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Effect of ultrasonic pre-treatment on coal slime flotation

Wenbao Lv [1,2], Jun Chen [1,2,3], Fanfei Min [2], Baohong Hou [2], Chunfu Liu [2]

[1] State Key Laboratory of Mining Response and Disaster Prevention and Control in Deep Mines, Huainan 232001, China

[2] Department of Materials Science and Engineering, Anhui University of Science and Technology, Huainan 232001, China

[3] Key Laboratory of Coal Processing and Efficient Utilization, Ministry of Education, Xuzhou 221116, China

Corresponding author: jchen412@126.com (Jun Chen)

Abstract: Combined with the characteristics of flotation feed originating from China's Panyidong Coal Preparation Plant, the ash, zeta potential, X-ray fluorescence spectroscopy and contact angle test were used to study changes in the surface properties of flotation feed under ultrasonic pre-treatment, and its effect on flotation of coal slime. Results show that Preferred pre-treatment process is ultrasonic secondary treatment, ultrasonic secondary pre-treatment can remove most of the high-ash fine mud for instance kaolinite, montmorillonite and quartz in the coal slurry, reduce the surface electronegativity of coal particles, and increase the contact angle of coal particles. Thus, the concentrate ash content decreases to 13%, the recovery rate, yield of flotation concentrate and combustible matter recovery reach 92.6%, 90.9% and 97.6%, respectively.

Keywords: ultrasonic pre-treatment, surface property, high-ash fine mud, flotation

1. Introduction

Coal is a non-homogeneous substance composed of organic and inorganic materials, and regarding the inorganic matter, clay minerals account for the majority, including kaolinite, montmorillonite, quartz, etc., and survive in coal. In recent years, with the mechanization of coal mines and transportation systems, minerals are stripped from coal into fine particles under the action of external forces, and the advances made in mechanized mining have increased the amount of clay minerals in raw coal. Furthermore, the content of fine mineral particles and high-ash fine mud in the slime has increased (Ren et al., 2014). Particles less than 0.5 mm in diameter in the coal slurry entering the flotation process account for most particles, and a variety of high-ash fine minerals are attached to the surface of coal particles. These high-ash fine mud contaminates flotation concentrate through fine mud entrainment and cover (Celik, 1989; Altun et al., 2009; Yu et al., 2015), which lead to poorer flotation efficiency and increased flotation of concentrate ash. Also evident is the larger content of high-ash fine mud attached to the surface of coal particles, the more that the ash content of flotation concentrate is seriously affected, and lead to the following results: deterioration of coal flotation, low ash content of flotation tail coal, loss of coarse coal, and flotation machine treatment pressure increases. If the coal slurry entering the flotation can be preliminarily delimed, that is, a part of the high-ash fine mud particles of the coal slurry can be removed before entering the flotation machine, this can greatly improve the flotation efficiency and the flotation of the concentrate (Zhang et al., 2008; Xu et al., 2017; Peng et al., 2018;).

Ultrasonic wave is a type of sound wave with a frequency higher than 20KHz, and has good directionality and strong penetrating ability. It is easier to obtain a more concentrated sound energy (Ambedkar et al., 2011; Ambedkar et al., 2011; Saikia et al., 2014; Ashokkumar, 2015), propagation in water requires a long distance, and the form of propagation is mainly longitudinal sound wave in character. The non-thermal effects generated during the propagation process mainly include mechanical vibration and cavitation, and the two complement each other. During the compression and sparse circulation of sound waves, the acoustic wave pressure overcomes the binding force between water molecules during the negative pressure cycle, thereby producing microbubbles. When the sound

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wave creates a positive pressure cycle, the microbubble collapses, and the microbubble instantaneously collapses to release a large amount of energy in a very small local area. The microbubble centre generates a high temperature of nearly 5000K and a pressure of more than 50 Mpa. Then the local area produces strong shock waves and high-speed micro jets, and subsequently these mechanical vibrations and cavitation affect the properties of the fine-grained mineral surface (Farmer et al., 2000; Kang and Lv, 2006; Kang et al., 2007). Oner et al. (2017) found that the ultrasonic pre-treatment could greatly reduce the particle size of calcite. Mao et al. (2019) have studied, ultrasonic pre-treatment can crush fine particles, change the shape of particles, and clean the surface of particles.

Besides particle size, the shape and surface properties of solid particles would also be changed by ultrasonic treatment (Mao et al., 2019). Safak et al. (2012) studied ultrasonic flotation experiments were carried out by using circularly shaped RK-106 model of ultrasonic bath with constant frequency and power, and good test results were obtained. Prasad et al. (2017) investigated effect of ultrasonic pre-treatment time on coal flotation, and ultrasonic pre-treatment time as well as reagent dosages were optimized to achieve maximum clean coal yield, with ultrasonic pre-treatment, the clean coal yield increased for all the reagent dosages. Emin et al. (2009) studied effect of ultrasound on separation selectivity and efficiency of flotation and the results indicate that there was a considerable effect of ultrasound on separation selectivity and efficiency in the flotation of a complex sulphide ore at intermediate and high level airflow rates whereas. Altun et al. (2009) investigated enhancement of flotation performance of oil shale cleaning by ultrasonic treatment and ultrasonic treatment had proved to be useful in improving the extent of ash rejection. Many of the published literatures are about the effects of ultrasound on the flotation of fine-grained ores (Ferihan et al., 2011; Can et al., 2016). However, the properties of the materials entering the flotation system such as ash, particle properties, mineral composition, etc. have not changed, and there is no significant improvement in flotation efficiency and flotation quality. In order to improve flotation efficiency and flotation quality, in this paper, the ultrasonic pre-treatment of the coal slurry entering the flotation is proposed, and the pre-treated concentrate is put into the flotation system to reduce the processing pressure of the flotation system and improve the flotation efficiency and quality.

In this paper, flotation feed is pre-treated by ultrasonic pre-treatment and compared with natural sedimentation pre-treatment. The changes in the surface properties of flotation feed under ultrasonic pre-treatment are studied by ash, zeta potential, XRF and contact angle test. Also discussed here is the influence of changes in surface properties of coal slurry on the flotation efficiency of coal slurry. This provides a theoretical basis for the development of coal slurry pre-treatment and flotation new technology.

2. Materials and methods

2.1. Materials

The coal sample was selected from the flotation of coal slurry generated by the Pan Yi Dong Coal Preparation Plant, the coal slurry was dried to make dry coal slime. After that, the ultra-pure water was used with a resistivity of 18.25 MΩ·cm to make coal slurry with a concentration of 80 g/dm^3 in a 300 cm^3 capacity beaker, and stirring for 5 minutes to mix the coal slime particles with ultra-pure water. Then the beaker containing the made coal slurry was placed in the tank of the ultrasonic cleaner with an ultrasonic frequency of 80 kHz and ultrasonic power of 200W. As shown in Figure 1, the water was injected into the tank of the ultrasonic cleaner. But the water in the tank had to submerge the 300 cm^3 mark of the beaker, but not above the beaker mouth.

2.2. Experimental methods

KQ5200E ultrasonic cleaner (Kunshan Ultrasonic Instrument Co., Ltd.) was employed for ultrasonic pre-treatment. Ultrasonic treatment times of 5, 10, 15, 20, and 30 minutes were recorded, and after ultrasonic treatment, the upper 225 cm^3 of coal slurry in the beaker was used as the ultrasonical pre-treated tailings, and the lower 75 cm^3 of the coal slurry of the beaker was used as the ultrasonic pre-treated concentrate. Both were simultaneously placed in an oven for drying. After the ultrasonic pre-

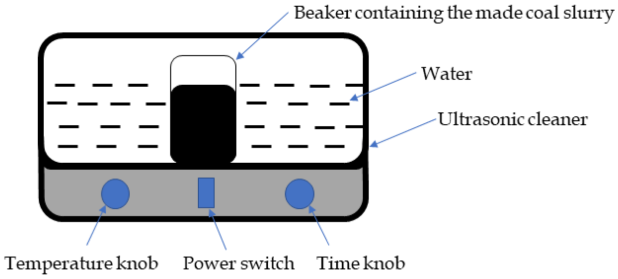

Fig. 1. Ultrasonic pre-treatment schematic

treated concentrate and tailing were dried, they were ground and sampled, and then the ultrasonic pre-treated concentrate and tailing were weighed separately. The ultrasonic pre-treated concentrate functioned as the flotation's new feed in the future. We stipulated that the pre-treatment tailings' weight as a percentage of the total weight of the concentrate and tailings after pre-treatment was called the desliming ratio. The natural sedimentation pre-treatment methods and procedures were the same as ultrasonic pre-treatment.

According to the GB/T4757-2001 pulverized coal (mud) laboratory unit flotation test method, n-dodecane was selected as the flotation collector, and Methyl isobutylcarbinol (MIBC) was used as the flotation agent for flotation.

The Colloidal Dynamics Zetaprobe (Colloidal Dynamics, USA) was occupied to measure the zeta potential of flotation feed, concentrate and tailings following ultrasonic and natural sedimentation pre-treatment. Measurement details were as follows: a coal sample of 2.5 g was weighed to a total of 250 cm^3 of coal slurry at a concentration of 1 g/dm^3; the stirring speed of the zeta potential tester was settled to 320 r/min; and measurements were taken until the pH of the slime water reached a stable stage (the pH was not adjusted).

Flotation feed derived from the ash was 35.5%, and concentrate obtained after ultrasonic secondary pre-treatment, i.e. concentrate ash was 19.5%. For the concentrate obtained after ultrasonic pre-treatment, the concentrate ash was 23.0%, and the concentrate obtained by natural sedimentation pre-treatment, concentrate ash was 26.8%, and the concentrate obtained by natural sedimentation secondary pre-treatment, concentrate ash was 23.2%. Five coal samples were tested via a flotation unit, according to the GB/T4757-2001 pulverized coal (mud) laboratory unit flotation test method. RK/FD type 1.5 flotation machine (Wuhan Lock Grinding Equipment Manufacturing Co., Ltd., China) was used for flotation. In the investigation, the n-dodecane was used as the oily collector and the MIBC was used as the frother. The n-dodecane dosage is 1000 g/t and MIBC dosage is 100 g/t coal. Flotation tests were conducted in a 1.5 dm^3 flotation cell. The impeller speed of the flotation machine was fixed at 1800 rpm and the airflow rate was 0.25 m^3/min. The flotation coal slime slurry's concentration was 100 g/dm^3.

The formula 1 for calculating the yield of flotation concentrate according to the ash balance formula (Kopparthi et al., 2017) is written as:

$$\gamma_j = \frac{A_y - A_w}{A_j - A_w} \times 100(\%) \tag{1}$$

where γ_j is the yield of flotation concentrate, %, A_y is the ash content of the feed, %, A_j is the ash content of the concentrate, %, and A_w is he ash content of the tailing, %.

Combustible matter recovery from the flotation concentrate can be further calculated by the following formula 2:

$$\xi = \gamma_j \frac{100 - A_j}{100 - A_y} \times 100(\%) \tag{2}$$

where ξ is combustible matter recovery, %.

3. Results and discussion

3.1. Effects of the desliming ratio and the ash of coal slime on flotation

Fig. 2(a) shows that the desliming ratio decreases when the ultrasonic pre-treatment time and natural sedimentation pre-treatment time increase. Also shown in Figure 2(a), ultrasonic pre-treatment has a much higher desliming ratio than natural sedimentation pre-treatment. Here the highest desliming ratio in ultrasonic pre-treatment lasting 5 minutes was 43.6%.

Fig. 2(b) shows the ash content of pre-treated clean coal increases with the ultrasonic pre-treatment time and natural sedimentation pre-treatment time both increasing. In Figures 2(b) and 2(c), the ash content of the tailings after ultrasonic pre-treatment average out to 48.8%, and the concentrate ash reduces to an average of 27.0%. The tailings ash after natural sedimentation pre-treatment average to 49.8%, and the concentrate ash falls to an average of 28.8%. As shown in Fig. 2(b), there is less concentrate ash after ultrasonic pre-treatment when compared to concentrate ash after natural sedimentation pre-treatment. It emerges that the optimal time for ultrasonic and natural sedimentation pre-treatment is 5 minutes. The concentrate ash after ultrasonic pre-treatment decreases to 24.6%, which is 10.9% lower than that of the unpretreated flotation feed coal slime ash (35.5%). This scenario indicates that the ultrasonic pre-treatment can do two things: firstly, remove most of the high-ash fine mud particles of coal slurry; and secondly, reduce the ash content of the flotation feed coal slime.

As can be seen from Figures 2(a) and Figures 2(b), the desliming ratio and the ash content of pre-treated clean coal are divided into a negative correlation, that is, the higher the desliming ratio, the lower the ash. As shown in Figures 2(a) and Figures 2(c), there is no obvious correlation between he desliming ratio and the ash content of pre-treated tail coal.

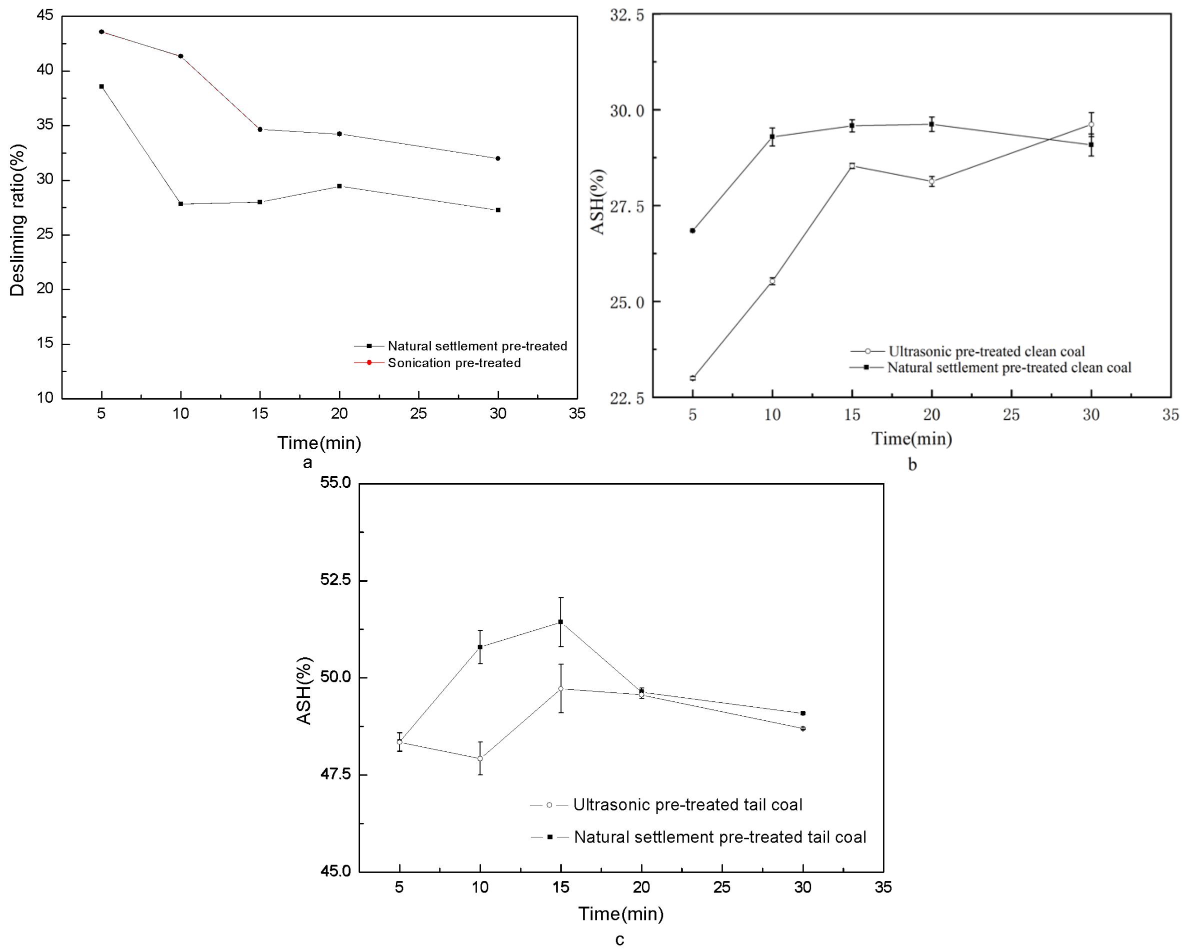

Fig. 2. Ultrasonic pre-treatment and natural sedimentation pre-treatment ash and deslimation rate (a: deslimation rate; b: the ash content of pre-treated clean coal; c: the ash content of pre-treated tail coal)

The high-speed microjets and shock waves are generated near the surface of coal particles under the action of ultrasonic vibration and cavitation (Barma, 2019). These high-speed microjets and shock waves strengthen the vigorous movement and collision of coal particles, increase the friction between coal particles and coal particles, and cause some high-ash fine mud to separate from the surface of coal particles into the aqueous solution of coal slime (Peng et al., 2018). On the other hand, the collision between coal particles and these particles can cause wear and cracking, even resulting in coal particles being broken, and some high-ash fine mud can overflow from inside the coal particles. At the same time, particle breakage caused by shock waves and collision of coal particles can increase the surface area of the particles (Farmer et al., 2000; Mason et al., 2004; Raman and Abbas, 2008; Balraj et al., 2011). Also shown in Figure 3, Figure 3 shows that adsorption of clay minerals on the surface of coal particles after ultrasonic pre-treatment and natural sedimentation pre-treatment, Figure 3(a) shows that the clay particles adsorbed on the surface of coal particles are the least after ultrasonic secondary pre-treatment, Figure 3(d) shows that the clay particles adsorbed on the surface of coal particles are the most. It is indicated that ultrasonic pre-treatment can remove most of the high-ash fine mud adsorbed on the surface of coal particles, and the natural sedimentation pre-treatment can remove very little the high-ash fine mud adsorbed on the surface of the coal particles.

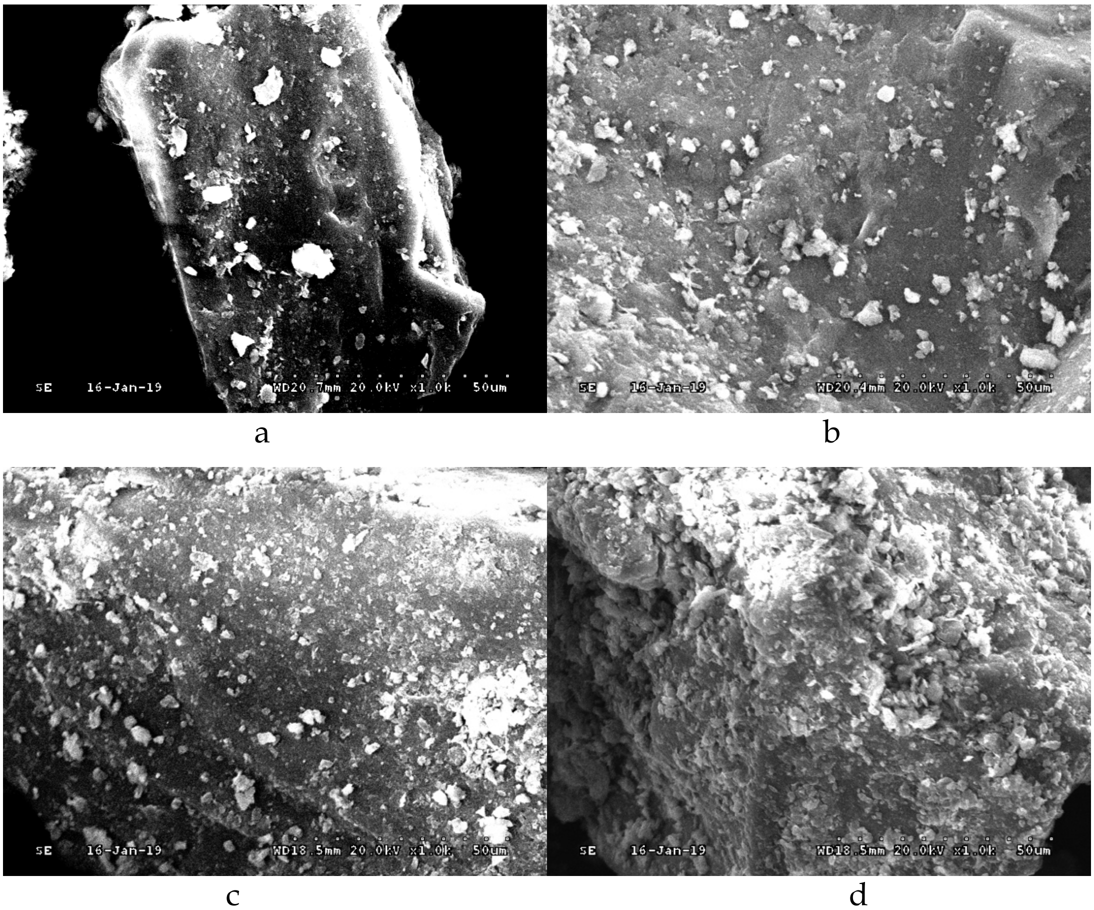

Fig. 3. Scanning electron microscopy of coal slime (a: ultrasonic secondary pre-treatment; b: ultrasonic pre-treatment; c: natural sedimentation pre-treatment; d: unpretreated)

The surface area of the particles increases the selective adsorption and adsorption capacity of the flotation reagent (Kang et al., 2008; Cilek and Ozgen, 2009; Ozkan, 2017; Mao et al., 2018). For natural settlement pre-treatment of coal slime water, under the action of natural gravity, the surface of the coal particles in the coal slurry and the high-ash fine mud inside cannot be removed. As well, the surface area of the coal particles cannot increase, and only a large part of the high-ash fine mud suspended in the coal slurry can be removed. A consequence of this is a small difference between the ultrasonic pre-treatment and the natural sedimentation pre-treatment of the concentrate and tailings ash. However, the mud removal rate is quite different.

3.2. Zeta potential measurement of coal slime

The measurement results are shown in Table 1, and it is documented that the zeta value of the flotation feed is -31.34 mV, after the ultrasonic pre-treatment and natural sedimentation pre-treatment. The absolute value of the concentrate zeta is greatly reduced, at around -17 mV, and the pre-treated tailings' zeta absolute value increases significantly, reaching -49 mV. Measured zeta values are all negative, indicating that the coal slime surface has a negative charge, since the minerals contained in the slime are polar minerals, namely kaolinite, montmorillonite and quartz. The surface of the particles is negatively charged, due to the presence of a large amount of negatively charged minerals in the slime water and the adhesion of minerals to the surface of the coal particles; the zeta value of the coal slime is negative (Chen et al., 2015). There is little difference between the zeta potential of concentrate and tailings after ultrasonic pre-treatment and natural sedimentation pre-treatment. This is because the fine-grained coal slime is not completely dispersed in water, and the mechanical stirring speed of the zeta potentiometer was settled at 320 r/min. It was not possible to generate a large enough agitation shear force due to the low rotational speed. Therefore, under the weak shear force, it is not enough to completely separate the coal and clay particles in the slime water. It causes flocculation between coal particles and between coal particles and mineral particles due to hydrogen bonding or gravitation between certain functional groups (Min et al., 2014; Chen et al., 2019). Peng et al. (2010) also pointed out that the zeta potential was also affected by the agglomeration or dispersion behavior of the particles, which mainly becomes violent fluctuations near the zero point. Therefore, the ultrasonic pre-treatment and natural sedimentation pre-treatment of the concentrate and tailings' zeta values do not differ markedly.

Table 1. Comparison of concentrate and tailings' zeta values after ultrasonic pre-treatment and natural sedimentation

Time（min）	Concentrate Zeta (mV)		Tailings Zeta (mV)	
	A	B	A	B
5	-18.27	-17.44	-48.94	-46.98
10	-16.11	-20.90	-49.31	-52.75
15	-17.55	-16.53	-48.67	-50.73

A: Ultrasonic secondary pre-treatment, B: Natural sedimentation secondary pre-treatment

3.3. XRF analysis of coal slime

The concentrate and tailings obtained after 5 minutes of ultrasonication and natural sedimentation and flotation of the feed slime were subjected to XRF analysis, and for this an EDX-3600K X-ray fluorescence spectrometer (Jiangsu Tianrui Instrument Co., Ltd.) was used. After analysis, the main mineral components in the flotation feed are Al_2O_3 and SiO_2, and they amounted to 19.96% and 39.76%, respectively. As shown in Figure 4, the mineral composition of Al_2O_3 and SiO_2 in the concentrate after ultrasonication and natural sedimentation for 5 minutes is much reduced. The contents of Al_2O_3 and SiO_2 in the concentrate after ultrasonication are 15.84% and 32.37%, respectively, while the amounts of Al_2O_3 and SiO_2 in the concentrate after natural sedimentation are 16.79% and 33.95%, respectively. Minerals, specifically kaolinite, montmorillonite and quartz in the slime are removed by ultrasonic and natural sedimentation pre-treatment. However, ultrasonic pre-treatment removes more minerals such as kaolinite from flotation feed. The mineral content of Al_2O_3 and SiO_2 in tailings increases, but the amount of kaolinite in the tailings after ultrasonic pre-treatment increases greatly (Sonmez et al., 2004).

3.4. Secondary pre-treatment

After the flotation feed coal slurry is pre-treated by ultrasonic pre-treatment and natural sedimentation, this makes it possible to remove some high-ash fine mud. However, the best concentrate ash after ultrasonic pre-treatment is 23.0%, and the best concentrate ash after natural sedimentation pre-treatment is 26.8%. Evidently, the ash content is still relatively high, as is the high-ash fine mud in coal slime. It is necessary to further remove the high-ash fine mud in the coal slurry to ensure a better flotation outcome. In order to obtain less flotation feed coal ash, the concentrate after ultrasonic pre-treatment is again subjected to ultrasonic treatment, and the concentrate after natural sedimentation pre-treatment is again subjected to natural sedimentation treatment.

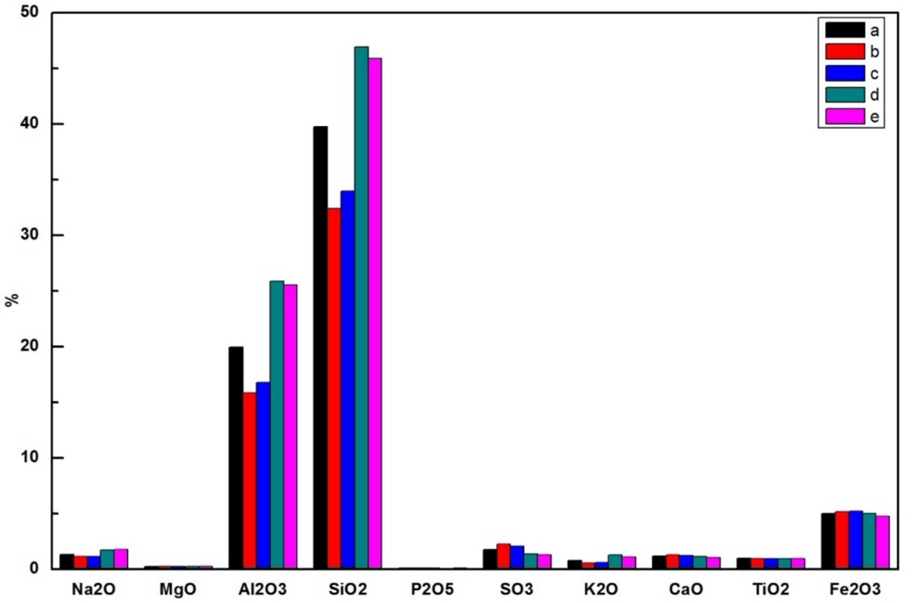

Fig. 4. Coal slime mineral composition (a: Untreated slime; b: Concentrate after ultrasonic pre-treatment for 5 minutes; c: Concentrate after 5 minutes of natural sedimentation pre-treatment; d: Tailings after 5 minutes of ultrasonic pre-treatment; e: Tailings after 5 minutes of natural sedimentation pre-treatment)

The conditions of ultrasonic secondary pre-treatment and natural sedimentation secondary pre-treatment are the same as those for ultrasonic pre-treatment and natural sedimentation pre-treatment. zeta potential measurements are conducted on the concentrate and tailings after ultrasonic and natural sedimentation secondary pre-treatment. The results are shown in Table 2 and Table 3. As can be seen in both tables, ultrasonic and natural sedimentation secondary pre-treated concentrate removes more flotation feed coal ash. In particular, the effect of ultrasonic secondary pre-treatment is remarkable in that the absolute value of the zeta potential is further reduced. It indicates that the secondary pre-treatment removes more ash fine mud in the flotation feed, which further improves the quality of the flotation feed.

Table 2. Comparison of ash content between concentrate and tailings after ultrasonic pre-treatment and natural sedimentation

Time（min）	Concentrate (%)		Tailings (%)	
	A	B	A	B
5	19.5	23.2	50.8	54.1

A: Ultrasonic secondary pre-treatment, B: Natural sedimentation secondary pre-treatment

Table 3. zeta value comparison between ultrasonic pre-treatment and natural sedimentation

Time（min）	Concentrate Zeta (mV)		Tailings Zeta (mV)	
	A	B	A	B
5	-11.49	-11.25	-45.65	-48.02

A: Ultrasonic secondary pre-treatment, B: Natural sedimentation secondary pre-treatment

3.5. Contact angle measurement of coal particle surface

The unpretreated flotation feed and the concentrate obtained from the flotation feed were subjected to natural sedimentation pre-treatment. Meanwhile the concentrate obtained from the flotation feed was subjected to ultrasonic pre-treatment, and the concentrate obtained from the flotation feed was subjected to ultrasonic secondary pre-treatment and then subjected to contact angle measurement; For this purpose, the SL200C dynamic and static contact angle measuring instrument (American Kono

Industrial Co., Ltd.) was used. The measurement results are shown in Figure 5. It illustrates the following: (i) the contact angle of the concentrate after ultrasonic secondary pre-treatment of the flotation feed coal slurry is the largest; (ii) the coal particles have the most hydrophobic surface; (iii) ultrasonic pre-treatment is superior; (iv) natural sedimentation pre-treatment is the second-best method; (v) the contact angle of the unpretreated flotation feed is the smallest; and (vi) the surface hydrophobicity of the coal particles is the worst. It is evident that ultrasonic secondary pre-treatment can remove the high-ash fine mud adsorbed on the surface of the coal particles in the flotation feed coal slurry. This method can also clean the surface of the coal particles, and increase their surface area and hydrophobicity.

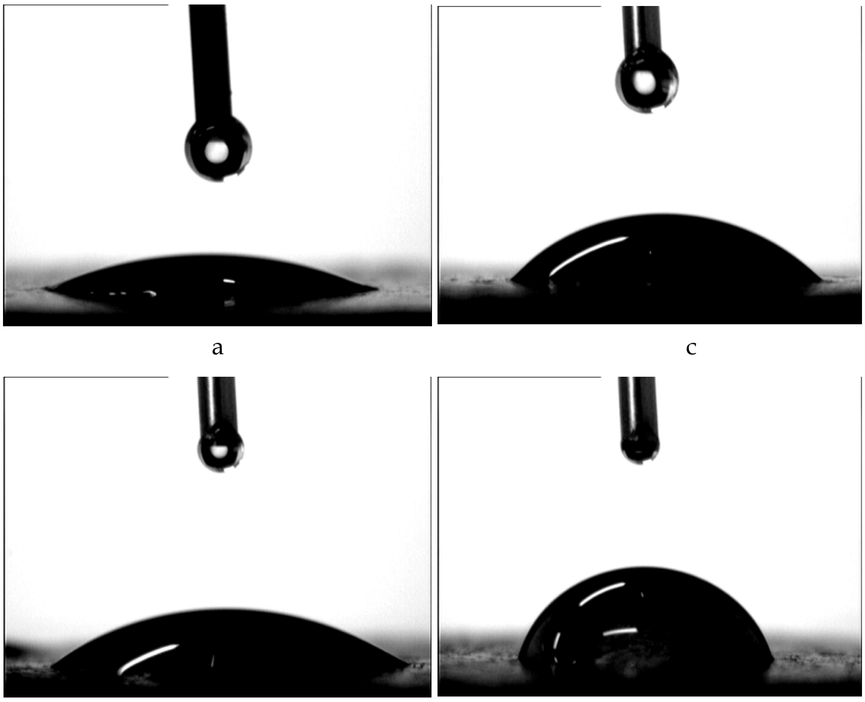

Fig. 5. Measurement of contact angle of coal slime (a: Unpretreated flotation feed, 23.56°; b: Flotation feed after natural sedimentation pre-treatment, 30.22°; c: Flotation feed after ultrasonic pre-treatment, 39.03°; d: Flotation feed after ultrasonic secondary pre-treatment, 59.28°)

3.6. Flotation test

The flotation ash data index obtained after the flotation test is shown in Table 4, under the same flotation conditions and reagent system. There are significant differences between the five coal samples, i.e. A, B, C, D and E in the flotation process. When the coal sample C was floated, bubbles were quickly generated when the inlet valve of the flotation machine was opened. In fact, the amount of bubbles was large, their size was small and mostly uniform, bubble stability was strong, flotation speed was fast, and efficiency was high (Ozkan, 2002). Using the GB/T4757-2001 pulverized coal (mud) laboratory unit flotation test method that was specified before the flotation lasting 3 minutes, the coal particles in the slime water slurry underwent complete flotation, and white-colored foam appeared when the flotation ended. The type A coal sample flotation process was similar to C, in that during the flotation process the bubble size was relatively uniform and the bubble volume was good, but no white flotation foam appeared at the end of flotation. In the B coal sample flotation process, the bubbles were relatively uniform, the amount of bubbles was good, and the flotation time was long. The type E coal sample flotation process was similar to B, however, compared with B, the E flotation foam is denser, the amount of foam is more, and the flotation effect is better. During the D coal sample flotation process, there were large bubbles, the amount of bubbles was general, the flotation time was long, efficiency was poor, and a large amount of slime remained at the bottom of the flotation tank after the flotation.

For the ash analysis of concentrates and tailings after coal flotation in A, B, C, D and E, as shown in Table 4, compared with the ash of coal sample D, coal samples C, A, B, and E decrease by 5.5%, 5.0%, 4.1% and 5.8%, respectively. That is, when the flotation feed is pre-treated by C, A, B and E, the ash of the flotation clear coal reduces compared to the untreated flotation feed. Furthermore, the quality of flotation clear coal has increased significantly. Compared with the D coal sample, the C, A, B, and E samples had the ash of the flotation tailings increase by 22.8%, 16.9%, -7.1%, and -7.4% respectively. In other words, further improvement of flotation tailings ash after ultrasonic pre-treatment and ultrasonic secondary pre-treatment was achieved (Ozkan and Kuyumcu, 2006; Chen et al., 2015). However, after natural sedimentation pre-treatment and natural sedimentation secondary pre-treatment, the flotation tailings ash decrease, but the flotation concentrate ash also decreases, due to the phenomenon of "running rough" during the flotation of coal slime after natural settlement pre-treatment and natural sedimentation secondary pre-treatment. It is observed that the surface of the coal particles adsorbs more high-ash fine mud, the agent fails to adsorb or adsorbs only a small amount on the surface of the coal particles. Therefore, coal particles cannot reach the flotation foam layer with the foam and become a flotation tail.

Table 4. The ash content of the concentrate and tailings

	A	B	C	D	E
Concentrate (%)	13.6	14.5	13.1	18.6	12.8
Tailings (%)	72.9	48.9	78.8	56	48.6

A: Ultrasonic pre-treatment, B: Natural sedimentation pre-treatment, C: Ultrasonic secondary pre-treatment, D: Un-preconditioned, E: Natural sedimentation secondary pre-treatment

Calculating the recovery rate of flotation concentrate, the yield of flotation concentrate and combustible matter recovery of concentrates after coal flotation in A, B, C, D and E was done using formula (1) and formula (2). The recovery rate of flotation concentrate indicates that this specific type of flotation accounts for the weight percentage of the flotation concentrate and flotation tailings after flotation. Combustible matter recovery is a parameter for evaluating the recovery effect of combustible materials in flotation concentrate, and is also an important indicator for evaluating flotation outcome. The recovery rate of flotation concentrate, the yield of flotation concentrate and combustible matter recovery of concentrates are shown in Table 5. The effect of flotation on the flotation feed coal slurry after ultrasonic secondary pre-treatment is best. The recovery rate of flotation concentrate, the yield of flotation concentrate and combustible matter recovery of concentrates are, respectively, 92.6%, 90.9%, 97.6%. These three indicators are the best, ultrasonic pre-treatment flotation effect is second best, and flotation effect of natural sedimentation secondary pre-treatment is third best and therefore poor. The worst is the flotation effect of untreated flotation feed.

Table 5. Comparison of slime flotation outcomes

	A	B	C	D	E
Flotation clean coal recovery rate (%)	85.1	63.3	92.6	57.5	67.9
Flotation clean coal yield (%)	84.1	64.3	90.3	54.9	70.9
Combustible body extraction rate (%)	94.4	75.1	97.4	69.2	81.6

A: Ultrasonic pre-treatment, B: Natural sedimentation pre-treatment, C: Ultrasonic secondary pre-treatment, D: Un-preconditioned, E: Natural sedimentation secondary pre-treatment

4. Conclusions

(1) Ultrasonic secondary pre-treatment can remove high-ash fine mud containing minerals such as kaolinite and montmorillonite in coal slurry, reduce high-ash fine mud adsorbed on the surface of coal particles, and remove high-ash fine mud suspended in flotation feed coal slurry. The high-ash

fine mud reduces the zeta value of the coal slurry, increases the surface area and hydrophobicity of coal particles, and the selectivity of adsorption by the reagent.

(2) The flotation effect of the feed slime after ultrasonic secondary pre-treatment is greatly improved, compared with the unpretreated coal slurry flotation, the ash content of the concentrate is reduced by 5.5%, and the recovery rate of flotation concentrate rises by 35.1%. In addition, the yield of concentrate is increased by 36%, and combustible matter recovery is increased by 28.4%.

(3) Concentrate of feed coal slurry is evident after ultrasonic secondary pre-treatment, and this is due to its enhanced hydrophobicity and increased surface area of coal particles. The high-ash fine mud content is reduced and under the same flotation conditions, the high-ash fine mud is reduced in the slime water system. This in turn reduces the accumulation of high-ash fine mud in the slime water system and curtails the flotation pressure of the flotation machine. The process improves the throughput per unit time and flotation efficiency of the flotation machine, reduces the amount of flotation reagents, and improves flotation efficiency and flotation product quality.

Acknowledgments

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