Fuel 188 (2017) 277–284

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

An experimental study of ignition and combustion of single biomass pellets in air and oxy-fuel

Fupeng Shan, Qizhao Lin *, Kun Zhou, Yakun Wu, Wei Fu, Po Zhang, Lanbo Song, Chunyu Shao, Bolun Yi

Department of Thermal Science and Energy Engineering, University of Science and Technology of China, Jinzhai Road, Hefei 230026, China

HIGHLIGHTS

- The oxy-fuel combustion behavior of biomass pellet was detected.
- Heterogeneous ignition on the surface of biomass pellets was observed.
- The volatile matter showed a hetero-homogeneous combustion at larger oxygen concentration (than 50%).
- The higher oxygen concentration was useful to reduce the length of the flame.
- The skeleton of the biomass pellets remained intact during burning process.

ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 19 September 2016
Accepted 23 September 2016
Available online 13 October 2016

Keywords:
Biomass pellets
Ignition mechanism
Combustion characteristic
Oxy-fuel
Single pellet

ABSTRACT

This study presents an experimental investigation of the ignition and combustion characteristics of single biomass pellets in air and O_2/CO_2 atmospheres containing 21%, 30%, 40%, 50% and 100% oxygen mole fractions. In this experiment, the temperature of the gas surrounding the biomass pellets was set respectively at 873 K, 973 K and 1073 K. The rate of co-flow gas was set at 10 L/min, 15 L/min and 20 L/min. Single pellets of *Pinus bungeana* and rice husk were fixed on a thermocouple and burned in a vertical heating tube furnace. High-speed photography was used to record images of the combustion process of biomass pellets. The resulting images exhibit two ignition behaviors: (1) homogeneous ignition of volatile, and (2) heterogeneous ignition on the particles' surface. After ignition, the combustion was no longer a homogeneous combustion of volatile. When the oxygen concentration exceeded 50%, the biomass showed a hetero-homogeneous combustion. Similarly, when the concentration of O_2 increased, the flame became shorter and more stable. With the same oxygen concentration, and once the N_2 was replaced by CO_2, the ignition delay, internal ignition temperature and the volatile combustion time increased. Inversely, when the oxygen concentration exceeded 21% (i.e. under the conditions of oxy-fuel), these parameters were correspondingly reduced. In other words, the ignition and combustion intensity were increased. The effects of oxygen concentration and co-flow temperature on ignition and combustion of biomass pellets were greater than that of co-flow velocity. The study's results show that the biomass pellets did not break during combustion.

1. Introduction

Given the recent increase in people's awareness of threats to the environment, as well as global events such as the climate conference held in Paris in 2015 [1], the general public now understands that the excessive use of fossil fuels is one of the chief causes of climate change. In order to tackle the increasingly serious energy crisis and other environmental issues, new energy must be developed. Among current alternative forms of energy, biomass energy has become a potentially vital source of renewable energy due to its excellent properties: renewable, clean, rich raw material and alternative advantages.

The main purpose behind shaping loose biomass into pellets is to change its fuel density. This density solves the bottleneck of transportation and storage, which currently restricts large-scale utilization of biomass energy. The applications of biomass pellets have shown a recent increase around the world. Countries with the fastest-growing biomass pellet production include the United States, Canada, and Russia. The main demand for biomass pellets is still in the European Union. China's demand for biomass pellets is currently increasing [2,3].

* Corresponding author.
E-mail address: qlin@ustc.edu.cn (Q. Lin).

http://dx.doi.org/10.1016/j.fuel.2016.09.069
0016-2361/

Oxy-fuel combustion is a promising technology used to promote carbon dioxide capture and storage (CCS) by burning fuel in a mixture of oxygen and recycled flue gases (rather than in air, as conventional combustion). The flue gases mainly contain carbon dioxide. This technique of CCS needs more carbon dioxide to work properly, so biomass offers a great advantage. Riaza et al. [4] have concluded that the combustion of biomass in the oxy-fuel atmosphere could be conducive to capturing carbon dioxide and enhancing combustion intensity. Current research on biomass burning focuses more on co-firing biomass with coal. Some studies suggest that the combustion of biomass-coal blends under oxy-fuel conditions cannot only reduce carbon dioxide emissions and atmospheric carbon dioxide, but also control the maximum temperature of coal combustion [5–10]. This technology has been called "clean" coal combustion. Other researchers have also studied the combustion of pulverized biomass particles. Riaza et al. [4] studied the combustion of single biomass particles in air and in oxy-fuel conditions in a drop-tube furnace. The temperature of the furnace wall was set to 1400 K, and the gas atmosphere was air and O_2/CO_2 containing 21%, 30%, 35% and 50% oxygen mole fractions. Riaza et al.'s results show that increasing the oxygen mole fraction in the CO_2 background gas enhanced combustion intensity of biomass and decreased the burnout time of volatiles and char residues. However, it increased the temperature of the burning char particles. Tran et al. [11] have concluded that the torrefaction process of biomass particles integrated with simulated oxy-fuel combustion flue gases can reduce mass and energy yields. However, the biomass would get better grindability. The mass yield (Y_{mass}) and energy yield (Y_{energy}) were determined by the following equation, respectively: $Y_{mass}\ (\%) = \frac{m_{biochar}}{m_{feedstock}} \times 100\%$, $Y_{energy}\ (\%) = Y_{mass} \frac{HHV_{biochar}}{HHV_{feedstock}} \times 100\%$. In addition to the above coal-based studies, many researchers have only studied biomass combustion. Most of the prior studies have been applied to boilers and small heating devices. Grotkjær et al. [12] studied the ignition mechanism of wheat straw. In this study, the straw sample was connected to the thermocouple and the supportive rod. Air flow temperature was set to 260–350 °C. The ignition temperature was determined according to the carbon conversion ratio. The flue gas was collected to measure the amount of carbon monoxide and carbon dioxide. Results of this study indicated that when the superficial gas velocity decreased, the ignition temperature increased. This was consistent with the homogeneous ignition mechanism. Boman et al. [13] studied the combustion characteristics and environmental performance of pelletized hardwood of aspen. In this study, biomass pellets were placed in a sample holder. Their test method had a great influence on the combustion flame, so their research only concentrated on the emissions and slagging. Kuo and Hsi [14] studied the pyrolysis and ignition of single wooden spheres in high-temperature airflow. They also analyzed the impact of the wood spheres' diameter, air velocity, and temperature on their ignition rate. Their conclusion was that biomass anisotropy had the largest effect on ignition time. The above studies are concerned with the combustion of biomass powder particles (such as wood spheres) in oxy-fuel and air. However, few studies have been carried out to examine the ignition and combustion of biomass pellets under oxy-fuel conditions. Further research on this topic is necessary. The present study is therefore useful for future applications of biomass pellets in power plants, the metallurgical industry, and other areas.

In this paper, two kinds of biomass pellets (*Pinus bungeana* and rice husk) were used to investigate their ignition and combustion characteristics under the conditions of oxy-fuel and air in a tube furnace. The thermocouple and high-speed photography were used to record the effects of gas velocity, oxygen concentration and gas temperature on the ignition and combustion characteristics.

2. Experimental

2.1. Biomass samples

Two kinds of biomass pellets were used as the research object, which are *Pinus bungeana* and rice husk. They were obtained from a pellet factory in Hefei City, Anhui Province, China. The pellets' diameter was 9 mm. Then the length of biomass pellet was processed to 10 mm. A hole with a depth of 5 mm and a diameter of 1 mm was drilled into the biomass pellets. These column of biomass samples are similar to that in [15–17]. The proximate and ultimate analyses of the biomasses are given in Table 1 (GB/T 28731-2012).

2.2. Experimental equipment and methods

An electrically-heated tube furnace with an inner diameter of 8.0 cm was used for the experiments, and the schematic diagram is shown in Fig. 1. In this experiment, oxygen (1) and nitrogen (2) were used to form air in the gases mixing chamber (7) before flowing through steady flow chamber (8) into the vertical heating tube furnace (9). Carbon dioxide (3) and oxygen (mole fractions of 21%, 30%, 40%, 50% and 100%) were used to simulate the oxy-fuel combustion conditions. The gas flow rate was set respectively to10 L/min, 15 L/min and 20 L/min.

Ignition and combustion experiments of biomass pellets were conducted under a flow gas condition. The gas temperature surrounding biomass pellets was respectively set to 873 K, 973 K and 1073 K. The ignition temperature of solid biomass was approximately 473 K [12,18]. Therefore, the heating rate of biomass was sufficient. The gas temperature was determined by heating control cabinet (13) and a thermocouple (14) which measures feedback temperature. The furnace was heated until the temperature of the thermocouple (14) reached the set value.

The biomass pellet (18) was fixed on a thermocouple (15) with high-temperature resistant inorganic glue. The thermocouple (15) was supported by a bracket (16) and used to measure the internal ignition temperature of biomass pellets. When the gases flow and the temperatures of the gases stream were stable, the biomass was fed into the furnace. The biomass was ignited when the visible flame was observed, and the temperature demonstrator (12) indicated the internal ignition temperature of biomass. High-speed photography (10) was used to record the ignition and combustion

Table 1
Proximate and ultimate analyses of the biomass.

Component	*Pinus bungeana* (wt%)	Ricehusk (wt%)
$(Ash)_{ar}$[a]	4.84	11.67
$(Moisture)_{ar}$	6.54	7.45
$(Volatiles)_{ar}$	85.89	73.08
$(Fixed\ carbon)_{ar}$[b]	2.73	7.80
$(LHV)^{c}_{db}$ (MJ/kg)	19.32	17.53
$(Carbon)_{db}$	47.17	39.88
$(Hydrogen)_{db}$	6.43	5.54
$(Oxygen)_{db}$	42.5	36.71
$(Nitrogen)_{db}$	0.07	0.46
$(Sulfur)_{db}$	0.46	0.48

LHV = Low heating value.
[a] ar indicates the abbreviation of 'as received basis'.
[b] Calculated by difference.
[c] db indicates the abbreviation of 'as dry basis'.