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Characteristics of rice husk char gasification with steam

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HIGHLIGHTS

- A drop-tube reactor was used for the measurements.
- The temperature is the primary factor that influences the steam gasification reaction of rice husk char.
- The conversion rate of rice husk char increases as the steam flow rate.
- The reactivity of rice husk char prepared at low temperature is relatively high.
- When the temperature is more than 850 °C, the diffusion through gas controls the overall reaction.

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ABSTRACT

Biomass char gasification with steam refers to the reaction of the steam and biomass char under high temperature when the biomass char converts to combustible gas. Rice husk was selected as the raw material for char preparation. A gasification reactor was designed and built for the study of characteristics of rice husk char gasification with steam. Results show that the temperature is the primary factor that influences the steam gasification reaction of rice husk char. The conversion rate increases significantly from 27.7% to 90.73% with the temperature from 700 to 950 °C. H_2 accounts for 46.9% of the product gas at 950 °C. The conversion rate of rice husk char increases with temperature. The conversion rate of rice husk char increases as the steam flow rate. H_2 and CO gradually increase while CO_2 and CH_4 decrease as the steam flow rate. The conversion rate can be increased by decreasing particle size at low temperature, but the influence of the particle size becomes smaller above 900 °C. The reactivity of rice husk char prepared at low temperature is relatively high. Both surface reaction controlled shrinking core reaction model and homogeneous reaction model can describe the steam gasification reaction of rice husk char when the temperature is less than 850 °C. However, when the temperature is more than 850 °C, the diffusion through gas controls the overall reaction.

1. Introduction

Biomass char gasification with steam refers to the reaction of the steam and biomass char under high temperature when the biomass char converts to combustible gas. During the gasification process, the reduction reaction between the steam and carbon and the reforming reaction between the steam and gaseous products are involved [1,2]. Compared with biomass, volatile and oxygen content in biomass char are significantly reduced, in which fixed carbon composition is largely accumulated [3,4]. Therefore, biomass char has high reaction activity with less N and S levels, results in little environmental pollution relative to coal char. That is why it is considered to be a quality gasification material. The introduction of steam as the gasification medium into the gasification process can not only improve the gasification activity of biomass char, but also boost the hydrogen yield and gas production rate and optimize the quality of gas. Moreover, the composition of the product gas can be controlled by adjusting the flow rate of steam [5]. Chaudhari et al. [3] studied the steam gasification of two biomass chars at 700, 750, and 800 °C in a fixed bed microreactor at different steam flow rates. The results suggest a strong potential for producing H_2 and syngas from biomass chars by a simple steam gasification process. Haykiri-Acma et al. [6] using the thermogravimetric analysis technique investigated gasification characteristics of some agricultural and waste biomass samples chars in a gas mixture of steam and nitrogen. It showed that gasification characteristics were fairly dependent on the ash and fixed carbon contents and the constituents present in the ash. Low ash content and high fixed carbon content biomass materials were recommended for the gasification processes. Ashish Bhat et al. [7] investigated the gasification of rice husk char in its original grain form in

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a silica tube reactor with steam, and of rice husk char powder in a thermogravimetric balance in a carbon dioxide medium for determining the kinetic parameters. Experiments were conducted at temperatures of 750–900 °C. The data was analyzed based on the volume reaction and shrinking core models.

However, there are still not enough experimental data to explain the typical characteristics of biomass char gasification with steam. In this paper, the rice husk is adopted as the raw material to produce biomass char in a muffle furnace under varying operating conditions. Then, the experimental setup is designed and established on which the experiment is performed to study the characteristics of the gasification reaction under varying operation conditions, and the kinetics analysis of the gasification reaction is performed. Thus, the experimental results can provide experimental and theoretical reference to engineering applications.

2. Methodology

Rice husk was chosen as the raw materials for this study. Rice husk, an agricultural biomass resource, is composed of fiber, lignin, extractives, and ash. Unlike other agricultural biomass sources, rice husk is easy to collect and use since it accumulates primarily in rice processing plants. When making char samples, rice husks are not crushed, but are instead screened, and husks of similar particle size are chosen. A muffle furnace was used to produce rice husk chars. After that, a gasification reactor was designed and built for the study of characteristics of rice husk char gasification with steam.

2.1. Preparation of rice husk char

The proximate and ultimate analysis of the rice husk is shown in Table 1. Instead of crushing, the rice husk is only screened to select the husk of similar particle size as the material. Then rice husk char is prepared by heating in a muffle furnace after being put into the sealed crucible. The muffle furnace is controlled by a temperature controller. The temperature program of the muffle furnace can be defined, and thus the temperature inside the furnace can be controlled. Therefore, the controller can be used to create various operating conditions (at the temperature of 600 °C, 700 °C, 800 °C, and 900 °C for 20 and 40 min) for the furnace while preparing the rice husk char. The main technical parameters of the muffle furnace are: the measurement range of temperature is from 0 to 1000 °C; the measurement resolution is 1 °C and the temperature control accuracy is ±5 °C.

2.2. Experimental setup for rice husk char gasification with steam

The experimental setup for rice husk char gasification with steam is shown in Fig. 1, whose principal part is a drop-tube furnace composed of a heating furnace and a temperature controller. In the drop-tube furnace, the gasification reaction of rice husk char with the steam generated by a steam generator occurs. The product gas is collected by the gas collecting bag after passing the condenser, drying bottle, and dust extraction pipe. The collected gas is to be used for performing sampling analysis. The electrical heating is adopted for the drop-tube furnace, in which there is a corundum tube whose inner diameter is 40 mm, and the length is 1300 mm. Meanwhile, a heating resistance wire twines around the corundum tube and thus a high-temperature environment in the corundum tube is formed by heating the resistance wire. Meanwhile, an external temperature controller is attached to the drop-tube furnace, which can set the temperature program of the heating furnace, and thus the temperature in the furnace is controlled. Moreover, the steam generator which produces saturated steam at atmospheric pressure consists of a power adjustable heating mantle and a round-bottomed flask. Before the experiment, output steam amount of the steam generator needs to be calibrated. The four calibrated steam production amounts are shown in Table 2. Nitrogen is used as the protective gas of the experiment setup and an anoxic environment with high temperature is created in the heating furnace. After that, the water gas reaction occurs between the rice husk char and the steam in the furnace, and then the product gas goes into the condenser. In the condenser, some unreacted steam and macromolecule condensable gas flow into the collection bottle, and then the residual gas enters the gas collecting bag after drying and dust removal.

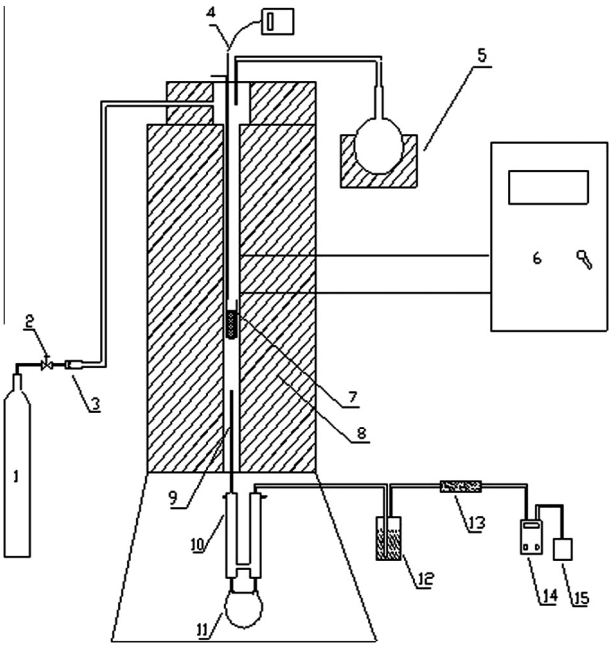

Fig. 1. The experimental setup for rice husk char gasification with steam. 1. Nitrogen cylinder. 2. Valve. 3. Rotameter. 4. Thermocouple. 5. Steam generator. 6. Temperature controller. 7. Boat. 8. Drop-tube furnace. 9. Sampling tube. 10. Condenser. 11. Collection bottle. 12. Drying bottle. 13. Dust extraction pipe. 14. Aspirator pump. 15. Gas collecting bag.

2.3. Measurement methods

Measurement of temperature: in the experiment, the temperature rise procedure of the heating furnace can be controlled by the temperature controller and the K-type thermocouple is inserted into the boat to monitor the temperature variation during the reaction.

Measurement of gas flow rate: install a rotameter at the outlet of the nitrogen gas cylinder to control the amount of nitrogen entering the furnace.

Table 1
Proximate and ultimate analysis of rice husk.

M_{ad} (%)	V_{ad} (%)	A_{ad} (%)	FC_{ad} (%)	C_{daf} (%)	H_{daf} (%)	O_{daf} (%)	N_{daf} (%)	S_{daf} (%)
5.08	63.05	14.98	16.89	46.18	6.08	45.02	2.62	0.10

Table 2
Steam generation with heating power.

Heating power (w)	100	150	200	250
Steam generation (g/min)	1.13	1.85	2.64	3.23