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The effect of wood biomass blending with pulverized coal on combustion characteristics under oxy-fuel condition

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ABSTRACT

In this study, combustion from the co-firing of coal and wood biomass, and thermal characteristics such as ignition temperature, burn-out temperature, and activation energy were discussed using a thermogravimetric analyzer (TGA). We investigated the effects of biomass blending with two kinds of pulverized coal (bituminous Shenhua, and sub-bituminous Adaro) under air and oxy-fuel conditions. The coal fraction in the blended samples was set to 1, 0.8, and 0.5. The oxygen fraction in the oxidant was set to 0.21, 0.3, 0.5, and 0.8. The ignition temperature was governed by the fuel composition, particularly in the blended biomass which has a much higher content of volatile matter comparing to coal. However, the burnout temperature, which shows a strong relationship with char combustion, depended on the oxidant ingredients rather than on the fuel components. Thermal characteristics such as ignition, burnout temperature, reaction region, and heat flow were very similar between air and a 0.3 oxygen concentration under oxy-fuel conditions with Shenhua coal.

1. Introduction

The consumption and price of coal have increased concomitantly with global economic growth. Coal cost is a very sensitive problem for most Korean power plants because of their dependence on imported bituminous or sub-bituminous coal. In addition, the use of coal can be problematic because of the global warming problem. The co-firing of fuel blended with wood biomass, which is presently considered an alternative fuel, is a promising technique for fuel price stabilization and mitigation of the global warming problem. Wood biomass is low in cost and renewable, as well as a carbon dioxide-free fuel that contains a low amount of sulfur. Further, we expect that the alkali matter in the biomass will remove SO_2, and its nitrogen content will aid NO reduction by transfer to an NH radical [1–7].

Because wood biomass is currently the best alternative fuel, many researchers have investigated the co-firing characteristics of wood biomass and coal with respect to application in existing power plants with restricted retrofits. Wood biomass fuels can cause flame instability because of their low heating values, based on the large quantity of volatile matter in the biomass, and the low melting temperature of ash, which thereby leads to slagging and fouling. Therefore, the blending rate is controlled very carefully in power plants. However, the released volatile matter and the oxygen component in biomass

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Nomenclature

T_i	ignition temperature, K
T_m	DTG peak temperature of char, K
T_b	burnout temperature, K
C_{fr}	mass fraction of coal in blended sample
O_{fr}	oxygen fraction in oxidant

lead to a low ignition temperatures, and activation energies, and also affect char combustion [8–11].

The combustion of fossil fuels for power generation is a main contributor to greenhouse gas (GHG) emissions, and various studies have been conducted to address this problem. Power plants that use pulverized coal, which produces considerable GHG emissions, are considering carbon dioxide capture systems as a solution. The capture is difficult and the efficiency is low because existing combustion systems include about 15% CO_2 in the exhaust gas when air is used as an oxidant [12–14]. Oxy-fuel combustion technology uses carbon dioxide instead of nitrogen for efficient CO_2 capture. The CO_2 in the recirculated flue gas is used as an oxidant, and the concentration of CO_2 is continuously increased in the exhaust gas, which is mainly composed of CO_2 and H_2O. The CO_2 also controls the flame temperature and carries the generated heat to the walls of the boiler. In addition, the NOx in the flue gas in an oxy-fuel system is reduced due to the absence of nitrogen, and the de-NOx mechanism is promoted by recirculation [15–19]. However, under the oxy-fuel conditions, the characteristics of combustion such as gas composition, temperature distribution, burning stability, and char reaction are different from the characteristics under air combustion. These characteristics are important factors in the design and operation of boilers.

The co-firing of coal with wood biomass is a high efficiency technology, and offers a potential solution to coal exhaustion and the GHG problem [20]. However, additional investigation is needed for the application of this technique in a practical oxy-fuel system. Thermogravimetric analysis (TGA) has been applied to investigate the fundamental properties of solid fuel combustion even though the technique has a relatively low heating rate compared to actual thermal power plants. A detailed fundamental understanding of the co-firing of pulverized coals with biomass could provide practical information such as ignition and burnout characteristics, and mutual interference between coal and biomass, especially in oxygen-enriched conditions.

In this study, we examined the characteristics of reaction kinetics, such as ignition and burnout temperature, that are related to flame stability, pollution, and combustion efficiency, in terms of oxidant composition and the blending ratio of two kinds of coal currently employed in Korean power plants with wood biomass (sawdust from Korean pine).

2. Experiment

2.1. *Feedstock preparation*

Coals that are used in domestic power plants – a bituminous type (Shenhua) and a sub-bituminous type (Adaro) – were employed in combination with wood biomass (pine sawdust) to investigate their co-firing characteristics under oxy-fuel conditions. Table 1 shows the ultimate and proximate analyses of the samples. The proximate analysis was carried out by thermogravimetry using a standard American Society for Testing and Materials (ASTM) analysis procedure, as follows. The sample temperature was raised to 107 °C (380 K) and maintained for 60 min to effect dehumidification. Then, the temperature was raised by 10 K/min to 950 °C (1223 K) and maintained at that temperature for 7 min under nitrogen (devolatilization). The surrounding atmosphere was then changed to air, and the temperature of the ambient was increased to 750 °C (1023 K) and retained in an isothermal state for 10 min for char and ash analysis. The ultimate analysis of the wood biomass was carried out using an Elementar Analysen systeme (KBSI Busan Center, Korea). Ultimate analyses of the coal samples were provided by the thermal power company.

The heating value of Adaro coal was lower than that of Shenhua coal due to a larger amount of highly volatile matter, a lower carbon content, and in particular, a higher moisture content. These different properties of each coal affect the reaction characteristics of fuel combustion. The wood biomass had a lower fuel rank than the sub-bituminous coal, and its heating value was also much lower compared to that of the coals, based on its high volatile matter and low carbon content. A high proportion of inherent volatile matter induces the prompt combustion of fuels and can promote carbon combustion in a short time. The small quantity of carbon in these low rank fuels is favorable for the complete combustion of carbon. However, this substandard situation cannot generate enough thermal potential for power generation. As these characteristics make blending difficult for co-firing industrially, detailed blending effects must be investigated to safely apply this material in existing boiler systems.

The moisture contents of the fuels were controlled through solar drying and equilibration under laboratory conditions. The coal fractions in the blends and oxygen fraction in the oxidant were designated as C_{fr} and O_{fr}, respectively. Individual coal was blended with the biomass in proportions of 80% and 50% on a weight basis (C_{fr} = 0.8 and 0.5). Oxygen fraction conditions of O_{fr} = 0.21, 0.3, 0.5, and 0.8 were selected.

Table 1 – Proximate and ultimate analysis of feedstock.

Fuel	Adaro	Shenhua	Biomass
Proximate analysis (wt %)			
Volatile matter	40.95	32.17	81.77
Fixed carbon	42.01	54.21	9.71
Ash	2.82	7.24	0.1
Moisture	14.23	6.39	8.42
Ultimate analysis (wt %)			
C	71.20	75.90	48.45
H	5.27	4.81	6.27
N	1.28	1.40	0.14
S	0.03	0.00	0.11
O	18.93	10.15	43.53
Ash	3.29	7.73	1.5
Low heating value (kcal/kg)			
	4901	5913	4370