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Emission characteristics of co-combustion of a low calorie and high-sulfur-lignite coal and woodchips in a circulating fluidized bed combustor: Part 2. Effect of secondary air and its location

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HIGHLIGHTS

- Secondary air caused the combustor to have two different hydrodynamic regions.
- Increasing secondary air ratio lowered the recirculation rate.
- Secondary air increased CO and SO_2 emissions and decreased NO emission slightly.
- NO emission was under the emission limits for all cases of secondary air ratios.
- Limestone addition was required to lower SO_2 emission below the limit.

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ABSTRACT

In this study, co-combustion of woodchips and Bursa–Orhaneli lignite was carried out in a circulating fluidized bed combustor, 6 m long and 108 mm inside diameter. Co-combustion of lignite and woodchips was performed in order to investigate the effect of secondary air ratio (SAR) on the flue gas emissions. The woodchips content of the fuel mixture was 30% and 50% by wt. Secondary air (SA) was supplied to the combustor from five different locations along the combustor and at several SARs. During the combustion experiments, CO_2, CO, O_2, NO, and SO_2 emissions in the flue gas were continuously measured and recorded by ABB-AO 2000 flue gas analyzer.

Increasing SAR lowered the recirculation rate which was followed by an increase in temperature of the dense phase and a decrease in the temperature of the dilute phase in the combustor. CO emissions were increased for the co-combustion of 30% by wt. woodchips and lignite, and for SAR greater than 15%. Increasing SAR caused cyclone outlet temperature to decrease and this indirectly increased the CO emissions. NO emission decreased with increasing SAR. It was observed that the location of SA given into the combustor had a distinctive effect on NO emission especially for SA higher than 15% for the co-combustion of 30% by wt. woodchips with lignite coal. NO emissions increased with the increase in woodchips share in fuel mixture. While SO_2 emissions increased with SAR in all cases for the co-combustion of 30% by wt. woodchips, they did not change too much with SAR up to 20% for the co-combustion of 50% by wt. woodchips with coal.

1. Introduction

It is very important to use national and renewable energy sources in energy production in terms of energy security and global warming. 118 countries specified their renewable energy targets by early 2012 [1]. European Union has a target of 20% share for renewables in the EU energy mix by 2020 [2]. Among the renewable energy sources, solid biofuels take the lead with 9% of the world's total primary energy supply (12,782 Mtoe) and 69% of the total renewable energy sources [3]. Co-firing of biofuels with coals is one of the most economical ways to achieve CO_2 reduction [4]. It is also an efficient way of disposing biowastes. Among the combustion technologies, fluidized bed technology is a promising

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one for the combustion of biomass resources because of its fuel flexibility, good mixing of fuel and air, high heat and mass transfer characteristics, high efficiency of combustion and easy operation.

Turkey has a high biomass potential (32 Mtoe [5]) but this potential cannot be used efficiently for the energy demand of the country with conventional combustion technologies. On the other hand, Turkey is rich in lignite resources. However, these lignites generally have high sulfur and ash content. Turkey imports 72% of its total primary energy [6]. Energy demand is increasing every year because of economic growth rate on the average of 6%/year in the period of 2002–2011 [7]. Therefore, it will be wise to use lignite and biomass sources in energy production because biomass combustion is considered to be CO_2 neutral.

There are several studies in the literature investigating the effect of operational parameters such as secondary air (SA) on the combustion efficiency and air pollutants for the combustion and co-combustion of solid fuels. Lyngfelt and Leckner [8] studied the effect of temperature and air-staging on CO and NO emissions for the combustion of woodchips in a 12 MW circulating fluidized bed boiler. They tested SA addition in the cyclone outlet in combination with SA addition in the cyclone inlet and/or at 2.2 m height for three loads. They achieved a significant NO reduction without high CO emissions. They also found that increasing temperature of cyclone outlet had a decreasing effect on CO emissions. In 2000, Piao et al. [9] studied the combustion characteristics of two types of refuse derived fuel (RDF) in a bubbling fluidized bed combustor. They stated that SA addition decreased both CO and NO emissions for both types of RDFs. Suksankraisorn et al. [10] investigated the effect of mass fraction of municipal solid waste in fuel mixture, excess air and SA on emissions and combustion characteristics for the co-combustion of municipal solid waste and Thai lignite in a laboratory scale bubbling fluidized bed. They showed that NO emissions decreased by the increase in secondary air ratio (SAR). Ersoy et al. [11] studied the effect of SA on the hydrodynamics of circulating fluidized beds. A 0.23-m ID combustor was used for tests and it was stated that injection of SA divided the combustor into two flow zones: a dense turbulent zone below and a relatively dilute zone above the injection port. Xie et al. [12] performed a study to see the influence of excess air, air staging, biomass share and feeding position of fuel on SO_2, NO and N_2O emissions in a bench scale circulating fluidized bed combustor for a bituminous coal combustion and co-combustion of coal and rice husk. They reported that air-staging decreased NO emission without an increase in SO_2 emission. Zhu et al. [13] introduced high temperature air from a circulating fluidized bed combustor into the down-fired combustor and studied the effect of residence time, excess air, furnace temperature, oxygen concentration in high temperature air and air-staging on NO emission for the combustion of pulverized coal. They stated that air-staging with high temperature air had a reducing effect on nitrogen oxide emission. Li et al. [14] investigated the effect of SA on combustion performance of a 300 MW_e down-fired boiler. An anthracite coal was used for the experiments. The modification of the boiler consisted of injection of SA with an angle of declination of 25°. It was concluded that the modification on the system lowered the NO_x emissions and the carbon content in the fly ash. Munir et al. [15] performed co-combustion tests of pulverized Russian coal with different biomasses such as shea meal (SM), cotton stalk (CS), sugarcane bagasse (SB_T), sugarcane bagasse (SB_R) and woodchips (WC) in order to see the effect of air-staging on NO_x emission and combustion efficiency. A 20 kW down-fired combustor was used and the biomass shares in fuel mixture were determined to be 5%, 10% and 15% by thermal power. It was found that biomass addition had a positive impact on carbon burnout and NO reduction under optimum conditions. 10% of biomass addition was suggested in terms of NO reduction. Kuprianov et al. [16] studied air-staged combustion of rice husk in a swirling fluidized-bed combustor. While the effect of SA on CO and NO emissions was found to be weak, the effect of SA on C_xH_y emissions was apparent. Saikaew et al. [17] studied NO_x and N_2O emissions for the co-combustion of sub-bituminous coal with four biomasses, palm shell, coconut shell, sawdust and rice husk in a circulating fluidized bed combustor (CFBC). They stated that biomass addition in fuel mixture cause NO_x and N_2O emissions to decrease and they presented that the location of SA had an influence on NO_x and N_2O emissions. SA was introduced into the combustor (Height: 3 m, ID: 0.1 m) from three different locations; 1 m, 2 m, and 2.4 m above the distributor plate. For the case of coal combustion, it was observed that NO_x and N_2O emissions decreased when the location of SA moved upward from 1 m to 2.4 m. The decrease on NO_x (from 235 ppm to 195 ppm) emissions was explained by the excess air promoting fuel-nitrogen oxidation in the high temperature region of the combustor when it was given at 1 m. When it was injected from 2.4 m, the effect of excess air on the fuel-nitrogen oxidation did not seem too much due to the lower temperature in the upper part of the combustor.

Although there are several studies as to the effect of operational parameters on emissions in the literature, a limited number of studies concerning co-combustion of biomass and Turkish lignites in fluidized bed combustors are noticeable. Effects of operational parameters such as SAR on flue gas emissions for the case of co-firing Turkish lignite and biomass resources, have not been studied in circulating fluidized bed combustors in a detailed manner. Therefore, in this study co-combustion of Bursa–Orhaneli lignite with 30% and 50% by wt. woodchips in a circulating fluidized bed combustor was carried out in order to investigate the effect of SA and its location on flue gas emissions. Although there is no emission limits in the Turkish regulation for a laboratory scale CFBC system, the flue gas emissions, CO, NO, and SO_2 emissions were compared to the emission limits of larger systems specified by the Turkish regulation [18] and Directive 2001/08/EC of the European Parliament and of the Council of 23 October 2001 (EU Directive) [19] for the purpose of scale-up.

2. Materials and methods

2.1. Characteristics of fuels

Bursa–Orhaneli lignite and woodchips were used in this study. ''Woodchips'' refers to the Rhododendron genus of woody plants in Ericaceae family which mainly grows in the Black Sea region of Turkey. Proximate and ultimate analyses of Bursa–Orhaneli lignite and woodchips are given in Table 1. In all combustion tests, 1–2 mm of fuel particles were used. Two co-combustion tests were conducted in a laboratory-scaled circulating fluidized bed

Table 1
Proximate and ultimate analysis of Bursa–Orhaneli lignite and woodchips.

Proximate analysis	FC	VM	Ash	Moisture	HHV	LHV
	%, by wt. (as fired)				kJ/kg (as fired)	
Bursa–Orhaneli	30.83	36.21	14.83	18.13	17,745	17,197
Woodchips	16.55	71.55	1.99	9.91	17,501	16,161

Ultimate analysis	C	H	N	O	$S_{combustible}$	S_{total}	Ash
	%, by wt. (dry basis)						
Bursa–Orhaneli	65.28	5.30	0.92	9.33	1.06	2.38	18.11
Woodchips	52.20	5.79	0.03	39.43	0.34	0.40	2.21

FC: Fixed Carbon, VM: Volatile Matter, HHV: Higher Heating Value, LHV: Lower Heating Value.