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Experimental study on microwave pyrolysis of three Chinese lignite

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ABSTRACT

In this paper, the effects of lignite type, microwave receptor/coal ratio and microwave power on the yields and characteristics of pyrolyzed products of three Chinese lignite were studied systematically. The results showed that the yield of gaseous and oil products increased with increasing the microwave receptor/coal ratio and microwave power. The gaseous products were complex mixtures of H_2, CO, CO_2, and CH_4 etc. The yield of gaseous and oil products during MW pyrolysis of lignite increased with increasing MW receptor/coal ratio and MW output power. The concentration of H_2 in gas products was highest (54.1 vol.%), and the total composition of syngas (H_2 + CO) was 82.8 vol.%. Functional groups in the lignite upgraded were decreased more significantly. An increase in pore volume and specific surface area occurred because the volatiles were produced faster and more homogeneously. The semi-char had well-developed flow structures with irregular shapes and appeared fairly molten, which indicated structural change during the evolution of the gaseous products.

1. Introduction

Coal is a cheap and easily obtained fossil fuels, which plays a very important role in world's energy supply structure and is irreplaceable in a short time. Also, the utilization technologies of coal such as combustion, pyrolysis and gasification are mature compared to utilization of new energies. Thus, investigations on development and utilization of coal are of great significance in a certain period. Lignite is one kind of low rank coal (LRC) and abundant, which has many advantages of low mining cost, high reactivity, and low harmful elements (N, S, etc) content [1,2]. However, lignite also has some disadvantages of high moisture content, low calorific, easily weathered crack and oxidized spontaneous combustion, leading to many difficulties in utilization [3,4]. Therefore, it is necessary to develop new upgrading and conversion technologies to convert them to more valuable products.

Microwave (MW) pyrolysis is a promising technology for upgrading and efficient use of low-grade fuels, and attracts a lot of attentions. Up to now, many attempts for MW pyrolysis of various feedstocks have been reported in the literature [5–10]. Microwave heating has the characteristic of "internal heating" due to MW penetration. Consequently, a special heat and mass transfer process formed and the heating rate of coal particles during pyrolysis was largely increased, reducing the occurrences of secondary reaction and favoring more targeted products to be obtained [11,12].

As a fossil fuel, coals show significant differences in dielectric properties due to complex coal-forming conditions, resulted in huge difference in MW absorption capabilities [13]. The dielectric property of lignite is usually small, and the MW absorption capability is poor [14]. As a result, lignite can not be heated to a high enough temperature to induce pyrolysis in a short time. A common method for MW pyrolysis of these weakly absorbing materials is adding a strong absorbing substance into it, namely MW receptor [15–18].

Published studies on lignite pyrolysis behaviors, such as gaseous product evolution characteristics, morphological and structural changes of lignite are rare [19,20]. Given that pyrolysis is important to improve lignite quality and expand the application of derived products, understanding the evolution characteristics of gaseous products and semi-char features in through this method is valuable for practical application of MW pyrolysis of lignite. Then, the objective of this study was to investigate the effects of the MW receptor and experimental parameters on the yield and characteristics of pyrolysis products of lignite, as well as determining the relationship between lignite type and the characteristics of gaseous products, semi-char formed during pyrolysis of raw lignite.

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2. Experiment and methods

2.1. Sample and materials

Three Chinese lignite were used in this study, which are Baorixile lignite (BR), Dayan lignite (DY), and Shengli lignite (SL), collected from Eastern Inner Mongolia, respectively. The proximate and ultimate analysis of these lignite shown in Table 1 showed the high H/C and O/C atomic ratios in the lignite, which are related to the amount of aliphatic in the lignite. The C:H:O atomic ratio of the original lignite was 1.5:1:0.3, 1.1:1:0.2, and 1.4:1:0.2, indicating the numbers of unsaturated bonds in the lignite [21,22].

Fig. 1 displays the Fourier-transform infrared spectra (FTIR) of three lignite. The analysis of the spectra showed that the same functional groups are present for all the samples studied, but the intensities of the major peaks of the spectra are different for the various samples. The significant absorption band at approximately 3500–3700 cm^{-1} assign to OH groups. The absorption peaks at the 3000–2700 cm^{-1} zone correspond to the absorption peak of the aromatic hydrogen, CH stretching and aliphatic hydrogen. Significant absorption peaks for the oxygen-containing functional groups and C—O—R structures can also be observed in the 1800–1100 cm^{-1} and 1100 cm^{-1} zones respectively. The aromatic hydrogen was located in the 900–700 cm^{-1} zone. Furthermore, the significant absorption band at approximately 1700 cm^{-1} and presence of structures containing CO groups are consistent with the low rank of the lignite. These structures are probably due the presence of resinite [23,24].

The samples having higher H/C atomic ratio, DY, has relatively stronger peaks at the 3000–2800 cm^{-1} region (CHx stretching vibration) than that of lower H/C atomic ratio samples. In addition, BR and SL, with the highest O/C atomic ratio, shows relative stronger peak at the 1800–1000 cm^{-1} region than that of the other samples, which was ascribed to oxygen-containing structures [25].

2.2. Pyrolysis experiments

Pyrolysis experiments were carried out using a quartz reactor on a MW oven operating at a constant frequency of 2450 MHz and the maximum power output of 1000 W. The quartz reactor was specially designed and the volatile matters could leave the reactor quickly during pyrolysis. The schematic diagram of the experimental setup is shown in Fig. 2. Raw coal samples were crushed and sieved below 200 mesh prior to pyrolysis experiments. In this study, the temperature of the samples was measured by inserting a thin thermocouple into the coal sample from the top of the reactor during MW heating.

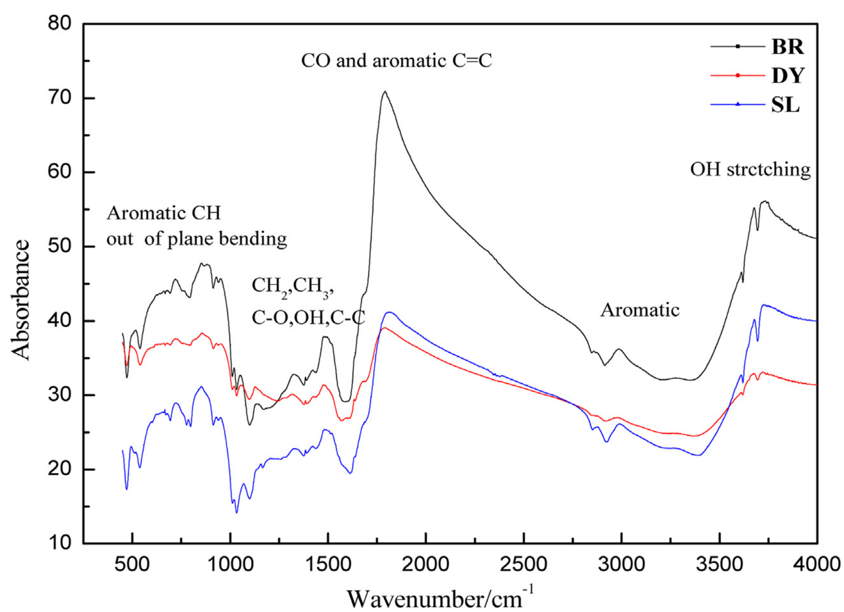

Fig. 1. FT-IR spectra of three lignite.

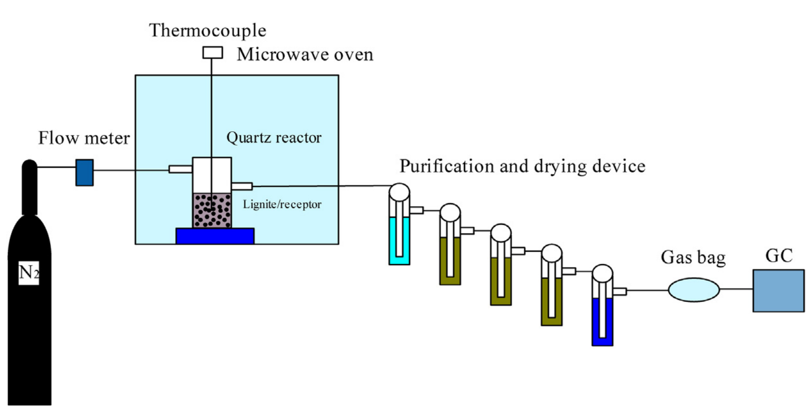

Fig. 2. Schematic diagram of the MW pyrolysis experimental setup.