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Caking property and active components of coal based on group component separation

Qin Zhihong *, Li Xiang, Sun Hui, Zhao Cuicui, Rong Liman

Key Laboratory of Coal Processing and Efficient Utilization, School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China

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ABSTRACT

The content and the caking index of the heavy, the dense medium and the loose medium components of coal, obtained by extraction and stripping with CS_2/N-methyl-2-pyrrolidinone mixed solvent (1:1 by volume), were studied and correlated with the caking property of raw coals. Images of the three group components after heat treatment were analyzed. The results show that both caking index (G) and maximum thickness of plastic layer (Y) of coals have a good linear relationship with the content of the medium component; the dense medium and the loose medium components are the two key factors to determine the caking property of raw coals-they are the source materials of fluidity and swelling of coal, respectively; the heavy component without the swelling and fluidity was cohered by the other components; two new indexes, which can extend current understanding of the caking properties, were introduced.

1. Introduction

Coal blending is a powerful means of increasing energy consumption efficiency, reducing fuel costs and lowering pollutant emission, and therefore has attracted much attention and been investigated extensively [1,2]. The means of coal blending, with some uncertainties, was and will be dominated by experience for a long time both at home and abroad [3–6]. However, traditional coal quality indexes (e.g., V_{daf}, Y, and G) for coal blending cannot accurately reflect the caking properties, because the behavior of coals during the carbonization process is very different for the several classes of coals [7,8]. Furthermore, when the type and quality of coals change, the quality of coke produced will be badly affected. It is therefore necessary to find a new reasonable way which can reflect the essence of coke-making and to clarify the interaction among coal components. To this end, extensive research has been carried out by scholars at home and abroad [9–12]. Some developments have been achieved, especially in the application of coal petrology [13–15], but each method of coal blending under different conditions, determination methods, etc., is limited, e.g., geographical limitations exist to different degrees. The reason is that, up to now, an index which can accurately characterize the caking properties of the active components in coal has not been found.

Though some concepts concerning the active components [16] and inert components [17] in coal have been put forward by coal petrologists, this kind of classification, with strong human factors, is just on the limits of physics. If a whole coal is heat-treated, it is difficult to ascertain the role of the caking component originally present in raw coal, since decomposition of the caking components takes place and new caking components are produced from decomposition of the coal matrix [18]. Therefore, it is necessary to separate the extracts (caking components) and the coal matrix without any reaction [19]. Early studies report that there are some associations between the caking properties and the solubility in various solvents of coal [20–24]. The object of this study is to investigate the relationships between the caking property and the content of group components and the caking property of raw coal, and to clarify the essential reason for the caking property of coal.

2. Experimental

2.1. Materials

Five coals, including a fat coal, a gas coal, a gas-fat coal, a coking coal, and a meager-lean coal, collected from Weitian Chemical Co., Ltd., Xuzhou, China, were pulverized into appropriate sizes for use. The properties of the coal samples are summarized in Table 1. The proximate analyses and the maximum thickness of the plastic layer (Y, mm) of coal samples were determined according to Chinese standards GB/T212-2008 and GB/T479-2000, respectively. Commercially available organic solvents were used without further purification.

* Corresponding author. Tel.: +86 516 83591059.
E-mail address: qinzh1210@163.com (Z. Qin).

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Table 1
Properties of raw coals used in the tests.

Sample	Proximate analysis (%)				Y (mm)	Contents (wt%, daf)			
	M_{ad}	A_d	V_{daf}	FC_{daf}		E_{HC}	E_{LMC}	E_{DMC}	E_{MC}
Fat coal	0.02	7.96	33.89	58.13	25.26	67.37	22.52	12.92	35.44
Gas coal	0.03	8.24	36.66	55.07	18.54	75.44	13.32	11.27	24.59
Gas-fat coal	0.03	8.29	38.52	53.16	29.57	72.85	18.54	9.54	28.08
Coking coal	0.01	8.54	28.63	62.82	12.67	79.27	10.53	11.67	22.20
Meager-lean coal	0.01	7.91	15.55	76.53	0	95.45	0.29	2.29	2.58

Note: M_{ad}: moisture (air dried base); A_d: ash (dry base, i.e., moisture-free base); V_{daf}: volatile matter (dry and ash-free base); FC_{daf}: fixed carbon content (dry and ash-free base). Due to a small amount of residual solvent, the sum of E_{HC} and E_{MC} of some coal was probably more than 100% (by weight).

2.2. Coal extraction and stripping

Extraction and stripping of coal was performed in the same way as that described elsewhere [25]. Coals (particle size 74 μm) were extracted with a mixed solvent (carbon disulfide (CS_2) and N-methyl-2-pyrrolidinone (NMP) (1:1, V/V) for 3 h at room temperature. After this, the insoluble part was the heavy component, i.e., the residue, symbolized as HC. Three layers after being added, a third solvent for stripping and centrifugation appeared. After separation and treatment, three kinds of group-components, i.e., the dense medium, the loose medium and the light components which were symbolized as DMC, LMC, and LC, respectively, were obtained. DMC and LMC are known collectively as the medium component symbolized as MC. After being dried, they were stored in jars for use. The procedures illustrated above were the group component separation as shown in Fig. 1. The content of LC was so small that it was negligible. The corresponding results are summarized in Table 1. Contents of group components in raw coals were calculated as follows:

$$E_i = M_i/M.$$

where M_i = the weight of HC, LMC, MC and DMC, respectively; and M = the weight of raw coal.

2.3. Caking index measurement

The measurement of caking index (G) according to the national standard of China (GB/T 5447-1997) was carried out in the same way as that described elsewhere [26,27]. The results are listed in Table 2. Briefly, 1 g sample (<0.2 mm) was mixed with 5 g standard anthracite (Ruqigou, China, <0.2 mm). The mixture was carbonized in an inert atmosphere at 850 °C for 15 min. The coke obtained was subjected to the drum test (5 min, 50 r/min) twice, which is slightly different from the Roga index testing (requiring three drum tests). The sample preparation, stirring, carbonization and drum test are all the same as those of the Roga index measurement, and the caking index (G) is calculated according to Eq. (1). When the measured value of G is smaller than 18, the test should be repeated. At this time, a mixture of 3 g sample and 3 g specified anthracite is contained in a crucible and tested. The results are calculated by Eq. (2).

Table 2
Caking index of raw coals and their group components (wt%, daf).

Sample	G	G_{HC}	G_{LMC}	G_{DMC}
Fat coal	90.49	11.47	96.60	92.22
Gas coal	53.99	11.56	89.68	88.47
Gas-fat coal	97.69	12.25	94.77	90.25
Coking coal	60.63	10.11	94.92	90.37
Meager-lean coal	15.23	10.00	92.45	91.08

$$G = 10 + \frac{30m_1 + 70m_2}{m} \quad (1)$$

$$G = \frac{30m_1 + 70m_2}{5m} \quad (2)$$

where m is the weight of coal sample (g); m_1 and m_2 are the weights (g) of the coke fraction (>1 mm) after the first and second drum tests, respectively. In Eq. (2), the coefficient, 5, in the denominator makes the value of G less than 18 for weakly caking coals.

2.4. Crucible swelling and fluidity experiment

The heavy, the dense medium, and the loose medium components of the five coals were pressed under 5 MPa pressure into tablets with the same size loaded into the crucibles. The crucibles were placed in the oven under an inert atmosphere and heated at a rate of 5 °C/min to 550 °C, then held at this temperature for 1 h, then cooled down to room temperature in about 10 h.

3. Results and discussion

3.1. Linear regression analyses

Table 2 indicates that the caking properties of coals differ markedly from each other; however, it is apparent that the caking properties of the group components do not depend on coal type. To study the inner relationships between the caking properties of raw coals and the content and the G value of their corresponding group components after heat-treatment, we have performed linear regres-

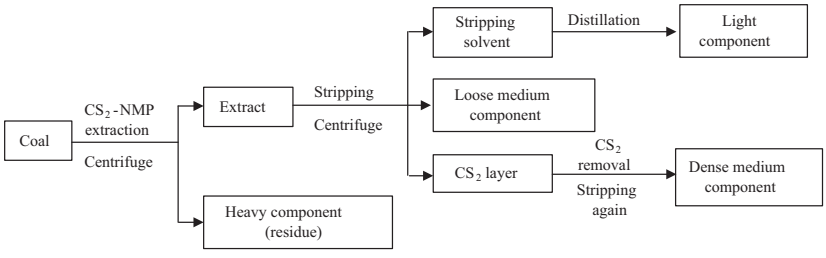

Fig. 1. Procedure for the group components separation of coal.