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Full Length Article

The investigation of co-combustion characteristics of tobacco stalk and low rank coal using a macro-TGA

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ABSTRACT

The macroscopic co-combustion characteristics of tobacco stalk, low rank coal, and their blends were investigated in a custom-designed macro-TGA. The interaction between tobacco stalk and coal during co-combustion, as well as effect of the proportion of the two, were also studied. The results showed that increasing the proportion of tobacco stalk was more effective in reducing the burnout temperature than the ignition temperature. The ignition temperature of the tobacco stalk (254 °C to 321 °C) varied greatly at different heating rates compared with coal (408 °C to 412 °C). The mixing of tobacco stalk and coal produced an inhibitory interaction before ignition, and gradually transformed into a promotion with the increase in temperature. The promoting interaction was most significant for the blends with tobacco stalk weight percentage of 70%. The results obtained in this study may be used to the understanding of the combustion of tobacco stalk/coal and also provide a basis for further applying tobacco stalks on industrial boilers with high efficiency.

1. Introduction

The energy demand of China is continuously increasing in parallel with the population growth and industrial development [1]. China's energy structure determines that industrial production and large-scale power generation are dominated by coal combustion, and this status is difficult to change in a short time [2]. However, with the increasing depletion of fossil fuel, serious air pollution, and other environmental problems brought about by coal combustion, the development and utilization of cleaner renewable energy is highly valued by the government. Increasing the proportion of renewable energy applications is an effective way to solve these problems [3,4].

Biomass energy is one of the renewable energy [5]. The potential of biomass, as a candidate fuel to play a supplementary role, for meeting the world's energy demand is widely recognized. The increased use of biomass will also extend the lifetime of fossil fuel resources and expect to contribute substantially to the CO_2 emission reduction targets defined in the Kyoto protocol [6–8]. Currently, thermal utilization of bioenergy includes gasification and combustion. Among them, gasification seems to be more promising and diverse. However, due to the difficulty and cost of gasification technology, the application of combustion technology in the industrial field is more extensive [9–13].

Tobacco stalk is a kind of biomass and a typical agricultural waste material produced during the manufacturing of cigarette [14]. A large amount of tobacco stalk is generated every year in China. China Statistical Yearbook-2015 depicted that, in 2015 China's tobacco planting area was 1.6×10^6 hm^2, producing 2.2×10^6 tons of tobacco leaves, and correspondingly produced about 1.2×10^6 tons of tobacco stalks. Due to the high potassium content and low calorific value, tobacco stalks are difficult to use as fuel alone. Most of them are discarded as waste or burned openly, which causes not only pollution to the environment, but also the waste of resources [15]. As a mature fluidized combustion technology, circulating fluidized bed (CFB) can be used for combustion of tobacco stalks, because of its good fuel adaptability, high efficiency, and low emission levels [16–18]. However, due to the high volatile content and low ash content of the tobacco stalk, co-combustion of tobacco stalk with coal is necessary to meet the requirement of fluidization and material circulation in CFB boilers [19].

The combustion characteristics of the fuel must be determined before it is used in thermal equipment, which plays an important role in efficient operation and accurate design of the boiler [20]. Because of the significant differences in volatile content, fixed carbon, and so on, the combustion behaviors of tobacco stalk and coal have a great many differences, such as ignition temperature, burnout temperature, and maximum burning rate. Mixing tobacco stalk with coal will affect the entire combustion performance. Therefore, based on the researches of

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other types of biomass, it is important to investigate the co-combustion characteristics of the blends of tobacco stalk with coal and to find out the optimum mixing condition to improve the efficiency of the boilers [21–23].

Thermogravimetric analysis (TGA) was developed to determine the kinetic parameters from weight loss data and widely used to investigate the mechanisms of solid-phase decomposition reactions [24–26]. Studies have been conducted in the past to investigate co-combustion process of biomass and coal by TGA, which show that the fuel property is an important factor affecting the co-combustion performance [27,28]. In the traditional TGA experiments, due to the size limitation of the crucibles, the weight of samples was mostly milligrams, and the particle size was less than 200 μm [29–34]. It is difficult to detect the effect of the macroscopic heat transfer process and the interaction between components on the co-combustion of samples of larger amount [35–37].

In the present study, the main objective is to investigate the combustion characteristics of tobacco stalk (TS), Yunnan low rank coal (C), and their blends with different TS weight fractions. The experiments were conducted by a custom-designed macro-TGA. Ignition and burnout properties of different samples, as well as the interaction of tobacco stalk and coal within the blends during the co-combustion, were obtained.

2. Methodology

2.1. Materials

The test samples, including tobacco stalk (TS) and Yunnan low rank coal (C), were collected from a tobacco re-drying firm in Yunnan province of China. They were fired as fuels in a CFB industrial boiler in order to obtain the heat for the re-dryers. The proximate and ultimate analyses of the samples were conducted by Beijing Coal Chemistry Branch of China Coal Research Institute following GB/T211-213, T476, T9227 (China) standards. The results are summarized in Table 1. The calorific value of the two fuels is very close. From the perspective of energy balance, adjusting the blending ratio of co-combustion will not have a great impact on the boiler load. Tobacco stalk contains a much higher content of volatile matter (VM) and oxygen, which are the important elements to promote ignition. Tobacco stalk has a lower fixed carbon content (20.17%) than Yunnan low rank coal (31.91%). From an environmental perspective, the co-combustion of tobacco stalk and coal can contribute to CO_2 reduction compared to burning coal only. For the Sulphur content, the co-combustion of the blends imply lower SO_x emissions too.

In order to make the experimental results closer to the actual

Table 1
Proximate and ultimate analyses of samples.

Sample	Yunnan low rank coal	Tobacco stalk
Proximate analysis (wt %)		
Moisture^{ar}	7.0	6.6
Ash^{d}	46.70	8.52
Volatile matter^{d}	21.40	71.31
Fixed carbon^{d}	31.91	20.17
Ultimate analysis^{d} (wt. %)		
C	40.44	41.09
H	2.99	5.02
O (by difference)	7.05	42.75
N	0.78	2.42
S	2.05	0.21
Calorific value^{ad} (MJ·kg^{-1})		
GCV	15.60	15.68
NCV	14.46	14.79

ar, as received basis. **d**, dry basis. **ad**, air-dried basis. **GCV**, gross calorific value. **NCV**, net calorific value.

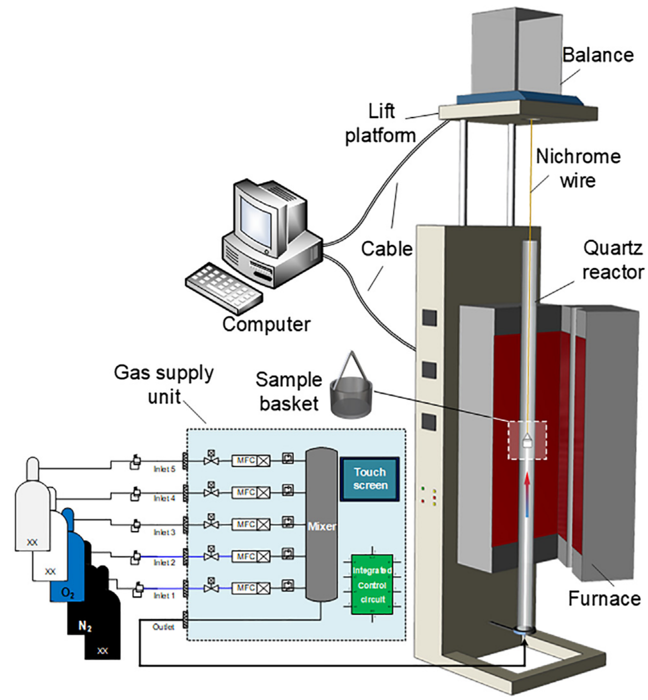

Fig. 1. The schematic of macro-TGA.

project, the samples were dried at room temperature about 4 h, then crushed and sieved into a particle size of 0.9–1 mm consistent with the actual fuel. According to the industrial background of this study, in order to minimize the consumption of coal, the main fuel in the mixed fuel is the tobacco stalk. A series of TS (tobacco stalk)/C (coal) blends were prepared with tobacco stalk weight percentages of 90%, 80%, 70%, 60%, and 50%.

2.2. Experimental method

The experiments were conducted by a custom-designed macro-TGA system. As shown in Fig. 1, the macro-TGA system includes gas supply unit, heating unit, balance unit and data acquisition unit [38].

The heating unit is composed of a three-section furnace, a quartz reactor and a sample basket. Samples of approximate 0.5 g are placed in the basket during the experiments suspended under a balance (Metter Toledo ME204E) by a nichrome wire. The weight of the samples can be monitored by the balance with a sampling frequency of 11 Hz. The carrier gas comes from high-pressure gas cylinders with two-stage pressure-release valves and is supplied from the bottom of the quartz tube. Air mixed with 21% volume fraction of pure oxygen and 79% volume fraction of pure nitrogen is used as the carrier gas. The gas is measured and controlled by a mass flowmeter. An electric furnace of 5 kW, which is monitored by the temperature control and data acquisition unit, surrounds the quartz tube of 1500 mm high with i.d. 60 mm. Samples were heated from ambient temperature to 950 °C under atmospheric pressure at three heating rates of 10, 20, and 30 °C·min^{-1}. The air flux was set to 1 L·min^{-1}.

A blank test was performed to obtain the background of the signal before the experiments, and the background signal was deducted from the results measured with the presence of a sample in the basket to eliminate the errors caused by the buoyancy force in the vertical furnace. Both runs were conducted under identical conditions. It was proved that macro-TGA had good stability and reproducibility by repeated experiments. The relative deviations were generally within ± 2.0%.