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Emissions during co-firing of RDF-5 with bituminous coal, paper sludge and waste tires in a commercial circulating fluidized bed co-generation boiler

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Abstract

Biomass fuel is the largest renewable energy resource and the fourth largest primary energy supply in the world. Because of its complex characteristics when compared to fossil fuel, potential problems, such as combustion system stability, the corrosion of heat transfer tubes, the qualities of the ash, and the emission of pollutants, are major concerns when co-firing the biomass fuel with fossil fuel in a traditional boiler. In this study, co-firing of coal with a biomass blend, including fuel derived from densified refuse, sludge, and waste tires, were conducted in a 130 ton/h steam circulating fluidized bed co-generation boiler to investigate the feasibility of utilizing biomass as a complemental fuel in a traditional commercial coal-fired boiler. The properties of the fly ash, bottom ash, and the emission of pollutants for various fuel ratios are analyzed and discussed in this study.

Keywords: Biomass; Co-firing; Circulating fluidized bed; Pollution emission; Densified refuse derived fuel (d-RDF or RDF-5)

1. Introduction

The co-firing of biomass and fossil fuel in the same power plant is one of the most important issues when promoting the utilization of renewable energy in Taiwan. According to the draft of the Taiwanese Renewable Energy Development Act, biomass energy is defined as the energy produced by utilizing or processing agricultural crops and forest plants, biogas, municipal solid waste (MSW), agricultural wastes, and general industrial wastes, etc.

Recently, the co-firing of fossil fuel together with biomass fuel, such as "densified refuse derived fuel" (d-RDF or RDF-5) or RPF (refuse paper & plastic fuel) from waste, has been considered as an environmentally sound and economical approach to both waste remediation and energy production [1]. A large number of beneficial engineering tests have been performed in order to understand the characteristics of emissions and ash by burning RDF-5 as fuel in mass burn or fluidized bed combustion systems [2–6].

Chang et al. [4] evaluated the comparative effects by burning MSW and RDF-5 in the same small scale modular incinerator. It appeared that the combustion of RDF-5 presented a relatively better performance in several aspects, including heat balance, ash property, and the quality of flue gas.

Fluidized bed combustors (FBC) constitute one of most important technologies used in the co-firing process [7–9]. Hupa [10] reviewed several of the interactions of various fuels in various FBCs and found that factors such as flue gas emissions, fouling tendency or bed-sintering tendency seldom revealed a simple linear function of the fuel mixture. Rather, non-linear relationships were often the norms in these cases.

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Generally, the ability to use a variety of fuels as feedstock and the resulting low pollution emissions are two of the more significant advantages of using circulating fluidized bed (CFB) combustion technology. However, the interaction between the emission of hazardous gas, such as sulfur dioxide, nitrogen oxide and chloride while co-firing of coal and biomass in a CFB is still an interesting issue.

Ducarne et al. [11] conducted co-firing of coal and MSW in a CFB. The results indicated that the acid flue gas increased as the proportion of MSW increased, and, furthermore, the SOx decreased as the amount of HCl in the flue gas increased. The main points identified by Liang et al. [12] showed that a large variation of chloride capture was displayed depending on temperature, moving from a low of 18% gaseous HCl at 700 °C to 99% at 950 °C. Liu et al. [13] found that HCl could be removed by adding an additional amount of CaO, which then reacted with the chlorine and produced $CaCl_2$. In an FBC system, it was determined that the temperature was a critical parameter in this reaction. The authors suggested that 650 °C was the optimal temperature for maximum HCl capture. They also evaluated the HCl removal capability of $Ca(OH)_2$ by measuring the fraction of HCl emissions in the flue gas.

There were several factors affecting the emission of dioxins from the combustion sources, including dioxins in the feed, precursors in the feed, chlorine in the feed, combustion temperature, residence time, oxygen availability, feed processing, and supplemental fuel [14]. McKay [14] published a comprehensive and intimate survey of dioxin characterization and formation during MSW incineration. To remove dioxins using end-of pipe treatment systems, flue gas quenching, semi-dry lime scrubbing and bag filtration coupled with activated carbon injection adsorption were all helpful in the prevention or minimization of dioxins in the final emission of flue gases into the atmosphere.

In this study, RDF-5 composed of paper rejects was co-fired with coal in a CFB boiler in order to investigate the feasibility of burning RDF-5 in a commercial coal-fired boiler. The properties of the fly ash, bottom ash, and the emission of pollutants for various fuel ratios are analyzed and discussed in this study.

2. Experiment and apparatus

2.1. The circulating fluidized bed boiler (CFBB)

All experimental investigations were conducted using a 130 ton/h (538 °C @140 kg/cm^2) atmospheric circulating fluidized bed co-generation boiler (CFBB). The co-generation plant designed and manufactured by Foster Wheeler Corporation has a thermal output of 103 MWth and an electric capacity of 27 MW. The plant consists of a furnace with a windbox, a hot cyclone recycle system, risers, a loop-seal, a fuel feeding system, an air supply system, heat convection sections, including superheater, economizer, and air preheater, a flue gas treatment system, and an electricity generation system, etc.

The fluidized bed furnace is 25 m in height with a rectangular cross-section of 3.8×7.7 m. The fuel feeding system employs the over-bed feeding of fuel, including coal, waste tires and a mixture of paper sludge and RDF-5. The combustion air is divided into two streams. The primary air is pre-heated at 150 °C and is used as fluidization gas through the gas distributor above the windbox. The secondary air, pre-heated to 130 °C for complete combustion, is injected to sites arranged at two levels above the distributor. Additionally, the operating temperatures of the bed, the freeboard outlet, and the hot cyclone outlet were around 880, 980, and 1000 °C, respectively.

2.2. Fuels and bed materials

A fuel blend composed of bituminous coal, paper sludge, waste tires, and RDF-5 was employed as feedstock for the CFBB used in this study. The paper sludge was collected from the wastewater treatment facility at a paper mill plant. The waste tires were shredded into pieces prior to the feed. The RDF-5 or RPF was composed of paper rejects following processing by shredding, magnetic separation, drying, air separation, and pelletizing. The analytical data for the four fuels used in this study are listed in Table 1.

As the heat transfer and mass transfer in CFB are strongly affected by the bed material, selecting a suitable carrying medium is extremely significant. In order to match the original design of the CFBB, silica sand with a mean diameter of 0.180 mm was chosen as the carrying medium. In addition, the bed material also consisted of a minor quantity of the fuel ash remaining in the bed after combustion.

2.3. Operating conditions

The operating conditions used in this study are summarized in Table 2, in which the co-firing ratio means the pro-

Table 1
The proximate and ultimate analyses of fuels used in this study

Property	Coal	Waste tires	Paper sludge	RDF-5
Proximate analysis (wt%)				
Moisture	5.20	4.03	63.47	4.50
Ash	4.18	8.16	10.22	6.37
Volatiles	46.31	63.82	21.88	81.17
Fixed carbon	44.30	23.99	4.43	7.97
LHV(kcal/kg)	4978	8070	607	5703
Ultimate analysis (wt%)				
Carbon	53.31	76.70	8.75	45.98
Hydrogen	5.13	5.76	1.25	6.43
Oxygen	29.96	2.73	15.73	34.55
Nitrogen	1.27	0.36	0.35	0.25
Sulfur	0.90	2.17	0.22	1.08
Chlorine	0.06	0.09	0.02	0.85