Bioresource Technology 100 (2009) 2278–2283

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Combustion characteristics and NO formation for biomass blends in a 35-ton-per-hour travelling grate utility boiler

Zhengqi Li *, Wei Zhao, Ruiyang Li, Zhenwang Wang, Yuan Li, Guangbo Zhao

School of Energy Science and Engineering, Harbin Institute of Technology, 92 West Dazhi Street, Heilongjiang, Harbin 150001, PR China

ARTICLE INFO

Article history:
Received 20 August 2008
Received in revised form 1 November 2008
Accepted 11 November 2008
Available online 16 December 2008

Keywords:
Biomass
Combustion
Travelling grate
Ash
NO

ABSTRACT

Measurements were taken for a 35-ton-per-hour biomass-fired travelling grate boiler. Local mean concentrations of O_2, CO, SO_2 and NO gas species and gas temperatures were determined in the region above the grate. For a 28-ton-per-hour load, the mass ratios of biomass fly ash and boiler slag were 42% and 58%, the boiler efficiency was 81.56%, and the concentrations of NO_x and SO_2 at 6% O_2 were 257 and 84 mg/m^3. For an 18-ton-per-hour load, the fuel burning zone was nearer to the inlet than it was for the 28-ton-per-hour load, and the contents of CO and NO in the fuel burning zone above the grate were lower.

1. Introduction

With the present major worldwide agenda to reduce greenhouse gas emissions, there is an emphasis on using conventional coal-fired utilities to burn renewable fuels such as biomass residues or energy crop-derived biomass fuels as a low-cost option for reducing greenhouse gas emissions (Peter, 2002; Matti, 2004). The need for finding new renewable sources of energy together with the necessity of searching for new technologies to reduce the negative impact of waste accumulation has led to the possibility of using biomass as an alternate fuel (Leung et al., 2004; Adnan et al., 2006; Demirbas and Bala, 2006). Combustion of biomass such as wood and straw in a fixed bed in the laboratory has been well studied (Saastanainen and Taipale, 2000; Van der Lans et al., 2000; Yang et al., 2004; Thunman and Leckner, 2005; Zhou et al., 2005, 2006; Li et al., 2008a; Zhao et al., 2008a, b). However, few detailed measurements have been performed in utility boilers. Most of the industrial pollution in China comes from coal-fired power plants and thus it is necessary to find ways to decrease the greenhouse gas emissions from these sources (Sun, 2004). One of the options that need to be considered is the application of biomass direct-combustion technologies to coal-fired power plants.

A 35-ton-per-hour (tph) coal-fired travelling grate boiler in the Lanxi coal-fired power plant has been retrofitted to co-fire biomass. In this study, data were recorded for local mean concentrations of O_2, CO, and NO, and gas temperatures in the region above the grate. The method for calculating the mass ratio of the biomass fly ash and boiler slag is presented. The NO_x and O_2 contents were measured in the flue gas and the boiler efficiency determined.

2. Utility boiler

A 35-tph travelling grate coal-fired boiler in the Lanxi power plant is used for electricity and heat supply. The boiler has operated since 1986. No flue gas cleaning method exists, except for using a multitubular cyclone. The main parameters of the boiler are shown in Table 1.

The bulk density of biomass fuel blends (forestry waste, such as cortex and wood blocks) was 265 kg/m^3, and the angle of repose was 46°. Table 2 shows the proximate and ultimate analyses of the biomass blends. The moisture content (as received basis) was 40%. The volatility of the biomass blends was quite high. The gross calorific value was low and only amounted to half the designed coal gross calorific value. Nitrogen and sulphur contents were low.

After biomass blends were burned, the fuel mass and volume both increased. Thus when the coal-fired boiler was retrofitted, the front collecting header was raised so that the height of the fuel inlet increased. Biomass cut and feed systems were added, and the hopper in front of the furnace was enlarged. The furnace and the tail-heating surfaces were unchanged. In this retrofitting, we successfully used the original travelling grate instead of an expensive and complex water-cooled vibrating grate.

With 100% biomass blends fired, the boiler operated stably, with parameters such as steam pressure and steam temperature

* Corresponding author. Tel.: +86 451 86418854; fax: +86 451 86412528.
E-mail address: green@hit.edu.cn (Z. Li).

0960-8524/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2008.11.005

Nomenclature

C_{fa}^{c}	carbon in fly ash
C_{bs}^{c}	carbon in boiler slag
x	the distance from the measurement points to the fuel inlet along the grate length
y	the distance from the measurement points to the inner face of the right wall along the grate width
z	the distance from the measurement points to the grate along the furnace height
α_{fa}	the supposed mass ratio of fly ash
α'_{fa}	the calculated mass ratio of fly ash in the first time
α''_{fa}	the calculated mass ratio of fly ash in the second time
α_{fa}^{n}	the calculated mass ratio of fly ash in the n time
α_{fa}^{n-1}	the calculated mass ratio of fly ash in the $n-1$ time
α_{bs}	the mass ratio of boiler slag
q_2	the heat loss due to exhaust gas
q_3	the heat loss due to unburned gas
q_4	the heat loss due to unburned carbon in fly ash and boiler slag
q_4^{fa}	the heat losses due to unburned carbon in fly ash
q_4^{bs}	the heat losses due to unburned carbon in boiler slag
q_5	the heat loss due to radiation
q_6	the heat loss due to sensible heat in slag
A_{ar}	the contents of fuel ash (as received basis)
C_{fa}^{c}	unburned combustible in flue dust
C_{bs}^{c}	unburned combustible in slag
$Q_{net,ar}$	the fuel gross calorific value
η	the boiler efficiency
B	the fuel-consumption rate of a boiler
D	the boiler output
$i_{sh,s}$	superheated steam enthalpies
$i_{f,w}$	feed water enthalpies
m_{ash}	the total mass of the ash in fuel
ρ	the fly ash concentration
V	the gas volume
m_{fa}	the fly ash mass rate

being within normal range. The moisture content of the biomass blends used reached 40%. With the 35-tph load, 78901 m^3/h of flue gas was produced with coal-fired and 91,462 m^3/h with biomass blends fired. When biomass blends were used, the amount of flue gas exceeded the normal load of the suction fan. Therefore, with the old suction fan unchanged, the normal load of the biomass blends-fired boiler decreased to 28 tph.

Experiments were conducted using 28- and 18-tph loads. The parameters measured were the gas temperature and concentrations of components in the region above the grate, the gas temperature of the furnace, the flue gas temperature and component concentrations and the fly ash concentration.

3. Data acquisition techniques

Parameters were measured as follows: (1) The gas temperature and gas species mean concentration in the region above the grate were measured with a nickel–chromium nickel–silicon thermocouple and a water-cooled stainless steel probe inserted through monitoring ports (at $z = 515$ mm, where $z = 0$ is the position of the grate face) in the side walls. (2) The same thermocouple was inserted through monitoring ports near the front and rear walls ($z = 4795$ mm) and the monitoring ports ($z = 9045$ mm) in side walls to measure the gas temperature distribution. (3) The flue gas temperature and component and fly ash concentrations were measured in the back-end duct.

The water-cooled stainless steel probe included a water-in pipe, water-out pipe, sampling pipe, and outer pipe. The samples passed through filtrating devices into a Testo 350 M gas analyzer to be analyzed. The fly ash was obtained with a sampling system that consisted of a sampling pipe, cyclone separator, ash collector, flow meter and air pump.

The accuracy of the Testo 350 M gas analyzer for each species measurement was 1% for O_2, 5% for CO, and 5 ppm for NO and NO_2. Calibration was carried out on each sensor before measurement.

4. Results and discussion

4.1. Combustion characteristics

The combustion of biomass blends on the grate had three zones. The first zone was the heating zone. In this zone, biomass blends received radiation heat from high-temperature gas and the boiler front arch after they were carried into the furnace through the inlet. The moisture in the biomass blends then vaporized rapidly so that we could see white vapor in the test. The second zone was the fuel-burning zone, where the volatile escaped rapidly and burned as the temperature of the biomass blends increased, and some of the char in the fuel burned also. The combustion of biomass blends was semi-suspension combustion with a bright flame. The third zone was the burnout zone for the large-size biomass

Table 1
Main design parameters of the coal-fired 35-tph boiler and main run parameters of the biomass-fired boiler.

Fuel	Coal	Biomass blends	Biomass blends
Boiler load	35 tph	28 tph	18 tph
Discharge pressure of superheated steam	3.82 MPa	3.40 MPa	3.4 MPa
Discharge temperature of superheated steam	450 °C	440 °C	440 °C
Feed water temperature	150 °C	143 °C	143 °C
Hot air temperature	151 °C	175 °C	154 °C
Flue gas temperature	159 °C	155 °C	130 °C
NO_x concentration at 6% O_2	/	257 mg/m^3	198 mg/m^3
SO_2 concentration at 6% O_2	/	84 mg/m^3	62 mg/m^3
Carbon in fly ash C_{fa}^{c}	/	53.64%	46.88%
Carbon in boiler slag C_{bs}^{c}	/	44.45%	21.50%
Distance from the end of the flame to the end of the grate	0 mm	1350 mm	2000 mm
Boiler efficiency	80.68%	81.56%	86.37%