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Experimental study on oxygen-enriched combustion of biomass micro fuel

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ABSTRACT

The oxygen-enriched combustion of biomass micro fuel (BMF) was carried out respectively in the thermogravimetric analyzer and cyclone furnace to evaluate the effects of oxygen concentration on combustion performance. The experimental results show that with the increasing oxygen concentration, the volatile releasing temperature, ignition temperature and burnout temperature were decreasing. Oxygen-enriched atmosphere subtracts burning time and improves combustion activity of biomass micro fuel. Oxygen-enriched atmosphere improves the combustion temperature of BMF in cyclone furnace; while the improvement is weaken as oxygen concentration is above 40%.

1. Introduction

Interest in using biomass feedstock to produce heat, power, liquid fuels and hydrogen, as well as to reduce greenhouse gas emissions, is increasing worldwide. Biomass processes, including direct combustion, gasification and pyrolysis, have been under development for many years. Combustion is the most simple and direct technology nowadays available for biomass utilization [1]. Nevertheless, the disadvantages [2] of raw materials (i.e. variability of quality and calorific value, difficulty in controlling the rate of burning and in mechanizing continuous feeding) and lower combustion temperature limit the wide use of combustion. These disadvantages may be attributed to the adverse effect of heterogeneity and low bulk density of raw materials. Thus, a proper biomass pretreatment method used to increase its uniform is essential.

In order to improve the performance of biomass, our team produced a new kind of powdery biomass fuel with particle size of less than 250 μm, named as biomass micron fuel (BMF) [3]. It was produced by feedstock (energy crops, agricultural wastes, forestry residues, and so on) through an efficient crushing process, which was mainly composed of primary crusher, advanced crusher, cyclone dust extractor and bag filter for collection of BMF, fan, etc.

In producing BMF, the fan worked first, followed respectively by the fine crusher and coarse crusher. Generally, the majority of raw biomass materials were first crushed in the coarse crusher to generate coarse particles with particle size less than 5 mm; they were then automatically directed into the fine crusher, cyclone dust extractor and bag filter in sequence, due to the driving force from the fan and rotation of crushers. About 90 wt% of BMF is between 83 and 198 μm (180 and 80 mesh) in size. Although such a process will increase overall costs for biomass handing and preparation, compared with the biomass briquette [4,5], the energy consumption is much lower about 100 kWh/ton. The maximum combustion temperature BMF in the lab-scale cyclone furnace can reach up to 1200 °C, with the combustion efficiency 97% [3].

In present, with the development of low cost of oxygen making technology [6,7], such as permeable membranes and pressure swing adsorption, oxygen-enriched combustion technology is gradually developing with its application range continuously expanded. Many studies [8–11] have investigated the behavior of pyrolysis and combustion of biomass under nitrogen, air, oxygen-enriched atmosphere by using thermogravimetry. Experiments and theoretical studies on kinetics of prolysis of wood branches and leaves have been conducted [8]. Experiments on prolysis of pine and oak under different oxygen concentrations such as 0%, 10.5%, and 21% were carried out by Ohlemiller et al. [9].

The work we report here focuses on the effects of oxygen concentration on combustion characteristics of BMF, as well as combustion temperature of BMF in cyclone furnace. The tests were carried out in thermogravimetric analyzer and lab-scaled cyclone furnace, respectively. The aim is to gather comprehensive data for which there is still a shortage.

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Table 1
Proximate analysis and elemental analysis.

Proximate analysis/wt%		Ultimate analysis/wt%	
Higher heating value (MJ/kg)	19.37	C	49.42
Moisture content	8.61	H	7.82
Volatile matter	76.50	O	42.49
Fixed carbon	14.41	N	0.12
Ash	1.02	S	0.06

2. Experimental

2.1. Materials

The raw materials of BMF were from pine sawdust in Wuhan City, Hubei Province, China. The sawdust was crushed in a lab-scaled crushing process. The BMF was separated into five different size fractions by sieving. The particle size distribution by sieving was as follows: 14 wt% below 140 mesh, 47 wt% 140–100 mesh, 32 wt% 100–80 mesh, 4 wt% 80–60 mesh and 3 wt% 60–40 mesh. Namely, BMF of 93 wt% is below 80 mesh in size. The proximate and ultimate analysis of BMF was shown in Table 1.

2.2. Experimental facilities and procedure

Slow combustion of biomass under different oxygen concentrations (20%, 30%, 40%, 60%, 80% and 100%) were performed in a STA409C thermogravimetric analyzer with a cylindrical alumina crucible. In these experiments, 20 mg of sample was heated from ambient to 730 °C by a constant heating rate of 20 °C/min under dry oxygen-enriched air flow of 20 mL/min. Derivative thermogravimetric analysis (DTG) profiles, showing the burning rates of the samples, were derived from the thermogravimetric (TG) data; and the TG–DTG method was applied to calculate the combustion characteristics during the process. All experiments were repeated, and the mean values were used provided that the deviations were within 5%.

The lab-scaled combustion system was composed of cyclone furnace, screw feeder, centrifugal fan, thermocouple and temperature measurement system, etc shown in Fig. 1.

The cyclone furnace was cylindrical and vertically oriented, with the effective height and diameter of combustion chamber being 900 mm and 400 mm, respectively. The inner walls were refractory lined over the whole length of the chamber and externally with a high-performance heat insulator. The flue gas flows upwards and exits through the chimney located at the top. The feed inlet was placed along tangent direction to the furnace wall at the bottom. BMF was fed with air by a high-pressure centrifugal fan and screw feeder. There exited a premixed region between the screw feeder and cyclone furnace, in which BMF and air undergo intensive mixing. The fuel feeding rate was set to approximately 250 g/min during the experiments. The different oxygen concentrations (20%, 25%, 30%, 35%, 40% and 50%) were achieved by adopting the flow rates of oxygen cylinder and centrifugal fan, respectively. Flow rate of air was computed by the value of pressure gauge connected with pitot tube.

BMF feeding rate was determined over a range of screw speeds prior to testing. To insure the reliability of test data, mass balance calculation was performed. At the start-up of each test, BMF was added to the screw feeder, and the controllers were set at the selected operating parameters. Some tinder was ignited (paper, paring, etc) for preheating the furnace. When the temperature of the bottom of furnace rose to 200–250 °C, the screw feeder, centrifugal fan and oxygen cylinder were simultaneously turned on. At the same time, the temperatures under different oxygen concentrations were continuously recorded automatically by digitizing temperature measurement system. To ensure the reliability of test data, each experiment in the cyclone furnace was repeated two times, and the results were in good agreement. The data reported in this paper are average values of two times. The tests in the cyclone furnace focus on the effect of oxygen concentration on the combustion temperature of BMF.

3. Results and discussion

3.1. TG and DTG curves analysis

Fig. 2 shows the variation of experimental mass loss with temperature under different oxygen concentrations.

As can be seen in Fig. 2, drying, thermal decomposition, volatile release, combustion of volatiles, char gasification, and char oxidation stages [8] caused mass losses from the solid matrices of the samples. Before the initiation of the burning, some increase in mass could be observed due to the chemisorptions of oxygen. Folgueras et al. [12] also reported a similar increase in the mass of the sample during such an experiment.

Fig. 3 shows the DTG curves of the experiments in Fig. 2. It was shown in Fig. 3 that mass loss rates of samples under different oxygen concentrations were similar until temperature was above 250 °C. The mass loss is attributed to drying and thermal decomposition of sample, in the kinetic control zone, mainly affected by temperature. And the effect of oxygen concentration is almost negligible.

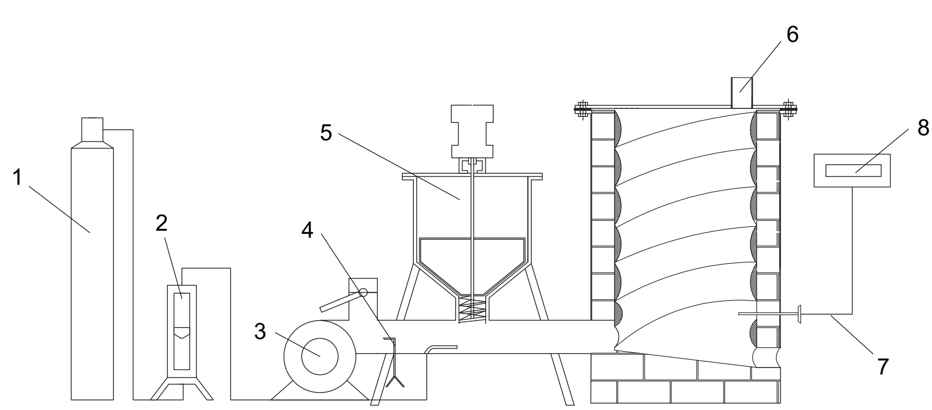

Fig. 1. The structure figure of BMF combustion system. 1 – oxygen cylinder; 2 – flowmeter; 3 – centrifugal fan; 4 – pitot tube; 5 – screw feeder; 6 – chimney; 7 – thermocouples; 8 – temperature measurement system.