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INVESTIGATION AND OPTIMIZATION OF USE OF ANIONIC COLLECTORS IN DIRECT FLOTATION OF BAUXITE ORES

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Abstract: Bauxite is the main raw material for the alumina industry. Direct flotation is the most widely used method for bauxite beneficiation. In this study, a large number of direct flotation tests were carried out using several anionic reagents. The testing concluded that vegetable oil acid (VOA), naphthenic acid (NA) and lauryl polyoxyethylene phosphate (AEP12) were the three outstanding collectors for bauxite direct flotation. ZMC collector was mixed and prepared using VOA, NA and AEP12, in which the mass ratio of VOA, NA and AEP12 was 1:1:0.5. When processing the bauxite ores of the mass ratio of Al_2O_3 to SiO_2 (A/S) = 4.99, the A/S of the final concentrate was 7.08 and the recovery of Al_2O_3 was 90.22%. When processing ores of A/S = 4.5, the A/S of the final concentrate was 7.04 and the recovery of Al_2O_3 was 92.16%. Thus, it can be seen that properties and behaviors of the ZMC reagent were remarkable and met the demands of the "Lime-Bayer Process".

Key words: *bauxite, collector, direct flotation*

Introduction

Bauxite is the main raw material for the alumina industry. Almost 90% of alumina all over the world is produced from raw bauxite ores (Wang, 2002). China has a large reserve of bauxite resources mainly distributed in the Shanxi, Henan, Guizhou and Guangxi provinces, and the industrial reserves are the 7th largest in the world. More than 98% of bauxite ores in China are of diasporic bauxite, and the main valuable mineral is diaspore. The main gangue minerals are aluminosilicate minerals including kaolinite, illite and pyrophyllite. Chinese bauxite has a high grade of Al_2O_3, SiO_2 and Fe_2O_3 and a low mass ratio of Al_2O_3 to SiO_2 (A/S). The mass ratio of Al_2O_3 to SiO_2 (A/S) in most Chinese bauxite ores is below 6. There are less rich bauxite ores in the

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Henan province, and most of the resources in the province are of medium and low alumina grades (Hong, 2002; Hu et al., 2000).

In order to economically exploit a large number of low-grade bauxite ores, the most widely used method to produce alumina was the Bayer Process, and the gangue minerals must first be removed by beneficiation methods. After the silicate minerals are separated, the mass ratio of A/S in the ores is raised above 8 to meet the minimum requirements of the Bayer Process. Recently, researchers and engineers in China had developed and invented a new process named the "Lime-Bayer Process" based on the Bayer Process, and the lowest demand for A/S ratio of ore materials is reduced to 7. This can reduce beneficiation difficulties remarkably (Niu et al., 2003).

Methods for decreasing silicates content include the process of grinding and screening (Liu et al., 2011), flotation, and biological processing. Generally, the direct flotation process is the most practical and widely applicable method in the bauxite industry. In the direct process, alumina minerals of diaspore are subjected to froth flotation.

Researchers at Central South University and the Beijing Institute of Mining and Metallurgy carried out industry tests for bauxite beneficiation in 1999. The processing capacity of the industrial tests was 50 Mg of bauxite ores per day, and the tests were continued for three months. The A/S of the raw ores was 5.7, and the A/S of the final concentrate after the beneficiation treatments was 11.39. Meanwhile, the grade of Al_2O_3 in the concentrate was 70.08%, and the recovery of Al_2O_3 was 86.45 % (Lu et al., 2003). In bauxite direct flotation, the key technique for de-silicating ores requires the use of cheap and strong collectors with a high selectivity (Liu et al., 2009, 2011, 2011). Like other common oxide ores, anionic reagents, such as sodium oleate, alkyl benzene sulfonate, alkyl sulfates and hydroxamic acid, were used in this bauxite direct flotation study.

After studying the interaction mechanism between sodium oleate and minerals of diaspore and kaolinite, Zhang et al. (2001) concluded that the difference in flotation performance between diaspore and kaolinite was associated with the abundance of Al^{3+} on the mineral surface. This conclusion also provided theoretical foundation for direct flotation of bauxite. Chen et al. (2006) carried out direct flotation of bauxite to process low grade bauxite ores, using modified fatty acid (HZ) agents as collectors. When the A/S of the raw ores was 4.4, the A/S of the final concentrate was 8.51, and the recovery rate of Al_2O_3 was 79.31%. Zhang et al. (2001) investigated the applications of a modified fatty acid (RL) collector in bauxite flotation, and achieved successful results. Li et al. (2004) studied the properties and effects of hydroxamic acid polymer in bauxite beneficiation and also focused on the interaction mechanism between anionic surfactant and kaolinite. They believed that hydroxamic acid polymer should be a good reagent for bauxite flotation. Jiang et al. (2001) designed and synthesized a novel chelating collector of carboxyl hydroxidoxime (COBA). They found that COBA indicated a stronger collecting ability for diaspore than for kaolinite and also provided better selecting ability than salicyl hydroxamic acid.

Recently, there has been limited studies concerning collectors used in the direct flotation of bauxite. In this study, the authors tested direct flotation using a series of anionic reagents in pursuit of a new and efficient collector. The property requirements of the new collector were either a single or mixed collector with strong collecting abilities, excellent selectivity, a wide variety of sources and a reasonable price. The new collector was verified by direct flotation tests using different grades of bauxite ores.

Materials

Characteristics of ores

There were two types of raw bauxite ores used in this study, named Sample I and Sample II. Sample I was gathered from the Xinmi mine while Sample II was collected from the Xiaoguan mine. X-ray diffractograms of these two ore samples are shown in Fig. 1-2 and results of chemical analysis of the ore samples are given in Table 1. Both ores are of diasporic bauxite type. The valuable mineral in the two samples was diaspore. The gangue minerals in Sample I were mainly illite, kaolinite, chlorite, anatase and hematite. The gangue minerals in Sample II were mainly kaolinite, illite, quartz, anatase and hematite.

Table 1. Chemical analysis of bauxite raw ores

Sample code	Ore sources	Grade (%)		(A/S)
		Al_2O_3	SiO_2	
I	Xinmi mine	58.85	11.79	4.99
II	Xiaoguan mine	61.88	13.75	4.50

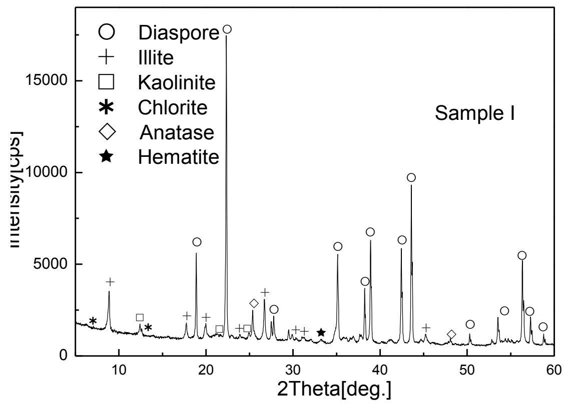

Fig. 1. X-ray diffractogram of bauxite ore from Xinmi Mine (Sample I)

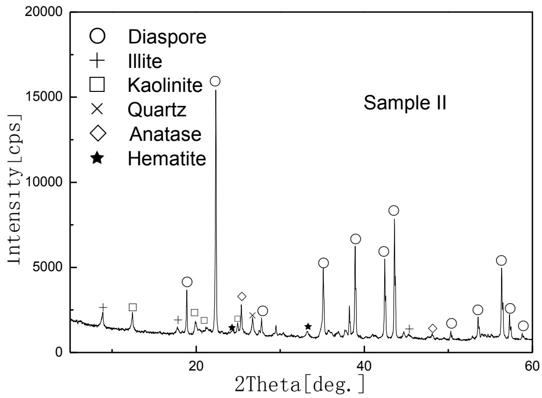

Fig. 2. X-ray diffractogram of bauxite ore from Xiaoguan Mine (Sample II)

Characteristics of reagents

In order to determine the best collector for use in bauxite direct flotation, the authors gathered five collectors from all kinds of chemical reagents and plant oil. There was no literature indicating that these five reagents had been used for bauxite collectors by others in the past. The collectors were, as shown in Table 2, naphthenic acid, alkyl phosphate, lauryl polyoxyethylene phosphate, octanoic polyoxyethylene phosphate and vegetable oil acid. When the collectors were used in the tests, all the anionic reagents were reacted with sodium hydroxide to create solubility in aqueous solution to an appropriate degree.

Table 2. Reagents used for bauxite direct flotation tests

Collectors name	Main components
HOL	Oleic acid (analytical reagent)
Acid 8	Octanoic acid
Acid 9	Pelargonic acid
Acid 10	Decanoic acid
Acid 12	Lauric acid
Acid 16	Palmitic acid
Acid 18	Stearic acid
SDS	Sodium dodecyl sulfate
SDBS	Sodium dodecyl benzene sulfonate
SLS	Sodium lauryl sulfate
SHA	Salicyl hydroxamic acid
PO soap	Paraffin oxide soap
NA	Naphthenic acid
AP	Alkyl phosphate
AEP12	Lauryl polyoxyethylene phosphate
AEP8	Octanoic polyoxyethylene phosphate
VOA	Vegetable oil acid

Calgon was employed as the depressant for aluminosilicate minerals, soda was used as a pH regulator, and analytical grade sodium oleate was used as the collector in the rougher flotation.

Result and discussion

Direct flotation of bauxite ore from Xinmi Mine (Sample I)

In order to determine the appropriate particle size distribution, reagent dosage for pH regulation, and amount of depressant and collector in bauxite direct flotation, the flow sheet shown in Fig. 3 was used. Optimum conditions determination tests including particle size distribution and dosage of soda, Calgon and sodium oleate were performed and results are shown in Figs 4–7, respectively.

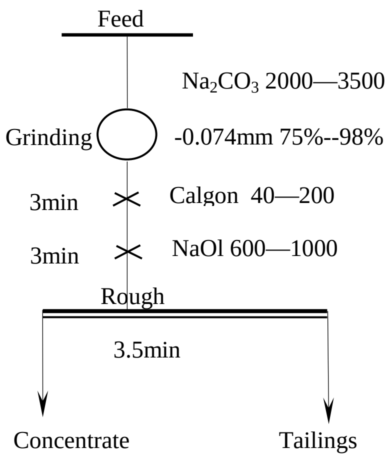

Fig. 3. Flowsheet and test conditions for direct flotation of the bauxite ore (dosages in g/Mg)

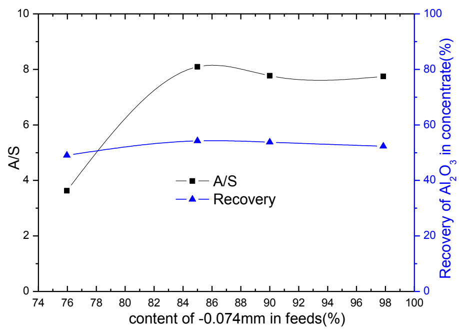

Fig. 4. Effect of fineness on direct flotation ($NaOl$ 800 g/Mg, Na_2CO_3 3000 g/Mg, Calgon 60 g/Mg)

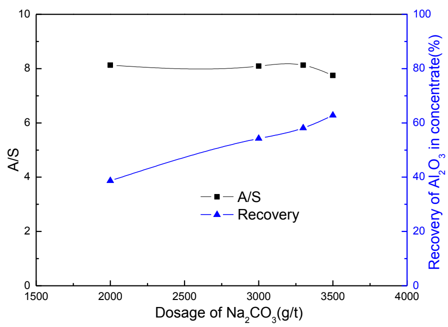

Fig. 5. Effect of Na_2CO_3 on direct flotation (-0.074mm 90%, NaOl 800 g/Mg, Calgon 60 g/Mg)

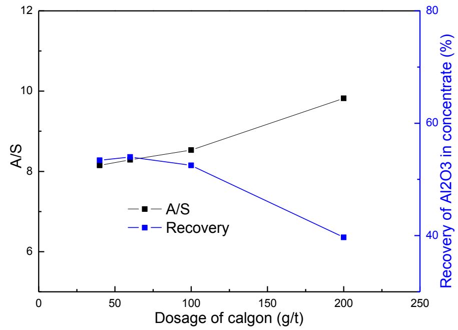

Fig. 6. Effect of Calgon on the direct flotation (-0.074mm 90%, Na_2CO_3 3000 g/Mg, NaOl 800 g/Mg)

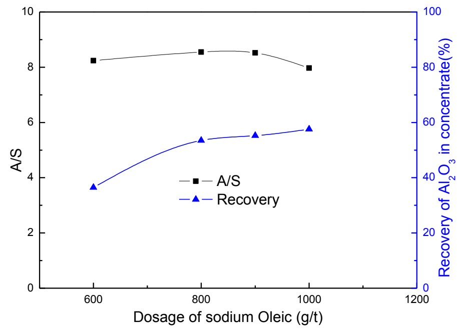

Fig. 7. Effect of sodium oleate on the direct flotation (-0.074 mm 90%, Na_2CO_3 3000 g/Mg, calgon 60 g/Mg)

The results shown in Fig. 4 indicated that the most suitable range of grinding fineness was 85-90 % minus 0.074 mm (here 0.074 mm was chosen as the grinding fineness because in China all the labs and/or flotation plants use this as the ideal grinding size for flotation tests). The results of the soda dosage tests are given in Fig. 5, and the appropriate dosage of Na_2CO_3 was 3000 g/Mg. At this dosage, the test indexes of direct flotation were quite good and the cost of Na_2CO_3 was relatively low. The results in Fig. 6 showed the effect of Calgon on the direct flotation. The recovery of Al_2O_3 in concentrate decreased with the rising dosage of Calgon but the mass ratio of A/S increased. The requirement of A/S for the Bayer Process was about 7–8, so the dosage of Calgon was chosen at 60 g/Mg. At this dosage the A/S of the concentrate was about 8.2 and the recovery reached 56 %. The influence of sodium oleate dosage on the direct flotation is given in Fig. 7. With the rising dosage of sodium oleate the recovery of Al_2O_3 in concentrate increased, first significantly and then slightly, and reached around 58%, but the mass ratio of A/S remained about 8. Thus, the sodium oleate dosage was 800 g/Mg.

Based on the results of the conditions testing mentioned above, it was concluded that the appropriate grinding fineness was 85-90% –0.074 mm and the reagent dosages of Na_2CO_3, Calgon and sodium oleate were 3000, 60 and 800 g/Mg, respectively.

Effect of various anionic collectors on direct flotation of bauxite

After determination of the optimum test conditions, the authors continued to carry out the direct flotation using the flow sheet given in Fig. 3 on Sample I, and varieties of anionic reagents listed in Table 2 were employed as collectors. The flotation behaviors of varieties of anionic collectors on bauxite are given in Figs 8–10.

Flotation results using a straight chain alkyl fatty acid as collectors are shown in Fig. 8. It can be seen that the flotation performances of acids 8, 9, 10, 12, 16, 18 and HOl were quite different. Flotation performances were poor when acids 8, 9, 10 and 18 were used and the A/S of the concentrate was 5 or less. This can be attributed to their poor selectivity to separate diaspore from alumino-silicates in direct flotation.

Compared to the poor behaviour of those four collectors, acid 12, acid 16 and HOl indicated better flotation performances. The A/S of the concentrate was above 7, and recovery of Al_2O_3 was approximately 55 %. The most effective collector was HOl, which showed the best selectivity and collectivity of the seven collectors. When HOl was used, the A/S reached 8.5, and the recovery of Al_2O_3 reached 53.51%.

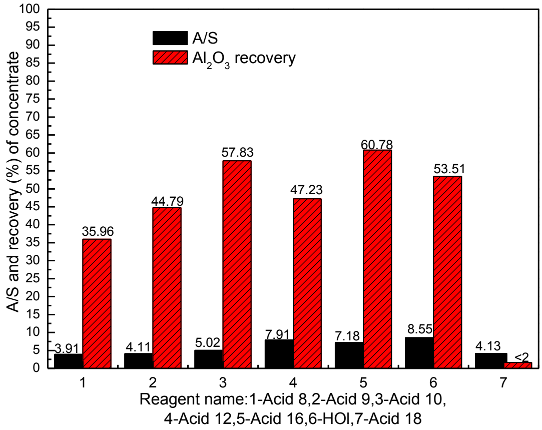

Fig. 8. Flotation results using straight chain alkyl fatty acid as collectors

Flotation behaviour with the use of several anionic collectors including SDS, SDBS, SLS, SH and PO soap is shown in Fig. 9. The selectivity of SDS, SDBS, SLS and SH were poor, the A/S of the concentrate was lower than 5.5. The flotation performance of PO soap was relatively better, but the A/S of the concentrate was still not higher than 7. Hence, SDS, SDBS, SLS, SH and PO soap were not suitable for direct flotation of bauxite.

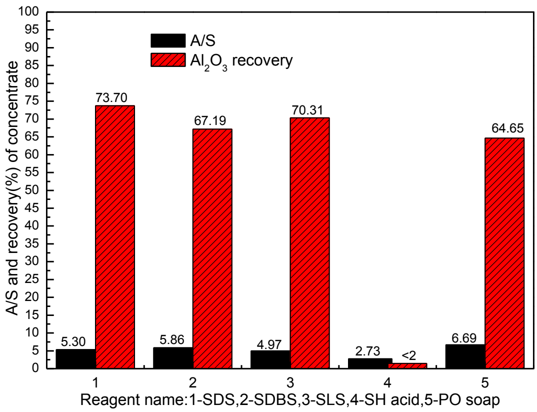

Fig. 9. Flotation results using the other five anionic collectors

The effects of NA, AP, AEP12, AEP8 and VOA in direct flotation are shown in Fig. 10. Flotation performances of AP and AEP8 were poor, the A/S ratio of the concentrate was 6.55 and 5.81, and recovery were 28.89% and 60.24%, respectively. However, NA, AEP12 and VOA indicated excellent flotation performance in bauxite direct flotation. NA showed a strong collectivity for bauxite, the recovery ratio of its concentrate reached to 90.30%, and the A/S was 6.78. AEP12 showed an outstanding selectivity for bauxite, the A/S of concentrate reached 9.95, and the recovery ratio was 60.79%. VOA provided a better balance between collectivity and selectivity, the recovery of its concentrate reached 70.89%, and the A/S was 8.41.

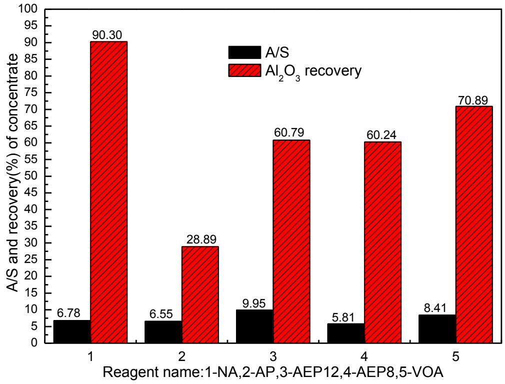

Fig. 10. Flotation results using five novel chemical reagents as collectors

Direct flotation tests for reagent preparation and application

Based on the flotation results, several collectors were selected from a number of anionic reagents. It can be seen that VOA and NA indicated stronger collecting abilities, and had normal selectivity. Meanwhile, AEP12 showed outstanding selectivity, and at the same time its collectivity was quite strong. After comprehensively considering the collectivity, selectivity, solubility and market price of reagents, the collector of ZMC was mixed and prepared.

The ZMC reagent is a mix of anionic collectors, and its main ingredients are saponification of VOA, NA and AEP12. The mass ratio of VOA, NA and AEP12 in the ZMC reagent was 1:1:0.5. When using ZMC reagent in the bauxite flotation, VOA and NA were employed as the key collectors, meanwhile, NA effectively promoted the solubility of VOA. AEP12 played an important role in improving the selectivity of the ZMC reagent. Relying on the efficient synergistic effects of anionic mixed collectors, a ZMC reagent with a better solubility, collectivity, selectivity and lower market price could be absorbed more efficiently on the diaspore than normal anionic collectors of oleic acid.

In order to confirm the flotation performances of the ZMC reagent, the authors carried out a number of direct flotation tests for two bauxite samples using the ZMC reagent. Two samples were chosen to be different from each other, so that the applicability of the ZMC collector could be determined. Direct flotation tests for Samples I and II were performed according to the flow sheet shown in Fig. 11 and the results were given in Table 3. The results indicated that the A/S of the final bauxite concentrate was 7.08, and the recovery rate of Al_2O_3 was 90.22%, when processing Sample I. When processing Sample II, the A/S of the final bauxite concentrate was 7.04, and the recovery rate of Al_2O_3 was 92.16%.

The Bayer process is the most used method to produce alumina and the minimum requirement for the mass ratio of A/S in the Bayer process is 8. Currently, based on the Lime-Bayer Process, the lowest demand for A/S of ores can be reduced to 7. According to the direct flotation results for different bauxite samples, performances of the ZMC reagent were quite satisfactory, and the A/S of the final concentrates was greater than 7. Thus, one can see that the properties and behaviour of the ZMC reagent were acceptable and met the demands of the "Lime-Bayer Process".

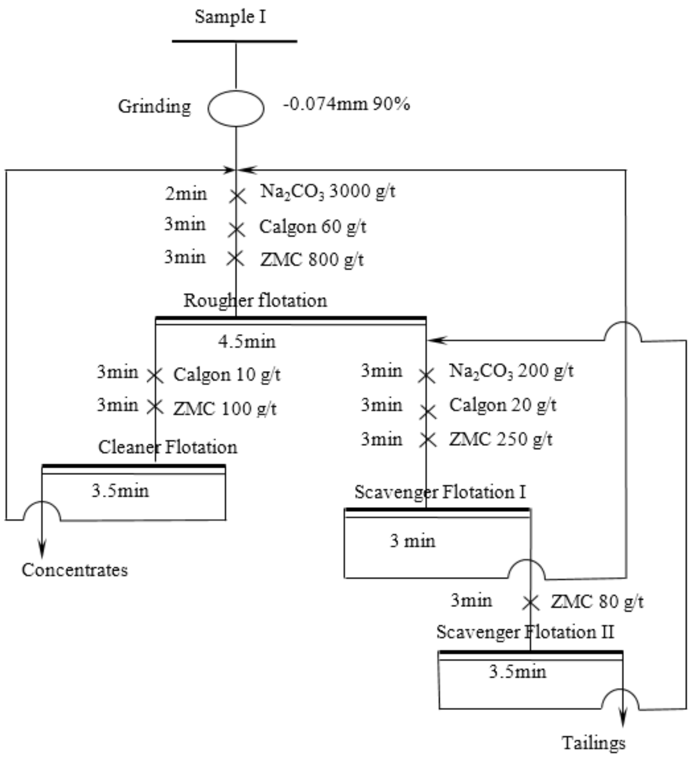

Fig. 11. Direct flotation tests for the Xinmi Mine ore (sample I) using ZMC collector (symbol g means gram while symbol t mean megagram)

Table 3. Direct flotation test results for Xinmi Mine ore (sample I) and Xiaoguan Mine ore (sample II)

Product name	Yield (%)	Grade (%)		A/S	Recovery rate (%)	
		Al_2O_3	SiO_2		Al_2O_3	SiO_2
Concentrate I	85.85	62.09	8.77	7.08	90.22	65.00
Tailings I	14.15	40.84	28.64	1.43	9.78	35.00
Sample I Feed	100.00	59.08	11.58	5.10	100.00	100.00
Concentrate II	86.83	65.87	9.36	7.04	92.16	61.90
Tailings II	13.17	36.94	37.98	0.97	7.84	38.10
Sample II Feed	100.00	62.06	13.13	4.73	100.00	100.00

Conclusions

Two samples of middle-low grade of ores were designated as diasporic bauxite, the main valuable mineral was diaspore, and the main gangue minerals were illite and kaolinite. VOA, NA and AEP 12 were three outstanding collectors for bauxite direct flotation based on a series of direct flotation tests using various anionic collectors. The reagent of VOA and NA had stronger collecting abilities, and normal selectivity. The reagent of AEP12 had both outstanding selectivity and collectivity. Finally, the ZMC collector was mixed and prepared using VOA, NA and AEP12 with the mass ratio of 1:1:0.5.

The direct flotation processing bauxite gained good results using the ZMC collector. When processing the bauxite ores having A/S = 4.99 and 4.5, for both the A/S of the final concentrate was higher than 7, and both Al_2O_3 recoveries were more than 90%. The final concentrate were acceptable and met the demands of the Lime-Bayer Process.

Acknowledgements

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