion. Similar or lower NO_x emissions can be achieved with improved burnout. The improved burnout is attributed to the longer residence time produced by lower volumetric flow rates obtained when CO_2 rich recycled flue gas is used in place of air.

Oxygen assisted combustion has been investigated in gaseous flames [8–10]. The flame temperature was found to increase with increasing oxygen concentration. In addition to higher flame temperatures, higher NO emissions and higher radiative heat flux was measured and attributed to higher concentrations of CO_2 and H_2O [10]. The impact of oxygen on flame length is not consistent between investigators. Cheng et al. [10] reported an increase in flame length while Baukal et al. [11] and Joshi and Becker [8] found oxygen to decrease flame length. Sontos et al. [12,13] measured soot in an acetylene and natural gas flame and found that soot concentration increased, radiation increased, and NO emission decreased with increasing oxygen addition. Baukal and Gebhart [14] and Sontos et al. [12,13] concluded that non-luminous flame radiation from CO_2 and H_2O were not significant for heat transfer because the radiation produced is dominated by soot.

Oxygen enriched combustion has been investigated in only a limited number of experiments. Burners have been redesigned to accommodate oxygen injection [15], and oxygen has been added to the flame by a lance involving no modifications to the burner [16]. Oxygen injection has been investigated primarily for the potential to achieve reduced NO_x emissions, increased flame luminosity (radiant heat transfer), and to raise flame temperature. Bool and Laux [17] looked at several different oxygen injection strategies and reported a method of producing lower NO_x and improved burnout. They concluded that an oxygen lance designed to produce low mixing located in the center of the burner could help to stabilize a flame, create a NO_x reduction region, and improve carbon burnout.

The potential for oxygen injection to simultaneously stabilize a flame, reduce NO emissions, and improve burnout are worthy of additional investigation, particularly if this can be done with small (economical) amounts of oxygen addition to improve the burnout of biomass. The objective of the current work is to measure the impacts of oxygen injection (less than 25% of the total oxidizer flow) on burnout, NO, radiant intensity, and flame shape for two sizes of hardwood biomass in a swirled burner. These combustion performance parameters will be measured over a matrix of oxygen injection locations and flow rates to establish trends useful for oxygen injection strategies.

2. Experimental setup and methods

A nominal 150 kW_{th}, down-fired, Burner Flow Reactor (BFR) was used in conjunction with a burner designed and manufactured by Air Liquide. The BFR has a height of 2.4 m, an inside diameter of 0.75 m, and consists of six vertical, 0.4 m sections. Each of these sections has four access ports, positioned 90 degrees apart. The burner was mounted at the top with exhaust exiting the bottom.

Two hardwood biomass fuels were used with proximate and ultimate analyses shown in Table 1.

Table 1
Proximate and ultimate analysis (as received), heating value, and particle size of the biomass fuels.

	Small Particles	Medium Particles
Proximate (as received, wt.%)		
Moisture	5.83	5.28
Ash	0.54	0.30
Volatile	76.42	79.06
Carbon	17.21	15.36
Ultimate (as received, wt.%)		
H	5.36	5.40
C	49.87	49.85
N	0.32	0.26
S	0.10	0.09
O	37.98	38.82
HHV (kJ/kg)	17,638	17,463
Mean Size (μm)	224	500