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Technical note

Enhancing flotation cleaning of intruded coal dry-ground with heavy oil

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A B S T R A C T

Intruded coal is one type of unconventional coal resources in many coal fields of China. The research into the flotation of intruded coal has not received enough attentions. Plenty of intruded coal fines are produced during coal mining, screening and gravity separation. However, the intruded coal fines are difficult to float using common oily collectors because the intruded coal surface is porous and naturally hydrophilic. In this investigation, heavy oil was used as a collector associated with dry-grinding process to enhance the flotation recovery of intruded coal. The flotation recovery of intruded coal dry-ground with heavy oil was 82.40% which was higher than that (71.28%) of coal dry-ground with kerosene. The mechanism of heavy oil enhancing the flotation recovery of intruded coal was fully discussed by a combination of Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), attachment time measurements. FTIR results showed the heavy oil contained more unsaturated hydrocarbon and oxygen containing groups than the kerosene. The coal-bubble attachment was greatly improved because the attachment time was reduced after the dry-grinding with collectors. The intruded coal surface hydrophobicity was effectively improved by heavy oil through the adsorption of heavy oil drops, which made bubble catch intruded coal particles readily. In addition, the pores of intruded coal surface were filled by plenty of crushed coal fines during the dry-grinding process, which enlarged the contacting area for coal-bubble attachment.

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1. Introduction

Intruded coal is an unconventional coal resource in many coal fields of China (Dun et al., 2014). The intruded coal is produced by the heating of magmatic intrusion and coal fires underground. Both the high temperature heating and high pressure conditions make coal suffer a specific metamorphism process. The coal surface properties are changed, including physical and chemical properties.

In coal flotation industry, surface hydrophobicity is the main factor determining the floatability of coal particles (Albijanic et al., 2010). The hydrophobicities of bituminous and anthracite coals are reduced by both the heating of magmatic intrusion and coal fires. The intruded coal becomes difficult to float using common oily collectors. However, the flotation of intruded coal has not been paid enough attentions, and these coal fines are refused causing a serious waste of coal resource. A comparative study regarding the flotation performance of Juji intruded and conventional coals was conducted in our previous study and it showed the flotation recovery of conventional coal was much higher than that of intruded coal because the surface properties of Juji intruded coal was porous and relatively low hydrophilic (Xia et al., 2016).

Why the flotation of intruded coal should be paid sufficient attentions? Coal mining and crushing processes produce plenty of coal fines including intruded coal fines and others. In addition, gravity separation process produces another part of coal fines through the collision between lump coal and separators. The water immersion also has a negative role in the control of coal fines because coarse coal particles may be liberated during the water-based separation process. Therefore, a large number of intruded coal fines are produced and these coal fines usually need the flotation method to upgrade because these coal fines are difficult to separate using gravity separators, even using ultrasonic energy (Tao and Parekh, 2000), enhanced gravity separators such as Falcon and Multi Gravity Separator (Honaker et al., 2000; Özgen et al., 2011).

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In the published reports, there are many improvements regarding the effective flotation of low rank/oxidized coals (Dey, 2012). The surface properties of intruded coal are similar to the properties of low rank/oxidized coals. The effective flotation technologies for low rank/oxidized coals can be transplanted into the flotation of intruded coal. Grinding dry low rank coal with collector not only increased the flotation recovery but also reduced the clean coal ash content (Ateşok and Celik, 2000). The hydrophilic surface of coal could be covered by the collectors and hence the floatability of ground coal was enhanced (Ahmed and Drzymala, 2012).

This investigation was to use heavy oil as a collector and enhance the flotation recovery of Ningxia intruded coal through dry-grinding process. The mechanism of heavy oil enhancing the flotation recovery of intruded coal was fully discussed. Throughout this paper, a novel method for the effective flotation cleaning of intruded coal was proposed.

2. Experimental

2.1. Materials

Intruded coal samples were selected from Ningxia province of China. The lump intruded coal was selected by density fluid of less than 1.5 kg/L. Then, lump coal was crushed and screened to pass 0.5 mm. The ash content of coal sample is 8.82% on an air dried basis.

2.2. Dry-grinding treatment

The grinding process was conducted in a laboratory ball mill (QM-1). The volume of ball mill was 1 L. The grinding media was zirconia ball. The rotation speed of grinding tank was 300 r/min. 100 g intruded coal was dry-ground for 15 min with heavy oil and kerosene, respectively. After grinding process, ground coal samples were forwarded to flotation tests. The dosage of heavy oil or kerosene was fixed at 10 kg/t coal.

The size compositions of three coal samples, i.e. non-ground coal, coal dry-ground with heavy oil and coal dry-ground with kerosene were analyzed by the wet-screening process using 0.25, 0.125, 0.074 and 0.045 mm size screens. At last, five size fractions were obtained, i.e. 0.5–0.25, 0.25–0.125, 0.125–0.074, 0.074–0.045 and < 0.045 mm. The characteristic curve for the size composition of each coal sample was drawn.

2.3. SEM measurement

Quanta 250 SEM (FEI, USA) was used to analyze the surface morphology of intruded coal particles before and after dry-grinding process. The magnification time was fixed at 2000. Before the SEM tests, the coal samples were sputter-coated with a layer of gold.

In this investigation, three types of coal samples were prepared for the SEM measurements. The first sample was non-ground coal, i.e. raw coal. The second sample was the coal dry-ground with heavy oil. The third one was the coal dry-ground with kerosene.

All the above-mentioned three types of coal samples were conditioned in the flotation cell for 3 min. Then, they were forwarded to the wet-screening process to obtain a specific size fraction, i.e. 0.125–0.125 mm for the SEM analysis. The purpose of the conditioning and wet-screening processes is to remove ultra-fine coal particles as far as possible from coal surface (such as weakly adsorbed fines) and to investigate whether ultra-fine coal particles can strongly adsorb on the pore and surface of coal particles. If these ultra-fine coal particles cannot be removed from the coal surface through the conditioning and wet-screening processes, these fines will also be difficult to remove during the flotation process and hence have a significant role in the floatability of intruded coal particle.

2.4. FTIR measurement

FTIR spectrums of intruded coals before and after dry grinding process were obtained with KBr plates. The FTIR spectrums of kerosene and heavy oil were also obtained with KBr plates. When the pellet was prepared, one drop of kerosene or heavy oil was put on the surface of plate, and then the plate was forwarded to the FTIR measurements.

A Fourier Transform Infrared Spectroscopy Vertex 80v (Bruker, Germany) was used in this investigation and the spectrum was obtained at 2 cm^{-1} resolution, between 4000 and 400 cm^{-1}. Three types of coal samples, i.e. non-ground coal, coal dry-ground with heavy oil and coal dry-ground with kerosene were analyzed.

2.5. Attachment time measurement

The bubble-particle attachment time measurements were conducted using the Attachment Timer, made by University of Alberta, Canada (Gu et al., 2003).

The same three coal samples used in the SEM measurements were also used in the attachment time measurements. Firstly, coal sample was transferred to a small cell. Then, the distilled water was transferred to the cell. A bubble holder was on the top of the coal particle bed. One bubble was generated using a micro syringe and then hold by the bubble holder. Next, the bubble was kept in contact with the coal particle bed for a controlled contact time from 10 ms to 10000 ms (Xia and Wang, 2017). The attachment of bubble-coal particle was visually observed through the lens and CCD camera linked to a monitor. 10 repeated measurements at different positions of particle bed were obtained and the final coal-bubble attachment time was obtained using the arithmetic mean values of 10 attachment times.

2.6. Flotation tests

The flotation tests were conducted in a 1.5 L XFD flotation cell. The impeller speed of flotation machine was 1900 r/min and the airflow rate was 0.25 m^3/h.

The dry-ground coal sample (100 g) was first pre-wetted in the flotation cell for 3 min. Then, the frother (2-Octanol) was added into the flotation cell at a dose of 0.2 kg/t coal and the pulp was conditioned for 1 min. At last, the air inlet was opened and the flotation products, such as clean coal and tailings were collected. The flotation results were analyzed using clean coal ash and clean coal yield.

3. Results and discussion

3.1. Size composition analysis

As shown in Fig. 1, the characteristic curves for size compositions of three coal samples are illustrated. The size composition of coal dry-ground with heavy oil is similar to that of non-ground coal. However, the size composition of coal dry-ground with kerosene becomes much finer than that of coal dry-ground with heavy oil. The difference in the size composition between coal dry-ground with kerosene and coal dry-ground with heavy oil should be in a reasonable range because the same grinding time and machine were applied. Fig. 1 indicates this difference is out of a probable range. Many fines are produced during the grinding process. These fines will adsorb on coal surface and fill in the pore of intruded coal surface during grinding process. For the coal dry-ground with

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