Physicochem. Probl. Miner. Process. 53(1), 2017, 553−568

www.minproc.pwr.wroc.pl/journal

Physicochemical Problems of Mineral Processing

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

Received June 20, 2016; reviewed; accepted November 23, 2016

APPLICATION OF SPECIAL COLLECTORS AND FLOTATION COLUMN FOR BENEFICIATION LOW RANK COAL SLIMES

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Abstract: In this study the effect of a flotation device as well as non-conventional collectors and diesel oil on flotation response of low rank coal was investigated at different conditioning times. Additionally, Fourier transform infrared spectrometer, specific surface area analyzer, scanning electron microscopy, and contact angle measurements were used to determine the properties of coal and flotation of coal slime after conditioning with the collector. The results obtained from this study showed that the reagents containing oxygen-functional groups significantly improved the flotation of low rank coal. However, these oxygenated chemicals showed complex interactions with the surfaces of coal and gangue minerals. The combustible matter recovery at a low collector dosage was lower than that obtained at a higher consumption of collector while the ash content of concentrate could be higher. Therefore, it is important to create a suitable environment to separate low rank coals using oxygenated chemicals as collectors. A suitable conditioning time was crucial for the flotation performance. There was a marked decline in the concentrate recovery when the conditioning time was longer. This clearly indicated that flotation machines may not be the suitable equipment to separate the low rank coals. The better performance can be obtained by flotation column. The characters of flotation column which works under semi-static separation environment in column flotation zone and density separation in cyclone separation zone just met the requirements of low rank coal separation.

Keywords: *low rank coal, flotation, oxygenated chemicals, flotation column, combustible matter recovery*

Introduction

Coal flotation makes use of the natural hydrophobicity of the carbonaceous matter in coal. In order to enhance the hydrophobicity of the coal particles, oil materials such as diesel oil and kerosene are added as collectors industrially (Harris et al., 1995; Jia et al., 2000). For higher rank coals, the reagent consumption in flotation is low because

http://dx.doi.org/10.5277/ppmp170143

of the natural hydrophobicity of the coal. However, low rank coals are difficult to float due to its high content of oxygen-containing functional groups, most commonly, carboxyl, phenolic, and carbonyl functionalities on coal surface. These groups can reduce the hydrophobicity of the coal surface because the thick hydration shell will be generated through hydrogen-bonding interaction (Ceylan and Kucuk, 2004; Atesok and Celik, 2000; Xia et al. 2015). There are numerous holes and cracks on the coal surface which may lead to high collector consumption for low rank coal flotation (Xia et al., 2016). The poor flotation and high collector consumption are main obstacles to promote low rank coal flotation for industrialization.

The flotation reagents, especially collectors, usually play an important role in the flotation of either low rank coal or oxidized coal. In previous research, non-conventional reagents have been found very effective in the flotation of low rank coal. Sis et al (2004) conducted a research where ionic reagents were used as an alternative to conventional collectors in order to obtain clean concentrates from coal tailings of the Zonguldak Main Coal Washery in Turkey. Vamvuka and Agridiotis (2001) reported that the hydrophobicity of lignite was enhanced by cationic surfactants with better overall performance than anionic and nonionic surfactants. However, the selectivity of cationic dodecyl amine (DDA), a collector, for the reduction of ash content was not significant compared to that obtained with kerosene. Cebeci (2002) reported a better flotation performance of Yozgat Ayridam lignite using a nonionic surfactant rather than the cationic or anionic surfactant. Polat and Chander (1998) observed that a low-ash concentrate of a lignite coal with a higher combustible matter recovery was obtained by using a nonionic surfactant as a collector. Tetrahydrofurfuryl butyrate (designated here as THF-3) was found to be a very effective collector for both Pittsburgh No. 8 and Illinois No. 6 coals. For the same combustible matter recovery, the consumption was less than that for dodecane (Jia et al., 2002). This suggests that the THF series of reagents are effective alternatives as collectors in the flotation of both low rank coal and oxidized coal. Flotation of lignite was studied using kerosene along with different types of surfactants like cationic, anionic, and non-ionic surfactants (Zhang and Liu, 2015). It was found that the presence of surfactant with oily collector improved the flotation of low rank coal. It was further observed that the oxidized coal surface became hydrophobic after adding fatty alkyl propelene diamine, even when the oxidation was extensive (Shen and Wang, 2016).

On the other hand, flotation equipment also plays an important role in mineral separation. Since the flotation column was invented by Boutin and Tremblay (1964), the column flotation technique has developed rapidly and gradually became an important mineral concentration technology widely accepted by the mineral industry. Compared with conventional flotation machines, it features efficient self-cleaning and simple circuits (Zhang et al., 2013; Ding et al., 2001; Finch, 1995; Finch and Dobby, 1991; Flint et al., 1992; Honaker and Mohanty, 1996; Stonestreet and Franzidis, 1992). However, conventional flotation columns are run based on the theory referred to as air bubble mineralization by reverse collision. The improvement of the separation efficiency generally requires increased residence time and column heights. On the other hand, they normally have drawbacks (e.g. complexity, low reliability, and low separation efficiency) when mineral slime is very fine less than 20 μm. Therefore, a cyclonic-static micro-bubble flotation column (FCSMC) which employed flotation separation, cyclone separation, high–turbulence mineralization and cyclone scavenging has been designed.

In this study, the flotation tests using new collectors were designed for both flotation machine and flotation column (FCSMC). The interactions between collector molecules and coal surfaces were analyzed, especially in the separation process of flotation column. In addition, the properties of low rank coal with mainly regard to oxygenic functional groups and porosity were studied by using the test measurements such as Fourier transform infrared spectrometer (FTIR), specific surface area analyzer (BET) and scanning electron microscopy (SEM). Contact angle measurements were also used to indicate the flotation of coal slime. The reasons why the flotation of low rank coal was poor were also explored based on the results of these tests.

Experimental method and procedure

Materials

The coal samples (coal slime) and subbituminous coal were provided by Coal Preparation Plant in Ordos, China. The proximate analysis of coal samples were as M_{ad} = 5.96%, V_{ad} = 26.71%, FC_{ad} = 54.96%, A_{ad} =12.36%, where M_{ad} is the moisture content, V_{ad} volatile content, FC_{ad} fixed carbon content, and A_{ad} the ash content.

Table 1. Size distribution analysis data of coal samples

Size fraction (mm)	Yield (%)	Ash (%)	Cumulative oversize		Cumulative undersize	
			Yield (%)	Ash (%)	Yield (%)	Ash (%)
+0.5	0.26	9.12	0.26	9.12	100.00	12.32
-0.5+0.25	0.34	4.38	0.60	6.43	99.74	12.32
-0.25+0.125	2.99	3.74	3.59	4.19	99.40	12.35
-0.125+0.074	8.40	4.00	11.99	4.06	96.41	12.62
-0.074+0.045	14.37	7.55	26.36	5.96	88.01	13.44
-0.045	73.64	14.59	100.00	12.32	73.64	14.59
Total	100.00	12.32				

The size distribution analysis and the density composition of the coal slime are presented in Tables 1 and 2, respectively. As can be seen from Table 1, the dominant size fraction of the raw coal was -0.045 mm size fraction with a yield of 73.65% and ash content of 14.59%. The -0.25 mm particle size fraction accounts for 99.41% of mass with the ash content of 12.35%. The float-and-sink results (Table 2) showed that the yield of the -1.3 g/cm^3 density fraction was only 7.56%. The yield of the middle density fraction of 1.4-1.6 g/cm^3 amounts to 52.79%, indicating that the coal may be hard to separate. The ash content of the 1.80 g/cm^3 fraction was obviously high at 73.01%.

Table 2. Density distribution analysis of coal samples

Density (g/cm^3)	Yield (%)	Ash (%)	Cumulative float		Cumulative sink	
			Yield (%)	Ash (%)	Yield (%)	Ash (%)
-1.3	7.56	1.41	7.56	1.41	100.00	12.56
1.3-1.4	28.39	3.51	35.94	3.07	92.44	13.48
1.4-1.5	39.20	8.37	75.15	5.83	64.06	17.89
1.5-1.6	13.59	13.74	88.74	7.05	24.85	32.91
1.6-1.8	3.91	24.12	92.65	7.77	11.26	56.04
+1.8	7.35	73.01	100.00	12.56	7.35	73.01
Total	100.00	12.56				

Experimental procedure

FTIR analysis

The molecular structure of solid, liquid and gas can be confirmed by using a Fourier transform infrared spectrometer (FTIR). The surface functional groups of the low rank coal samples were tested by a Nicolet 380 type Fourier transform infrared spectrometer (Thermo) with a range of 4000–400 cm^{-1}. The scans were at a resolution of 4 cm^{-1} with a frequency of 32.

BET measurements

A 0.5 g sample of coal slime was degassed at 120°C for 4 h to remove moisture and residual volatiles prior to analysis. The specific surface area was calculated from the adsorption curve based on the volume of adsorbed gas in the relative pressure (P/P_0) range of 0–0.5 using the Brunauer-Emmet-Teller (BET) method. Pore size distributions and pore volume were determined from the adsorption curves in the pore size range of 1–100 nm under relative pressures (P/P_0) of 0.38–0.99 using the Barrett, Johner and Halenda (BJH) method.

SEM analysis

The surface morphology of coal slime was determined with the Quanta 250 type scanning electron microscope (SEM). Before the SEM analysis, the samples were sputter-coated with a layer of gold. The details operating parameters of SEM were as follows: HV 25.00 kV; WD 20.2 mm; pressure 1.21e^{-4} Pa and the spot was 2.5.

Contact angle measurements

The coal slime was dried at a low temperature after conditioning with the collector, and then the coal slime was firstly pressed into the plates. The plates of coal slime were measured using water contact angle analyzer (DSA100) such as a water droplet on the surface of coal plate in air.

Flotation

Diesel oil was used as a conventional reagent while a series of collectors, named FO1, FO2, and FO3, were used as non-conventional flotation reagents. Those were mixtures of diesel oil (hydrocarbon) and oxygenated chemicals (aldehyde, ketone, and carboxylic acid).

The conventional flotation machine tests were conducted in a 1 dm^3 laboratory flotation machine cell using 80 g of coal. The impeller speed of flotation machine was 2000 rpm, and the airflow rate was 0.2 m^3/h. At first, the coal slime was pre-mixed for 2 min. Then, the collector was added into the flotation pulp, and the pulp was conditioned for 2 min. At last, 2-octanol frother was added, and the pulp was conditioned for another 40 s. The concentrate was collected for 3 min.

The influence of different conditioning time was explored, and the operation was the same as mentioned above except the conditioning time. The flotation process is shown in Fig. 1. After adding the collector, the tests were carried on different conditioning times of 0.5, 1, 1.5, 2, 4, 8, 12, and 20 min, respectively. All of the tests were conducted at pH 7.

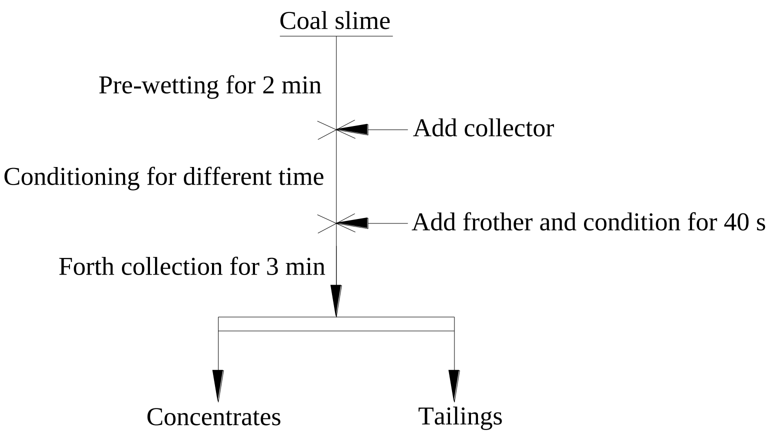

Fig. 1. Flotation process applying variable conditioning time

The flotation column test was conducted in a laboratory cyclonic-static micro-bubble flotation column (FCSMC) with 0.08 m diameter and 2 m height. The flotation column design, as shown in Fig. 2, includes column flotation zone, cyclone separation zone, and micro-bubble generation parts. The pulp concentration was 80 g/dm^3, and the flow was 0.6 m^3/h. A circulation pump with a 10 m of head, a 0.5-1 m^3/h of discharge was used for the column. The frequency converter (0–50 Hz) was used to change the circulation pump flow and regulate its outlet pressure of 0.10 MPa.

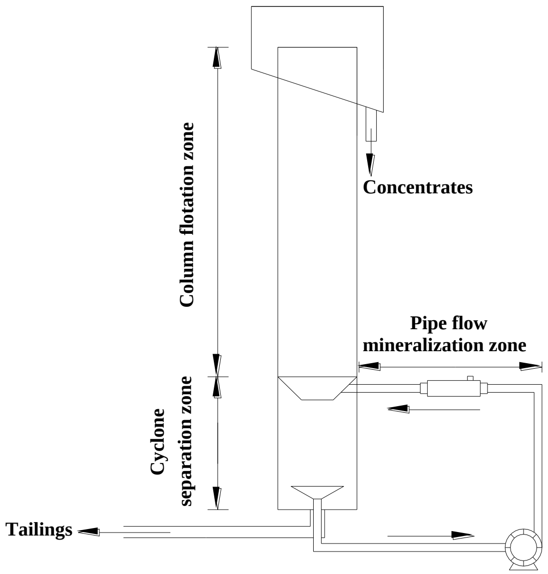

Fig. 2. Schematic of the cyclonic-static micro-bubble flotation column (FCSMC)

The indexes of combustible matter recovery and ash content were used for analyzing the flotation products. The combustible matter recovery was calculated using the following equation:

$$\text{Combustible matter recovery (\%)} = \left[M_C(100 - A_C) / M_F(100 - A_F)\right] \times 100 \qquad (1)$$

where M_C is mass of the concentrate (%), M_F weight of the feed (%), A_C the ash content of the concentrate (%), and A_F is the ash content of the feed (%).

Results and discussion

FTIR results

As shown in Fig. 3, the functional groups corresponding to appropriate peaks in the coal samples as follows (Wen, 2010; Zhu et al., 2001): the absorption peak at 3700 cm^{-1} to 3610 cm^{-1} represents the free hydroxyl group (-OH) and the peak at 3500 cm^{-1} to 3000 cm^{-1} represents the intramolecular hydroxyl (-OH). The characteristic absorption peaks at approximately 2922 cm^{-1} and 1384 cm^{-1} are the stretching vibration of methyl ($-CH_3$). The group of carbonyl (C=O) is represented at the peak about 1598 cm^{-1}. The absorption peaks at 1030 cm^{-1} and 1006 cm^{-1} represent the bending vibration of carbon-hydrogen bonds (C-H) on benzene ring. The absorbance at 911, 796, and 694 cm^{-1} are the substitution of carbon-hydrogen bonds (C-H) and the bending vibration of carbon-hydrogen bonds (H-C-H). At last, the absorption peaks at 533, 467, and 428 cm^{-1} represent the aromatic pairs of sulfide (-S-S-),-SH, and FeS_2, respectively. These analyses indicated that the existence of hydrophilic functional groups (C-OH, C=O, COOH) was the material causing poor flotation of low rank coal. It can be safely concluded that the surface of low rank coal has many hydrophilic functional groups. A thick hydration shell will cover the low rank coal surface in the pre-wetting process because the hydrophilic functional groups will interact with the water molecules through hydrogen bond, thereby having a significant effect on low rank coal flotation.

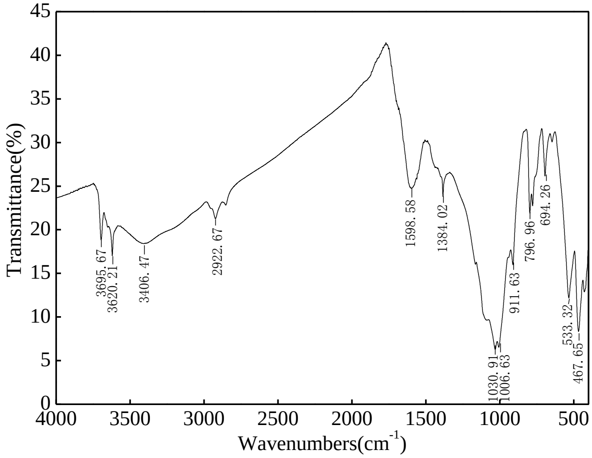

Fig. 3. FTIR analysis patterns of the coal sample

BET results

In this research, specific surface area (A_S, BET) and specific pore volume (V_P) were explored. The formula of BET depends on the Langmuir adsorption isotherm. It is common that the specific surface area is determined by BET nitrogen adsorption at low temperature. The results showed that the specific surface area (A_S, BET) and specific pore volume (V_P) were 19.56 m^2/g and 0.038 cm^3/g, respectively, which indicates that the porosity of low rank coal was developed. A large amount of diesel oil was consumed in low rank coal flotation, and this may be mainly because there are many holes and cracks on the surface. At the flotation processes, lots of diesel oil may be absorbed into holes rather than spread on the surface of coal particles. As shown in Fig. 4, number 1 represents oil drops which spread on the coal surface, and number 2 represents those which are absorbed into holes. Therefore, a large amount of diesel oil may not play a role in collecting.

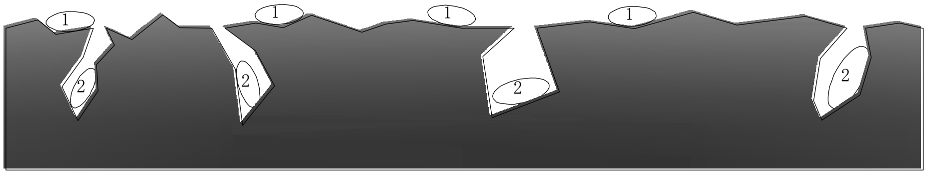

Fig. 4. Hypothetical model showing adsorption/spreading of collector on coal surface

SEM results

The surface morphology of low rank coal particles is shown in Fig. 5. As seen from Fig. 5, the surface of coal particles was very rough with lots of holes and cracks. The holes of low rank coal are described by Fig. 5(a) and (b), and the cracks on the coal surface are shown in Fig. 5 (c) and (d).

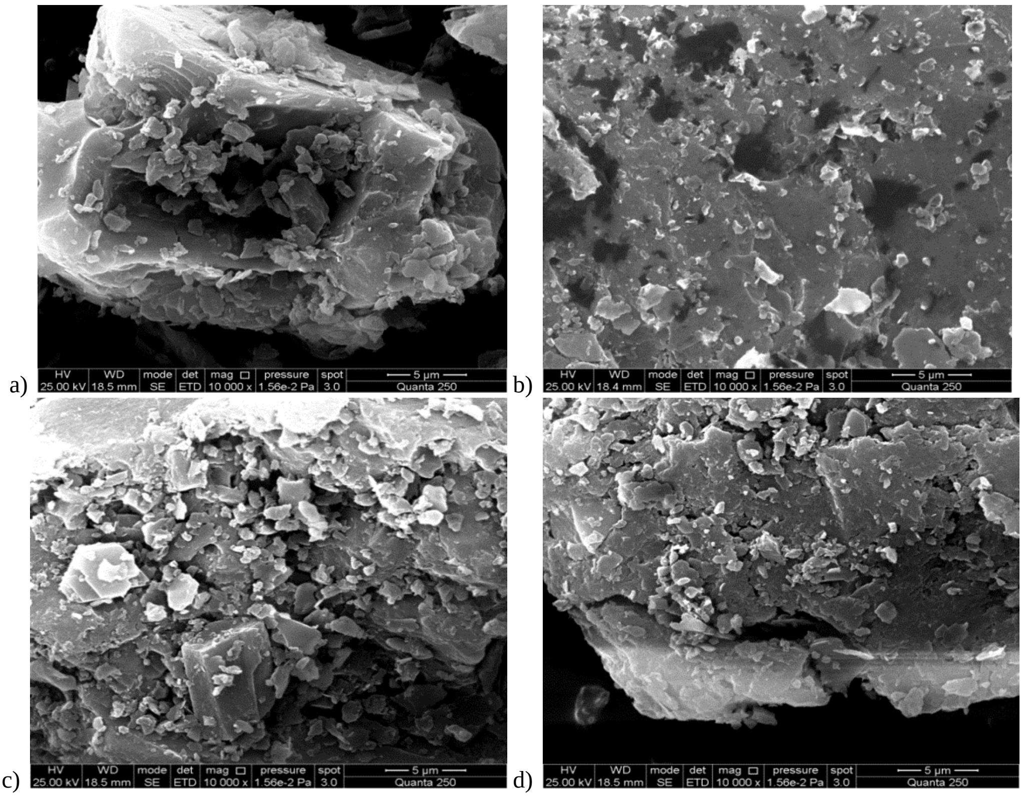

Fig. 5. SEM micrographs of low rank coal

The conventional flotation results

The flotation response of low rank coal slime using FO1, FO2, FO3, and diesel oil as the collector is presented in Table 3. The results indicated that FO3 was the most effective rather than other collectors for this coal. The combustible matter recovery at the FO3 dosage of 3 kg/Mg was 80.31% that was higher than that obtained at the FO1 and FO2 dosage of 3 kg/Mg. The results also showed that the collectors which contained oxygenated chemicals were generally more effective than diesel oil which consists of only alkane. The combustible matter recovery at the diesel oil dosage of 3 kg/Mg was 36.04%, which were much lower than that obtained at FO1, FO2 or FO3 dosage of 3 kg/Mg. It indicated that the oxygenated chemicals improved the flotation of low rank coals.

Figure 6 shows the contact angles of coal slime after conditioning with different collectors. The contact angle of raw coal was about 61, and the contact angle of coal slime after conditioning with collector was improved. After conditioning with FO1, FO2 or FO3, the contact angle of coal slime was higher than that in the presence of Diesel oil. This also indicated the flotation of low rank coals was enhanced by these oxygenated chemicals.

There might be two mechanisms for the interaction between the oxygenated chemicals and the coal surface. As we know, the surface of coal consists of inherently hydrophobic areas, and also sites containing oxygenated moieties such as carboxyl, carbonyl, phenolic, and ester group (Fuerstenau et al., 1987; Laskowski, 1995). The first mechanism of interaction between the oxygenated chemicals and the coal surface appears to be through the polar groups of the reagent interacting with the oxygenated functional groups on the coal surface by hydrogen bonding. The second mechanism involves the interaction of the nonpolar chain with the carbonaceous sites on the coal surface by dispersing water molecules from the coal surface. From this, it can be safely concluded that reagents containing oxygen-functional groups, with their increased bonding energy, are much better collectors than hydrocarbon oil, such as diesel oil, for the flotation of low rank coals.

Table 3. Flotation results of different collectors

Collectors	Consumption (kg/Mg)	Consumption of frother (kg/Mg)	Concentrate		Tailing	
			Ash (%)	Recovery (%)	Ash (%)	Recovery (%)
FO1	3.00	0.30	6.75	75.09	33.82	24.91
FO2	3.00	0.30	6.50	71.90	25.08	28.10
FO3	3.00	0.30	6.44	80.31	31.96	19.69
Diesel oil	3.00	0.30	5.56	36.04	15.75	63.96

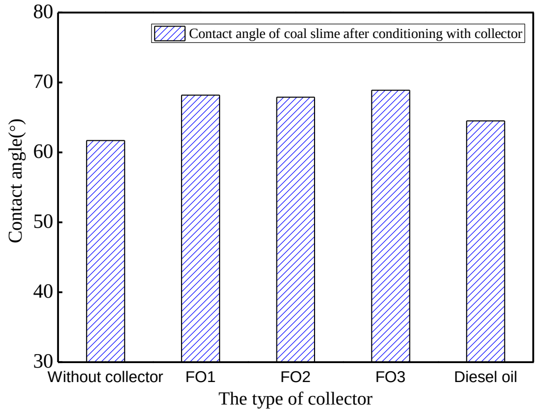

Fig. 6. Contact angle of coal slime after conditioning with collector

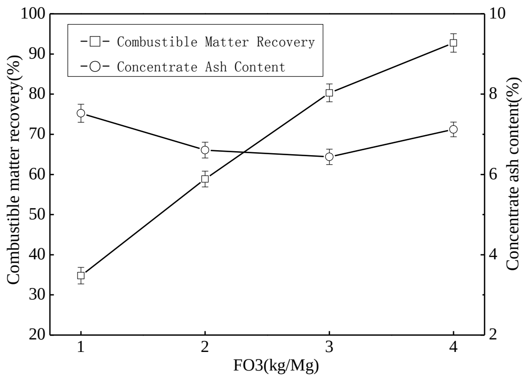

Fig. 7. Flotation results at different collector dosage of FO3

Because of its better collecting performance, 1–4 kg/Mg of FO3 were used in the flotation of coal slime, and the results are presented in Fig. 7. The combustible matter recovery increased with the increasing of collector dosage. However, the ash content of concentrate did not increase with the recovery. The combustible matter recovery at a collector dosage of 1 kg/t was lower than that obtained at a higher consumption of collector while the ash content of concentrate was higher than that obtained at a collector dosage of 3 kg/Mg. This may be mainly because there were many gangue minerals in the coal slime, such as montmorillonite, illite, and the surfaces of these gangue minerals may also contain oxygenated moieties due to damages of their crystal structures. The oxygenated chemicals in FO3 may more easily interact with the oxygenated functional groups on the gangue minerals surface by hydrogen bonding than these groups on the coal surface, which contributes to the hydrophobicity of the gangue minerals surfaces. Therefore, the ash content of concentrate at a lower collector dosage was higher than that obtained at a higher consumption of collector, and then lower ash content of coals got into froth concentrates in the case of higher consumption of collector. As a result, these oxygenated chemicals had complex interactions with the surfaces of coal and gangue minerals. In order to obtain lower ash content concentrates, it is important to create a suitable environment to separate low rank coal when using oxygenated chemicals as collectors.

Influence of conditioning time on flotation performance

Stirring is a common way to mix coal slurry with flotation reagents well. But there are some negative impacts on flotation response of low rank coal because there are lots of holes and cracks on the surface of low rank coal and a large amount of collector may be absorbed into holes and cracks rather than coal surface due to the intensified mixing. The flotation response of low rank coal slime at different conditioning time after adding collector is presented in Table 4. The FO3 dosage of 3 kg/Mg was used in this exploration. From Table 4, the combustible matter recovery decreased with the increasing of conditioning time, and the recovery at a conditioning time of 2 min was better than that obtained at a long conditioning time. There was a marked decline in the concentrate recovery when the conditioning time become longer. When the conditioning time was 20 min, the recovery of 65.18% was about 15% lower than that obtained at a conditioning time of 2 min. Additionally, when the conditioning time was 0.5 min, the concentrate recovery was a bit less than that at the conditioning time of 2 min. This may mainly because a certain time is needed for collector to spread on the coal surface. There was not distinctly difference in the flotation performance at the conditioning time of 1, 1.5 and 2 min.

Table 4. Flotation results at varying conditioning time

Conditioning time (min)	Concentrate		Tailing	
	Ash (%)	Recovery (%)	Ash (%)	Recovery (%)
0.5	6.38	78.03	29.69	21.97
1	6.50	80.02	30.32	19.98
1.5	6.47	79.85	30.01	20.15
2	6.44	80.31	30.67	19.69
4	6.49	76.51	28.89	23.49
8	6.21	70.28	25.86	29.72
12	5.77	66.67	24.41	33.33
20	5.24	65.18	23.35	34.82

In order to illustrate the phenomenon specifically, the contact angle of coal slime after conditioning with collector at different time was measured. The results are shown in Fig. 8. The contact angle at the conditioning time of 0.5 min was a bit lower compared to that at conditioning time of 1, 1.5, and 2 min, and the contact angle decreased with the increasing of conditioning time. To some extent, the contact angles of coal slime at different conditioning time were in accordance with their flotation performance.

It can be concluded that the conditioning time after adding collector showed a significant effect on the flotation response of low rank coal, and a suitable conditioning time was crucial for the flotation performance. In flotation machines, the operation takes place in a highly turbulent flow. Coal slurry is all the time stirred in flotation cell after conditioning, especially industrial flotation machines where coal slime is separated consecutively. Collector molecules may be absorbed into holes, which could weaken flotation performance. Therefore, flotation machines may not be the suitable equipment to separate low rank coal.

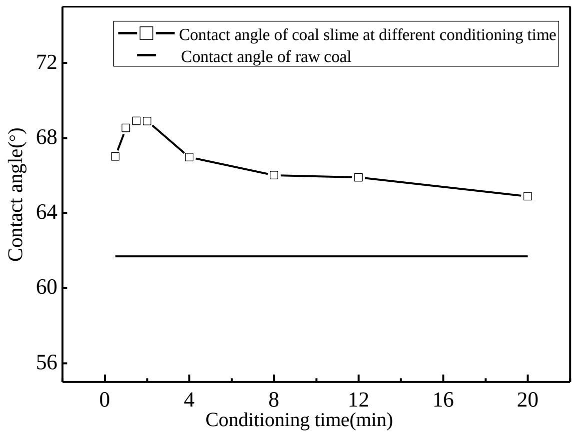

Fig. 8. Contact angle of coal slime after conditioning with collector

Flotation column test results

Enough coal slime were prepared and conditioned in an agitator for 2 min after adding collector of FO3. The dosage of FO3 collector was 3 kg/Mg and frother was 0.3 kg/Mg. After conditioning coal slurry flowed into flotation column automatically. The results were collected every 30 min, presenting in Table 5. Figure 9 shows a comparison of flotation performance obtained by FCSMC and flotation machine in the presence of FO3. The FCSMC could produce a clean coal concentrate of 85.14% combustible recovery with about 4.47% ash content compared to the flotation machine which produced a low combustible recovery of 80.31% with a high concentrate ash content of 6.44%. About 43% ash rejection could be produced by FCSMC while only 30.67% can be obtained with the flotation machine. The results suggested that the flotation column was superior to the flotation machine for low rank coal beneficiation.

Table 5. Flotation results of flotation column

Serial number	Concentrate		Tailing	
	Ash (%)	Recovery (%)	Ash (%)	Recovery (%)
1	4.65	84.48	42.05	15.52
2	4.22	85.50	44.54	14.50
3	4.54	85.44	43.80	14.56
Average value	4.47	85.14	43.46	14.86

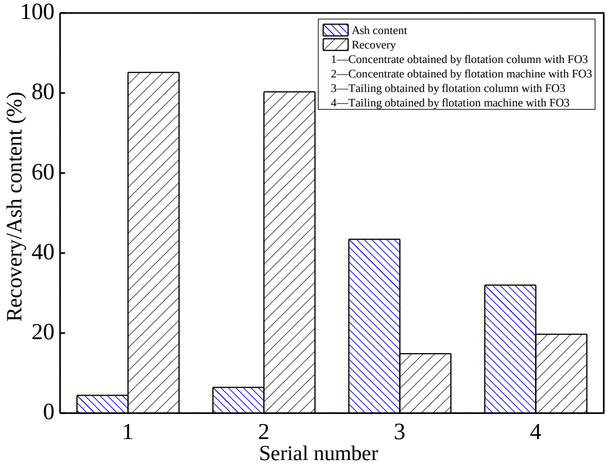

Fig. 9. Comparison of results obtained with FCSMC and flotation machine using FO3

There are several reasons to interpret better performance of the flotation column. The FCSMC consists of three parts which are a froth zone, a column flotation zone and a cyclonic separation zone. The collection zone includes the column flotation zone and the cyclonic zone. The coal slurry enters the column separation zone, flowing downward evenly within its whole section, and at the same time the bubbles rise from the bottom of the column zone and continuously collide with the coal particles. The easy-to-float coal particles are effectively got into froth concentrates though the stage of column flotation. As for low rank coal flotation, there is no highly turbulent flow at this zone and collector molecules absorbed into holes or cracks are less than that in flotation machine. In other words, the static separation environment in column flotation zone can make sure that more collectors are absorbed on the surfaces of coal particles rather than absorbed into holes, which significantly contributes to a better performance. Froth cleaning also plays an important role in producing low ash concentrates. A thick foam layer increases the residence time of particles which allow any entrained gangue particles to be drained back to the pulp. With the addition of wash water, the gangue particles are washed back into pulp zone thereby increasing the grade of the concentrate i.e. higher ash rejection.

The difficult-to-separate coal particles from the column flotation zone will be sent to the cyclone zone for its further processing after pressurization. Density separation and surface flotation take place in this zone. High density gangue particles will move towards the wall of the outer cylinder and are separated from the vertical flow under the action of centrifugal forces and collected on the bottom of the outer cylinder. As mentioned above, the surfaces of some gangue particles may interact with oxygenated chemicals, which can make surfaces of gangue minerals hydrophobic. However, the absorbed molecules on the surface of gangue particles may be desorbed because of the increasing dynamic turbulence intensity. At the same time, these gangue minerals are separated into tailings under the centrifugal forces. On the other hand, middlings are pumped in the pulp flow mineralization zone, which increases mineralization rate and flotation rate. High ash content particles will have a short residence time in the column. Therefore, the possibility of these gangue minerals entering into froth concentrates will decrease dramatically.

Conclusions

The reasons why it was difficult for low rank coal to float were explored through test measurements such as FTIR, BET, and SEM. The FTIR results indicated that the surface of low rank coal had many hydrophilic functional groups of C-O, C=O, COOH. When the coal is pre-wetted, the surface will be wrapped by the hydration hell which makes the low rank coal difficult to contact with oil collector or bubbles. In addition, the BET and SEM results indicated that there were lots of holes and cracks on the surface of coal particles. During flotation processes, lots of collector molecules may be absorbed into holes rather than spread on the surface of coal particles, which can lead to a diminished flotation performance.

The results of flotation and contact angle indicated that the reagents containing oxygen-functional groups, with their increased bonding energy, were much better collectors than hydrocarbon oil such as diesel oil for the flotation of low rank coals. But these reagents had complex interactions with the surfaces of coal and gangue minerals. The oxygenated chemicals in the collectors may more easily interact with the oxygenated functional groups on the gangue minerals surface by hydrogen bonding than these groups on the coal surface, which lead to high ash content of concentrates. Therefore, it was important to create a suitable environment to separate low rank coal with the using oxygenated chemicals as the collectors.

The flotation results and contact angle results also illustrated that the conditioning time after adding collector showed a significant effect on the flotation response of low rank coal, and a suitable conditioning time was crucial for the flotation performance. There was a marked decline in the concentrate recovery when the conditioning time become longer. In the flotation machines, the operation takes place in a highly turbulent flow. Coal slurry is all the time stirred in flotation cell after conditioning. Therefore, flotation machines may not be the suitable equipment to separate low rank coal. A better flotation performance can be obtained by flotation column (FCSMC). The characters of flotation column which contain the static separation environment in column flotation zone and density separation in cyclone separation zone just meet the requirements of low rank coal slime separation.

Acknowledgements

This research was supported by the Fundamental Research Funds for the Central Universities (2015XKMS039) and the National Nature Science Foundation of China (Grant No. 51054254).

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