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Co-gasification behavior of meat and bone meal char and coal char

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ABSTRACT

The co-gasification behavior of meat and bone meal (MBM) char and two types of coal (Jincheng anthracite (JC) and Huolinhe lignite (HLH)) char was investigated using a thermogravimetric analyzer (TGA). The effects of coal type, mineral matter in MBM, gasification temperatures and contacting conditions between MBM char and coal char on the gasification behavior were studied. The results show that the gasification behavior of MBM char and HLH char can be well described by ash diffusion controlled shrinking core model, while that of JC char can be described by chemical reaction controlled shrinking core model. The co-gasification rate of MBM/JC chars at 950 °C is approximately 1.5 times faster than that calculated from independent behavior. The mineral matter in MBM may play as a catalyst during co-gasification. However, the analogous effect observed in the blends of HLH/MBM chars is smaller, suggesting that the coal types play a great role. Furthermore, as the gasification temperature increased from 850 to 1000 °C, the maximum synergistic effect is observed at 900 °C. The lower temperature is not conducive to transferring the mineral matters of MBM to the coal char, while the higher temperature makes Na and Ca react with minerals of coal, leading to a loss of catalytic activity.

1. Introduction

Meat and bone meal (MBM), a by-product of the rendering industry, is produced in large amounts [1,2]. It is primarily used in the formulation of animal feed to improve the amino acid profile. However, this utilization has been forbidden for ruminant animals in European Union and some other countries since the bovine spongiform encephalopathy (BSE) emerged. Therefore, a safe utilization method should be developed to dispose these MBM. On the other hand, some works have reported that the viruses causing infection can be destroyed at 850 °C for 2 s, or at 3 bar and 133 °C for at least 20 min [3]. Thus, thermo-treatment processes (incineration or gasification) can be used to recycle the MBM.

Currently, co-incineration with coal is a common method to treat MBM in European Union countries [4–6]. However, conventional thermal oxidation process (like incineration) has been showing several environmental inconveniences, because this process can emit hazardous compounds such as furans, dioxins and nitrous oxide (NO_x) [7–9]. On the contrary, there are few references of the existence of this kind of compounds in gasification process, but it is known that the existing reducing environment in a gasifier does not benefit its formation at all [7]. Therefore, co-gasification of coal with MBM as secondary fuel may be an effective method to solve this problem. Additionally, an expected advantage of MBM co-gasification with coal is the possibility of using it as a source of inexpensive catalysts (improve reactivity of coal), due to its high contents of Ca and Na compounds. Thus, it can be deduced that, co-gasification of MBM with coal can not only reuse MBM but also has an economical potential.

Many factors should be taken into account during gasifier designing and operating, in which the gasification reactivity of feedstock is of great importance [10]. The char (remains after rapid pyrolysis of solid fuels) gasification is usually the rate-limiting step in the gasification process. Thus, the successful design and operation of a gasifier as well as its modeling requires reliable kinetic data. It is very important to investigate gasification reactivity of char under conditions relevant to applications.

In this work, TGA was employed to investigate the co-gasification of MBM char and coal char. Although the thermal analysis of the biomass and coal has already been investigated by numerous studies, MBM is quite different from any other traditional solid fuel in terms of chemical composition, ash content and micro-structural properties [11]. The co-gasification of MBM with coal has attracted limited attention. In addition, coal types, particle contacting conditions between coal and biomass [12] and gasification temperature have significant effect on co-gasification behaviors. For these reasons, two types of coal (anthracite and lignite) were selected in this work; the effects of char particle contacting conditions (intimate contact and total segregation) and gasification temperature on the co-gasification behavior of MBM char and coal char were also examined.

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2. Experimental

2.1. Materials

Three raw materials were tested in this study: MBM, Jincheng anthracite (JC) and Huolinhe lignite (HLH). MBM was provided by a British company, and the two types of coal with different rank came from China. The proximate and ultimate analyses of samples were performed according to Chinese standard GB/T212-2001and GB/T476-2001, respectively. The results are shown in Table 1. It can be found that MBM has the highest volatile and the lowest fixed carbon content, while JC coal shows the opposite result.

2.2. Apparatus and procedure for char preparation

In order to simulate the gasification of char in a gasifier (such as fluidized bed) experimentally, it is essential to realize rapid heating of coal particles during pyrolysis. In this work, the chars used for gasification were prepared by fast pyrolysis of MBM, HLH and JC coal in a fixed-bed reactor as shown in Fig. 1. The fixed-bed reactor mainly consists of four parts: the furnace, the reactor, the temperature controller and the sample transporter. The experimental procedures are briefly described as follows: Firstly, the crucible (35 mm I.D.) loaded with the samples is placed in the upper part of the closed reactor (50 mm I.D.), and then the nitrogen gas is introduced into the reactor with a flow rate of 450 ml/min to ensure the system air-free. Secondly, the reactor tube is heated to a setting temperature (900 °C), and the flow rate of N_2 is adjusted to 150 ml/min. After that, the crucible with samples is quickly pushed to the constant temperature zone of the reactor and the fast pyrolysis process begins. As the reactions reach the required residence time (30 min), the crucible is lifted to the top of the reactor to make the crucible rapidly cooled to room temperature. Finally, the samples are taken out and ground to less than 0.154 mm for gasification experiment. In pyrolysis, the particle size, is less than 0.178 mm for coal, and less than 1.7 mm for MBM; the sample weight is about 5 g, the sample depth in the crucible is less than 10 mm.

2.3. Gasification experiment

The gasification experiments were carried out in a modified PerkinElmer TGS-2 thermogravimetric analyzer (shown in Fig. 2). The analyzer mainly comprises an electrical furnace with an internal quartz tube reactor (20 mm I.D.), gas feeding system and computer data collecting system. Experimental procedures are performed as follows: Initially, the sample is placed in the upper part of the reactor. The reactor is heated in a nitrogen atmosphere with a flow rate of 150 ml/min. When the temperature reaches the required gasification temperature, the gasifying agent (60% steam +40% N_2, v/v %) is introduced into the reactor at a flow rate of 100 ml/min. N_2 is used as carrier gas here. Then, the reactor is moved upward until the sample is located in the reaction zone and the reaction begins. The reaction is finished when the weight of sample is unchanged. In each test, the sample weight is about 5 mg; the particle size is less than 0.154 mm. MBM char and coal char were mechanically premixed in the co-gasification experiment. The whole experiments were performed at normal pressure, and the effects of external diffusion on reaction were eliminated at the above mentioned reaction conditions through the pre-experiment.

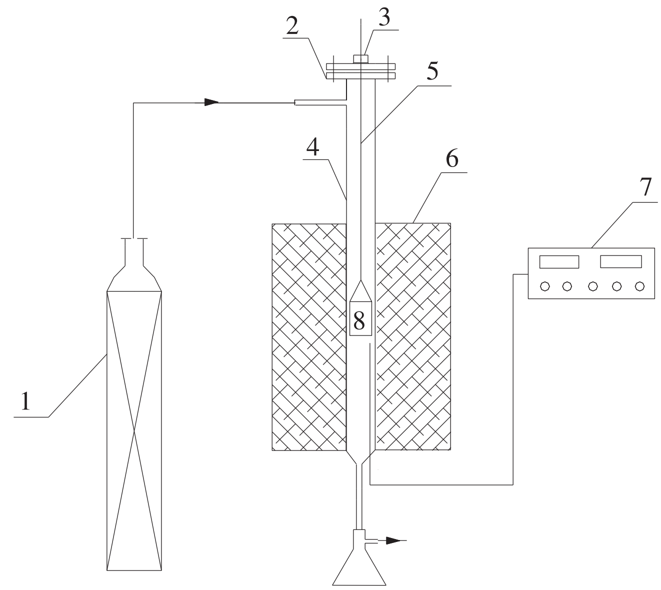

Fig. 1. Schematic diagram of fixed-bed reactor for char preparation: 1- N2 cylinder; 2- flange; 3- sealing element; 4-reactor; 5- stainless rod; 6-heater; 7- temperature controller; 8- Stainless Steel Crucible.

Table 1
Proximate and ultimate analyses of samples.

Sample	Proximate anal. (air-dried basis)				Ultimate anal. (dry ash-free basis)				
	V	M	A	FC[a]	C	H	O[a]	N	S_t
JC	7.4	0.9	23.5	68.2	88.5	3.5	4.9	1.1	2.0
HLH	29.1	7.57	31.2	32.2	67.4	3.9	25.4	1.3	1.9
MBM	58.4	2.5	30.1	9.0	60.7	5.5	24.9	7.5	1.4
JC char	0.8	1.1	25.8	72.3	95.1	1.2	1.4	0.8	1.6
HLH char	1.9	1.0	58.9	38.2	88.9	2.4	4.2	1.3	3.2
MBM char	2.3	1.3	77.3	20.1	64.1	6.1	24.0	5.1	0.7

Note: [a]By difference; S_t: the total sulphur content.

2.4. Method of data analysis

The results of each TGA test were saved in the form of a data-logging file. In this file, the weight value of sample was tabulated as a function of time. The carbon conversion (X) was calculated by Eq. (1). The calculated conversion (X_C), the sum carbon conversion of MBM char and coal char, was calculated by Eq. (2), based on the weight loss curves of gasification of single MBM char and single coal char, in which it is assumed that there is no synergistic effect during co-gasification. The synergy of the mixture (MBM/coal chars) during co-gasification could be evaluated by comparing the experimental values with calculated values. The gasification rate is generally defined with Eq. (3) [13,14]

$$X = \frac{w_0 - w_t}{w_0 - w_\infty} \tag{1}$$

$$X_C = \frac{\nu_c{}^*(w_{c0} - w_{ct}) + \nu_b{}^*(w_{b0} - w_{bt})}{\nu_c{}^*(w_{c0} - w_{c\infty}) + \nu_b{}^*(w_{b0} - w_{b\infty})} \tag{2}$$

$$r = \frac{1}{1-X}\frac{dX}{dt} \tag{3}$$

where w_0, w_t and w_∞ represent the initial weight of char, the actual weight of char at reaction time t and the weight of char residue at the end of the experiment, respectively; w_c and w_b represent the weight of coal char and MBM char; ν_c and ν_b are the ratio of coal char or MBM char in the blends.