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Preparation and coking properties of coal maceral concentrates

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ABSTRACT

The concentrates with different maceral contents were obtained from Kailuan coking coals with different coal ranks ($\overline{R_{o,ran}}$ varying from 0.88% to 1.73%) by float–sink separation in lab. Then these concentrates were characterized by proximate analysis, ultimate analysis, petrography analysis and coking index determination. The results show that the vitrinite is characterized as nature of lower carbon content, higher hydrogen content, higher volatile matter and stronger caking property compared to inertinite. The relationships between variation rate of volatile matter and maximum volatile matter and coal ranks are identified, and a linear model is developed for fast determination of the maceral contents. Compared to inertinite-rich concentrate, the blending ratio of vitrinite-rich concentrate is increased by 13%, which is considered to be a potential technique based on maceral separation for expanding the coking coal resources.

1. Introduction

China is rich in coal resources. However, the medium rank coals (namely coking coal), which only account for 29.0% of the total coal resources, are in pressing demand. Strongly caking coals (fat coal and coke coal) account for 1/3 of total coking coal resource, and most of them are not excellent in quality and are classified as hard-to-clean coal. Therefore, it offers important economic benefits by planning and utilizing coking coal resources rationally in China, which is of great importance to solve shortage of coking coal resources and to expand coking coal resources in the long run [1–5].

Coal petrography analysis mainly focuses on coal maceral composition, origin, formation, structures, characteristics and other properties on processing and utilization. The method has been widely applied in the fields of coal combustion, liquefaction, gasification and cokemaking, etc. [6–11]. Coal macerals can be classified into three groups, namely vitrinite, exinite (liptinite) and inertinite. Maceral content in coals of various ranks varies in proportions. Generally speaking, vitrinite, the major ingredient in coal macerals, accounts for as much as 40–80%, by volume, secondly inertinite 30–50%, by volume, and least exinite minus 10%, by volume [12].

Maceral properties and their contents, especially vitrinite and inertinite, are important to coal comprehensive utilization. There are numerous studies of maceral properties, especially chemical properties using electron microprobe, Fourier Transform Infrared Spectrometry technique (FTIR), X-ray photoelectron spectroscopy (XPS) and ^{13}C NMR [13–17].

When coal is heated, it undergoes physical and chemical changes, releases moisture content, volatile matter and produces solid residue. Two important physicochemical changes are observed during the heating of coal: thermoplastic stage (reactive thermal decomposition) and solid residue contracts at higher temperature range (secondary degasification stage). The coking properties depend mainly on the coal rank and petrographic composition of coals. Vitrinite and inertinite are the most significant constitutes which affect the properties of coking coal and behave different in the process of heating [18–23]. The chemical composition of macerals and the changes of macerals in pyrolysis show different in cokemaking, i.e., vitrinite and exinite, which have strong caking property and belong to reactive group, shape the formation of coke and produce volatile gaseous materials and non-volatile liquid substances in pyrolysis while inertinite which belongs to inert group is involved in the formation of coke structure components and has limited change [24]. Non-caking coal had no caking property in northwest region (China) because of its high inertinite content [25]. And vitrinite-rich concentrates had higher caking property than corresponding raw coals [26]. Therefore, based on coal maceral separation technique, reactive group concentrates are obtained by reducing inert group and used for cokemaking, which will increase the blending ratio of weakly caking coal, expand the coking coal resource and offer great economic benefits.

The objective of this paper is to explore the maceral properties of coals that have different ranks and to study the possibility of expanding Chinese coking coal resource by blending reactive group

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concentrates of weakly caking coal for cokemaking using maceral separation technique. Therefore, five coking coals of varying ranks from Kailuan coalfield, which is an important basin of high quality coking coals in China, were selected and separated into concentrates of various maceral contents. The properties, such as elemental composition, volatile matter and coking index, were investigated. Furthermore, the coking index determination of mixtures, the strongly caking coal and the concentrates of weakly caking coal of various maceral compositions, was also carried out in this paper.

2. Experimental

2.1. Coal samples

Five coking coals are from five different mines in Kailuan coalfield, and have density −1.40 kg/L and size 50–0.5 mm and vitrinite reflectance varying from 0.88% to 1.73%, and are labeled with DK, QK, FK, ZK and LK, respectively. Those five coking coals were sampled for the following preparation and properties tests of corresponding maceral concentrates. To explore the possibility of expanding the coking coal resource, a weakly caking coal with vitrinite reflectance 0.64% in Pingshuo (short for PS) was selected to be used for blend additive.

2.2. Preparation of coal maceral concentrates

Preparation of coal maceral concentrates was carried out using float–sink separation in lab at specific gravities of 1.30 and 1.35 for all five coal samples in Fig. 1. The concentrates of various densities were generated based on the density difference of macerals for the study. Take DK (labeled with DK (−1.40) for an example, the concentrates with −1.30, 1.30–1.35 and 1.35–1.40 kg/L were labeled with DK (−1.30), DK (1.30–1.35) and DK (1.35–1.40), respectively.

2.3. Properties testing of maceral concentrates

The ash content, moisture and volatile matter were determined following GBT 212-2008 standard procedure. The elemental analysis was performed using a 5E-CHN2000 elemental analyzer with 0.01 ± 0.001 g coal sample for carbon (C), hygrogen (H) and nitrogen (N), a SDSM-IV sulfur analyzer with 0.05 ± 0.005 g coal sample for sulfur (S), and oxygen (O) was obtained by difference. The coking index was determined following GBT 479-2000 standard procedure.

The petrography analysis was performed with Leica DM4500P microscope and Deta V4000 photometer following GBT 6948-2008 and GBT 8899-1998 standard procedures. About 2 g of coal sample was mixed with shellac at the volume ratio of 2:1 and heated to 50 °C for preparing a briquette, and then the briquette

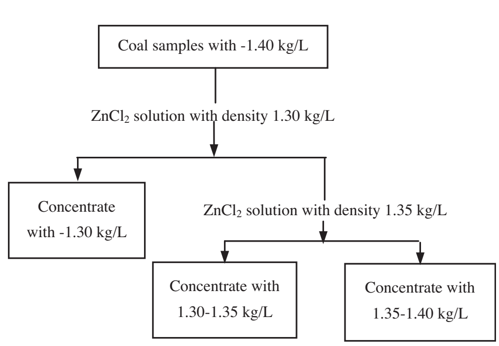

Fig. 1. Separation processes of coal macerals.

was polished. The polished briquette was analyzed for the content of exinite (E), vitrinite (V), inertinite (I) and mineral matters (M). The same briquette was also used to determine mean random vitrinite reflectance in oil.

2.4. Coal blending

To determine which factor, ash content or maceral composition, has greater effect on the coking index, coal blending tests were performed with vitrinite-rich concentrates and pure gangue at varying blending proportion; meanwhile, the coking index of mixtures was determined.

In order to explore the possibility of expanding the coking coal resources based on maceral separation, the weakly caking PS coal sample was selected to produce the concentrates with different maceral contents. The concentrates were then used for coal blending with strongly caking FK coal sample at varying blending proportion. The coking index of the blending coal samples mixture was determined.

3. Results and discussion

Table 1 presents the properties and maceral compositions of Kailuan coal samples and their maceral concentrates.

3.1. Generation of maceral concentrates

As shown in Table 1, the mean random reflectance of vitrinite in oil ($\overline{R_{o,ran}}$) varies from 0.88% to 1.73%, which covers most of the range of coking coal used for cokemaking. From the results of float–sink test, it is demonstrated that density-based separation is a good technique for marceral separation. Vitrinite content varies from 85.48% to 98.62%, by volume, in vitrinite-rich concentrates with density −1.30 kg/L while inertinite content varies from 47.49% to 71.45%, by volume, in inertinite-rich concentrates with density 1.35–1.40 kg/L. There are also concentrates with the intermediate vitrinite content. The levels of enrichment are quite satisfactory for the following procedures. Also it shows that the exinite content remains almost unchanged with an increase in separation density, which is mainly due to the fine size of exinite and its high dissemination with large bulk vitrinite or inertinite, as shown in Fig. 2, thus has poor performance.

3.2. Elemental compositions

Fig. 3 describes the details of the variation in elemental compositions of coal concentrates with various vitrinite contents. From Fig. 3a and b, it is concluded that for the same rank coal, compared to inertinite, vitrinite is characterized as nature of lower carbon content and higher hydrogen content. Generally, hydrogen content decreases with an increase in rank, but it should be noted that, there is an exception that FK coal sample with greater vitrinite reflectance has more hydrogen compared with QK coal sample. It cannot be inferred from Fig. 3c that vitrinite always contains more or less nitrogen content than inertinite due to the fluctuation of nitrogen with an increase of vitrinite content. Meanwhile, there is no obvious and distinct variation in nitrogen content as the rank increases. There is similar situation for the relationship of sulfur content and vitrinite content, as seen in Fig. 3d. It is difficult to determine that which one, vitrinite or inertinite, contains more sulfur content. Also, it is attained that there is not close relationship between sulfur content and rank. And it should be pointed out that FK coal sample has great sulfur content, as high as 1.98% and sulfur content accounts for 2.16% in vitrinite-rich concentrate FK (−1.30).