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Full Length Article

Improvement on slurry ability of lignite under microwave irradiation

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HIGHLIGHTS

- The slurry ability of lignite after microwave irradiation was improved.
- A novel method was proposed to quantify the static stability of LWS.
- The $A_{H/C}$ and $A_{O/C}$ of lignite decreased after microwave irradiation.
- The hydrated film of lignite became thinner and the dispersant adsorption capacity increased.

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ABSTRACT

Under 900 W, the effects of microwave irradiation time on the solid concentration, rheology and static stability of lignite water slurry (LWS) were investigated. The results showed that with the gradual increase of microwave irradiation time the hydrated film on lignite became thinner and it contributed to the maximum solid concentration of lignite increased from 51.63% to 55.30% (irradiated for 12 min). At the same time, the oxygen/carbon and hydrogen/carbon atomic ratios decreased, the moisture content and oxygen-containing functional groups gradually removed, and the lignite surface became smooth. The changes of these interfacial properties improved the pseudo-plasticity and reduced the yield stress of LWS. Besides, the changes in lignite surface caused larger dispersant adsorption on lignite surface and therefore enhanced the static stability of LWS.

1. Introduction

With the abundant lignite reserves of 131.1 billion tons, accounting for about 13% of the total coal reserves, lignite-derived fuels could play a dominant role in the future energy [1,2]. Direct shipping of lignite is not economic and safe because of its high moisture content, low calorific value and high volatile [3]. Preparing lignite into lignite water slurry and then converting it in situ as a chemical material is one of the most important ways for lignite utilization. However, the slurry ability of lignite is poor due to its high inherent moisture content, developed pore structures, abundant oxygen-containing groups and fusinite [4]. Therefore, preparing upgraded lignite into coal water slurry is a new direction of clean coal utilization.

Thermal heating [5], fluidized-bed drying process [6], mechanical thermal expression [7] and hydrothermal treatment [8] have been applied to lignite dehydration. Compared with these conventional dehydration techniques, the main advantages of microwave dehydration technique are real-time, rapid, selective and efficient [9–15]. This is because it forms the same direction of temperature gradient, pressure gradient and moisture migration, which improves the condition of moisture migration and shortens the dehydration time [16]. Seehra [17] found that the efficiency of microwave dehydration is an order of magnitude higher than that of thermal heating. The internal high temperature and pressure from microwave irradiation can remove large amount of moisture in lignite, destroy the pore structures and oxygen-containing functional groups of lignite at the same time. These variant changes on the physical and chemical properties of lignite after microwave irradiation will improve its slurry ability [18]. Zhu et al. [19] found that the maximum solid loading of lignite increased by 4.55% after being irradiated at 900 W for 6 min. Wang [20] discovered that microwave irradiation had a good suitability for various lignite in improving the slurry ability. Therefore, microwave irradiation is an effective method for further utilization of lignite.

Microwave technique has been widely used in lignite dehydration lab tests, and it has been proved that microwave irradiation has the potential to enhance the lignite slurry ability [19].

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However, these researchers didn't study the important factors that directly affect the slurry ability of lignite, such as the thickness of hydrated film and the amount of dispersant adsorption on lignite, as well as the entire properties of LWS wasn't measured. So in this work, the interfacial property changes (such as moisture content, coal characteristic, oxygen-containing functional groups, and surface morphology) on lignite, the thickness of hydrated film and the amount of dispersant adsorption on lignite before and after microwave irradiation were investigated to adequately elaborate the effects of the microwave irradiation on maximum solid concentration, rheology and static stability of LWS. A novel method for systematically characterizing and quantifying the static stability of LWS between 7 days was also proposed.

2. Experimental

2.1. Materials

Lignite from the Inner Mongolia was used in this investigation. The raw coal was crushed and sifted to particle size less than 3 mm, and then ground to two particle sizes groups with the volume average particle sizes of 61.82 μm and 20.74 μm respectively.

2.2. Experimental methods

2.2.1. Microwave dehydration experiments

Microwave dehydration experiments were performed in a microwave oven with a frequency of 2450 ± 50 MHz, a maximum power output of 900 W, and a microwave cavity of 0.014 m^3. The mass ratio of coarse and fine samples was 7:3 for highest packing efficiency according to Tu [21]. These samples were evenly mixed and irradiated in the microwave oven for 2, 4, 6, 8, 10 and 12 min which are defined as S2, S4, S6, S8, S10 and S12, respectively. As a contrast, the same ratio of coarse and fine sample (defined as S0) was dried in a vacuum drying oven for 360 min.

2.2.2. Oxygen-containing functional groups measurements

The active oxygen-containing functional groups in lignite mainly include carboxyl and phenolic hydroxyl groups [4]. To quantify their contents, chemical titration experiment was carried out according to Schafer's [22] research.

Table 1
Maximum solid loading of lignite samples under different microwave irradiation time.

Microwave irradiation time/min	0	2	4	6	8	10	12
Maximum solid concentration/%	51.63	52.50	52.86	53.19	53.62	54.59	55.30
Standard deviation	0.12	0.14	0.07	0.17	0.12	0.11	0.13

Table 2
Coal characteristic analysis of lignite before and after microwave irradiation.

Sample	Proximate analysis (%)				$Q_{b,ar}$	Ultimate analysis (%)					$A_{O/C}$	$A_{H/C}$
	M_t	A_d	V_{daf}	FC_{daf}	(MJ/kg)	C_{daf}	H_{daf}	N_{daf}	S_{daf}	O_{daf}		
S0	0.54	16.63	50.03	49.97	18.35	69.86	5.92	1.16	1.06	21.99	0.236	1.017
S2	17.95	17.26	49.17	50.83	19.53	71.41	5.34	1.17	1.17	20.92	0.220	0.897
S4	11.69	17.51	47.81	52.19	20.38	72.42	4.93	1.14	1.09	20.50	0.212	0.817
S6	3.73	17.74	47.26	52.74	20.44	72.80	4.80	1.18	1.00	20.21	0.208	0.792
S8	2.60	18.70	46.48	53.52	20.96	73.84	4.56	1.21	1.05	19.39	0.197	0.741
S10	1.73	18.78	44.58	55.42	21.40	74.21	4.51	1.21	0.97	19.11	0.193	0.729
S12	1.08	18.86	43.63	56.37	21.44	74.50	4.35	1.20	0.97	18.99	0.191	0.700

Note: *M* refers to moisture content. *A*, *V*, and *FC* refer to ash, volatile, and fixed carbon contents, respectively. Q_b refers to the bomb calorific value. "t" refers to total moisture. "d" and "ar" represents dry basis and air dry basis respectively. "daf" refers to dry ash-free basis.

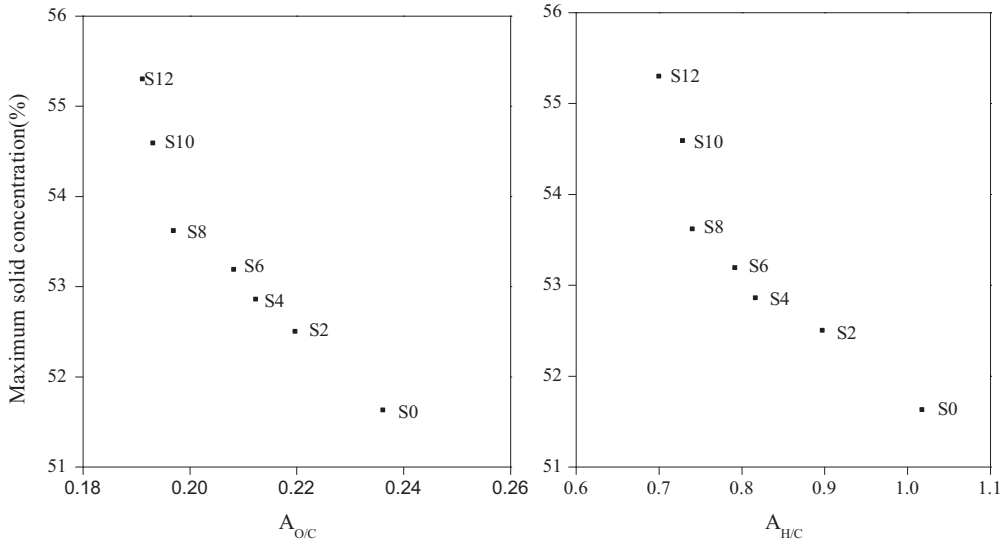

Fig. 1. Relationship between the $A_{O/C}$ and $A_{H/C}$ and the maximum solid concentration.