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Title: Improve the recovery of fine auriferous pyrite using a collector mixture

Article Type: Research Paper

Keywords: Auriferous pyrite; Collector mixture; Flotation; Isomeride

Abstract: The beneficial effects of the synergy between two reagents were realized long time ago. The purpose of using a mixture of collectors was to increase both the recovery and selectivity. In this work, sodium iso-amylxanthate (SIAX) and its isomeride (Y89), having different molecular structure, were used. The separation performance of these collectors were investigated at various SIAX : Y89. The results showed that the better recovery of auriferous pyrite was observed with collector mixture comparing to use collector alone. There exist an optimal mass ratio between SIAX and Y89, and it is 1:2. The adsorption measurements of collector mixture and single collector were investigated at pH= 9, indicated that adsorption density of collector on auriferous pyrite surface was improved when collector mixture was used. Infrared spectral analysis suggested stretching vibration peaks from chemical adsorption were increased by using collector mixture. At an optimal mass ratio 1:2 of SIAX:Y89, an Au concentrate assaying 12.79 g/t Au was produced with a Au recovery of 84.24% from a feed containing only 3.44 g/t Au by one rough flotation. The advantage of this collector mixture can improve the recovery of auriferous pyrite at the same collector concentrations, and this collector mixture has great potential for industrial application.

Highlights

Improve the recovery of fine auriferous pyrite using a collector mixture SIAX + Y89.

Mixing mass ration 1:2 of SIAX + Y89 is preferred.

Density of collector on auriferous pyrite surface was improved when collector mixture was used

are commonly used in flotation, and a range of performance benefits can be obtained (Lotter and Bradshaw, 2010; Chryssoulis et al., 2004). This is a synergistic effect (Bradshaw, 1997). The synergistic enhancement of flotation performance observed has largely been attributed to improved adsorption characteristics of the collector mixture on the mineral surface as compared to those of the pure collectors. The improved adsorption characteristics would result in improved floatability by increasing the bubble-mineral attachment tenacity which would result in less mineral detachment and elutriation. The frother-collector interactions may also be increased resulting in stronger mineral-bubble attachment. Hangone et al., 2005, reported that the mixed collector system produced a more stable froth because of the increased hydrophobicity and wider range of particle sizes held in that froth.

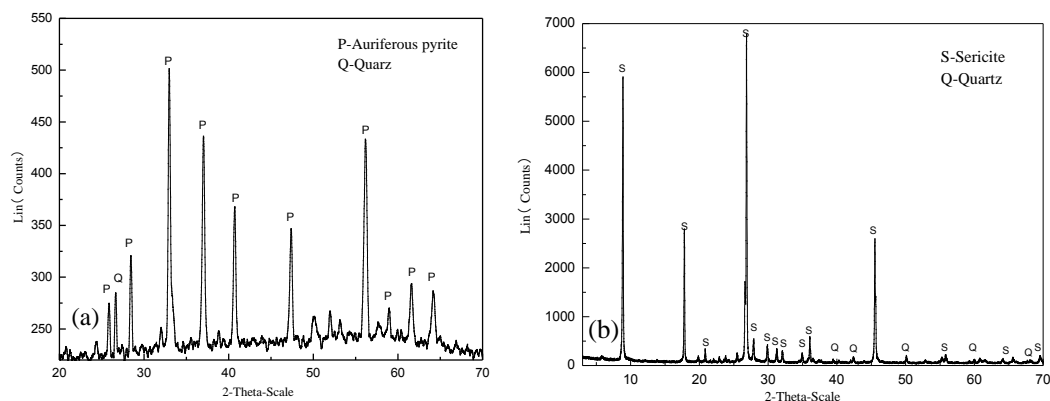
For example, testwork reported by Glembotskii, 1958, showed that when a weaker collector is added to a stronger collector, the mixture results in a recovery gain of 2-5% relative to the single strong collector system. Glembotskii explained that the consistent better performance by the mixed collectors was due to the synergy effect generated between the two different collectors. He claimed that the larger the difference in structure and composition, the larger the synergy effect. Similarly, Alim et al., 2012, showed that mixtures of ethyl xanthate with diethyl dithiophosphate or ethyl dithiocarbamate resulted in large improvements in the flotation rate and recovery with pure galena in a microflotation cell. There have been numerous reports on flotation of auriferous pyrite using the mixture of the two different collector. However, a mixture collector of xanthate and its isomeride has not been extensively studied.

In this study, the flotation of fine auriferous pyrite particles ($< 38 \mu\text{m}$) was studied with a collector mixture of Sodium iso-amylxanthate (SIAX) and its isomeride (Y89). The mechanisms underlying the mineral-reagent interaction were further investigated by adsorption measurements and infrared spectral analysis. The results provide a reference for effectively recovering fine auriferous pyrite before smelting.

2. Materials and methods

2.1. Pure minerals and reagents

Pure auriferous pyrite, sericite, quartz and dolomite were sourced from Xinjiang, China. X-ray powder diffraction data confirmed that the auriferous pyrite, sericite, quartz and dolomite were 97%, 95%, 98% and 96% pure, respectively. X-ray diffraction of auriferous pyrite, sericite, quartz and dolomite are shown in Fig. 1. The $-38 \mu\text{m}$ fraction was used in the flotation tests.



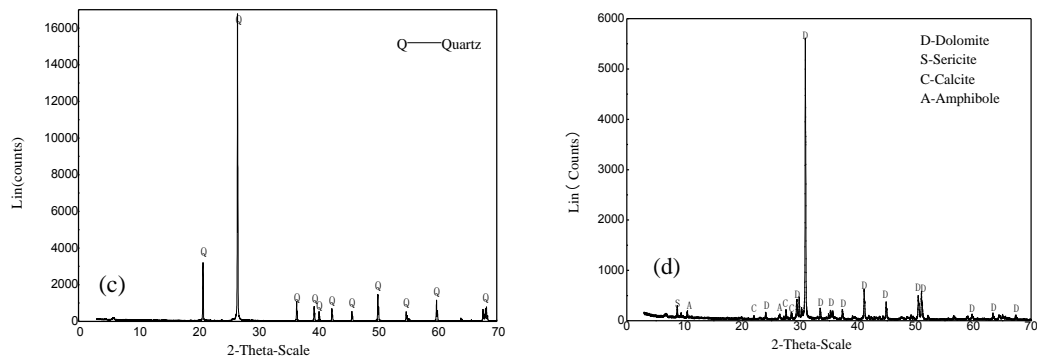


Fig.2. X-ray diffraction of auriferous pyrite, sericite, quartz and dolomite

The sources of flotation reagents were as follows: analytical grade sodium iso-amylxanthate (SIAX) and Y89 were from Zhuzhou flotation reagents factory, Hunan, China. The molecular of collectors are shown in Fig. 2. The pH was adjusted with NaOH or HCl stock solutions. Deionized water with a resistivity of more than $18 \text{ M}\Omega \times \text{cm}$ was used for all experiments.

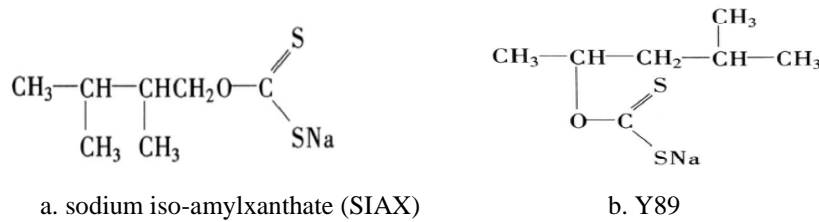


Fig. 2. Generic molecular structure of SIAX and Y89

2.2. Flotation experiment

Single mineral flotation tests were carried out in an XFG flotation machine with a 40 mL plexiglass cell, at an impeller speed of 1800 rpm. The mineral suspension was prepared by adding 3.0 g of minerals to 40 mL of distilled water. The pH of the mineral suspensions was first adjusted by adding NaOH or HCl. Once the desired reagent was added, the suspension was agitated for 3 min and the pH measured before flotation. The flotation lasted for 4 min before the products were collected, dried, and weighed. The recovery was calculated based on the weights of the dry products obtained.

2.3. Adsorption measurements

The adsorption measurements were completed on a TU-1810 ultraviolet visible spectrophotometer (Purkinje General, Beijing, China). The curves represent the averages of five measurements, and the error bars are based on the standard deviation. Two grams of mineral powder and 40 mL of distilled water were transferred into an Erlenmeyer flask. After the reagent addition to the solution, the Erlenmeyer flask was stirred on a magnetic mixer for 1 h, allowing the adsorption process to reach equilibrium. The solution was centrifuged and filtered, and the supernatant was collected for UV spectrometry analysis. According to the residual concentration of the reagent remaining in the solution,

the adsorption of the reagent on the mineral surface can be calculated as follows:

$$\Gamma = \frac{C_0 - C \times V}{m} \quad (1)$$

where Γ is the adsorption amount, mol/g; C_0 is the initial concentration of reagent in the solution, mol/L; C is the residual concentration of the reagent in the supernatant, mol/L; V is the volume of the solution, L; and m is the weight of the mineral, g.

2.4. Infrared spectral analysis

Prior to the test, pure minerals were ground to $-2 \mu\text{m}$ in an agate mortar before they were conditioned with reagent in the solution. The fully interacted sample was filtered and washed three times with the corresponding pH solution. The solid obtained was dried in a vacuum desiccator. Fourier transform infrared spectra were recorded with a Nicolet™ 740 FTIR spectrometer (Thermo Scientific, Waltham, MA, USA) at 25°C in the range of $4000\text{-}500 \text{ cm}^{-1}$.

3. Results and discussions

3.1. Microflotation

Firstly, the flotation separation using SIAX or Y89 at a dosage of 30 mg/L were evaluated by single mineral test. Flotation results show that, although high recovery of or auriferous pyrite could be obtained at pH 4, the preferred pulp pH ranges using SIAX and Y89 as individual collector for auriferous pyrite flotation is 9-10 because of dolomite existence in this material, as shown in Fig. 3. pH 9 was further used for all flotation tests.

As shown in Fig. 3(a), using SIAX alone as collector and Terpenic oil as frothing agent, better auriferous pyrite flotation could be achieved when the SIAX concentration is higher than 40 mg/L . When SIAX concentration is 40 mg/L , the recovery of auriferous pyrite is 73.98% . Fig. 3(b) shows the similar flotation regularity when Y89 was used as collector, but Y89 shows much stronger collecting capacity than SIAX at the same concentrations. When Y89 concentration is 40 mg/L , the recovery of auriferous pyrite is 75.25% .

From Fig. 4(a) and (b), it can be noted that auriferous pyrite has good floatability with Y89 and SIAX, indicating that Y89 is a better collector for auriferous pyrite than SIAX. Also, 40 mg/L of collector concentration is enough for recovering auriferous pyrite.

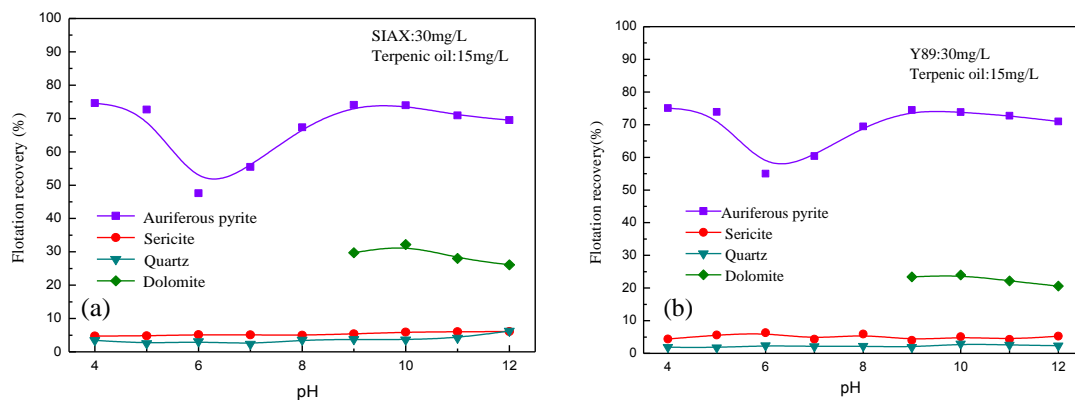


Fig. 3. Effect of pulp pH on flotation behavior of auriferous pyrite, sericite, quartz and dolomite using SIAX or Y89 as collector

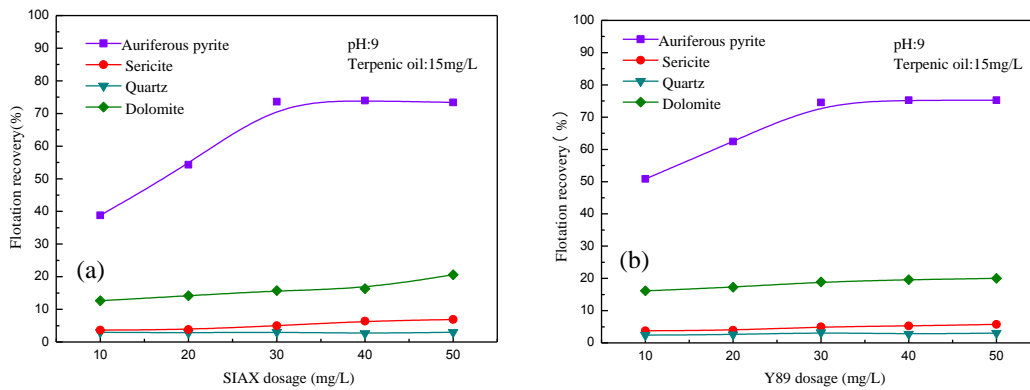


Fig. 4. Effect of SIAX dosage on flotation behavior of auriferous pyrite, sericite, quartz and dolomite

The flotation behavior of auriferous pyrite, sericite, quartz and dolomite individually using a collector mixture of SIAX and Y89 at different mass ratio was investigated. A series of flotation results demonstrate that the collector mixture of SIAX and Y89 at a mass ration of 1:2 achieves the best flotation separation performance, as shown in Fig. 5. Auriferous pyrite has a favorable recovery of 85.19%. Compared with the results using SIAX and Y89 as individual collector in Fig. 5, marked differences in the recovery of auriferous pyrite implies that the flotation separation performance is improved using 1:2 collector mixture SIAX +Y89.

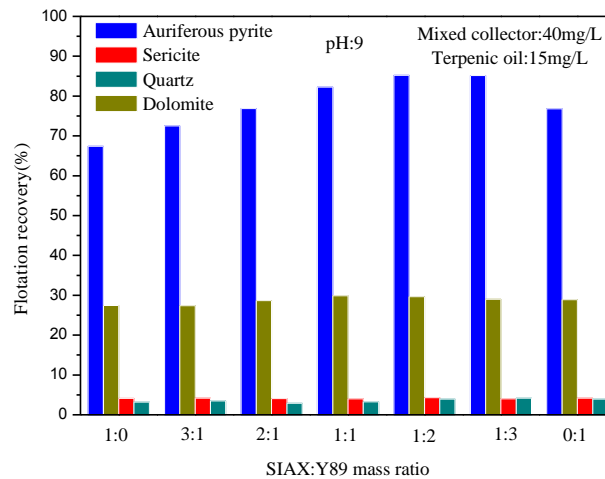


Fig. 5. Effect of mass ratio of SIAX+Y89 on flotation behavior of auriferous pyrite, sericite, quartz and dolomite

As shown in Fig. 6, using SIAX+Y89 as mixed collector and Terpenic oil as frothing agent, better auriferous pyrite flotation could be achieved when the concentration of mixed collector is higher than 40 mg/L. At the point of 40 mg/L of mixed collector, the recovery of auriferous pyrite is 85.19%. Further increasing concentration of mixed collector, recovery of auriferous remains almost unchanged, but recovery of dolomite would increase slightly.

From Fig. 5, it can be noted that the two strong collectors mixed is benefit for further increasing

their collecting capacity at the same concentrations. There exist an optimal mass ratio between two collector.

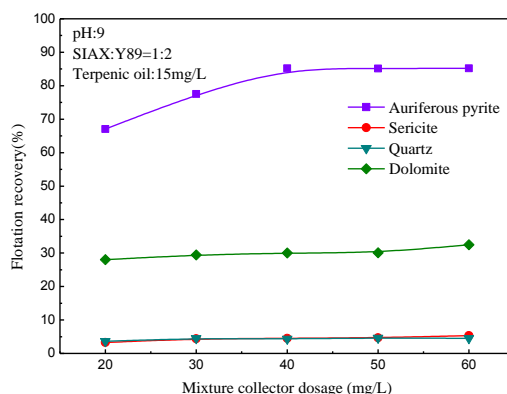


Fig. 6. Effect of mixed collector (SIAX:Y89=1:2) dosage on flotation behavior of four minerals

3.2. Adsorption measurements

A series of adsorption studies were completed to probe the adsorption behavior of the single collector and mixed collector.

Fig. 7 illustrates that the adsorption density of SIAX on auriferous pyrite decreases from 0.69 to 0.46 mg. g⁻¹ as increasing the pH of pulp from 4 to 12. On the surface of auriferous pyrite, the adsorption amount of SIAX decreased slightly when the pH rose from 4 to 9. However, a sharp drop in the adsorption density of SIAX occurred at pH > 9.

Fig. 8 shows the adsorption density of Y89 on auriferous pyrite decreases from 0.71 to 0.56 mg. g⁻¹ as increasing the pH of pulp from 4 to 12. Although the adsorption density of Y89 has the same shape with SIAX, Y89 collector has much stronger adsorption capacity on the surface of auriferous pyrite in the whole pH range. When Y89 is used as collector, the difference from SIAX is that adsorption amount of collector on dolomite decreased with the pH of pulp increasing. That will benefit the improvement of separation performance in recovering auriferous pyrite.

Adsorption studied were conducted on four minerals when the collector mixture of SIAX and Y89 was at a mass ration of 1:2. As shown in Fig. 9, the adsorption density of mixed collector on auriferous pyrite decreases from 0.80 to 0.63 mg. g⁻¹ as increasing the pH of pulp from 4 to 12. Comparing to use collector alone, the mixed collector has better adsorption capacity on the surface of auriferous pyrite. That is the reason why the higher recovery of auriferous pyrite can be obtained when the mixed collector was used.

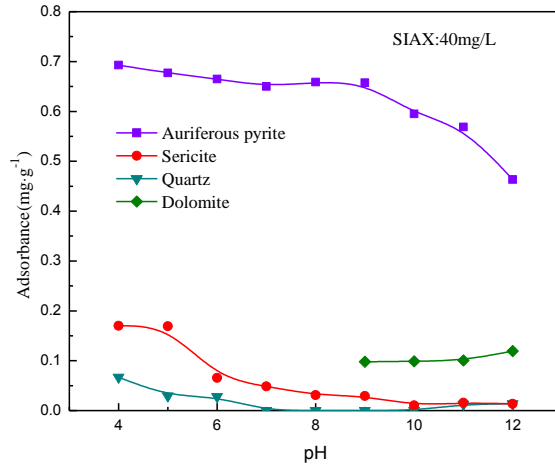


Fig. 7. Relationship between SIAX adsorbance on four minerals and pulp pH

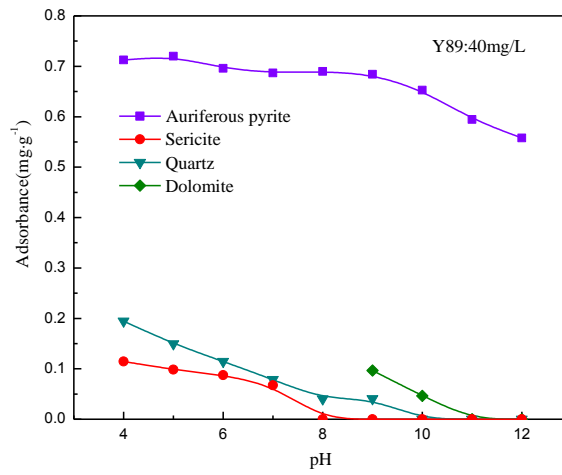


Fig. 8. Relationship between Y89 adsorbance on four minerals and pulp pH

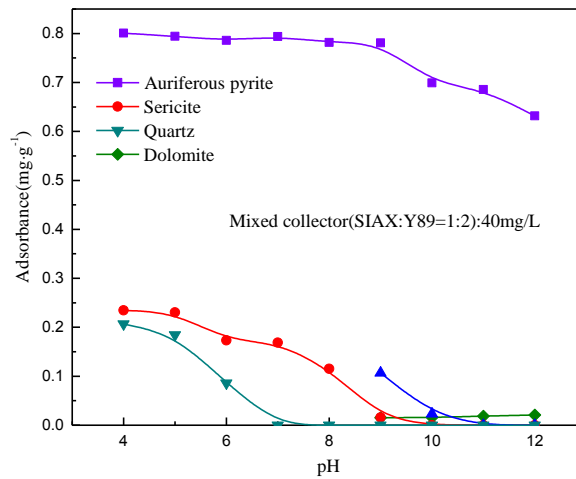


Fig. 9. Relationship between mixed collector(SIAX:Y89=1:2) adsorbance on four minerals and pulp pH

3.3. Infrared spectral analysis

Fig. 10 shows the infrared spectral patterns of auriferous pyrite before and after interaction with SIAX. Fig. shows that, 2956.15 cm^{-1} and 2874.08 cm^{-1} are stretching vibration absorption peaks of C-H in $-\text{CH}_3$ and $-\text{CH}_2$, respectively. 1146.01 cm^{-1} is stretching vibration absorption peaks of C-O-C, 933.54 cm^{-1} - 1027.52 cm^{-1} is stretching vibration absorption peaks of C=S (Sun et al., 2014; Sun et al., 2015). IR spectrum of auriferous pyrite in Fig. 10 is consistent with the standard spectrum of pyrite, and there are three characteristic absorption peaks such as 408.55 cm^{-1} , 1090.71 cm^{-1} and 1453.49 cm^{-1} . Compared spectra in Fig. with Fig. , stretching vibration peaks of C-H in 2955.35 cm^{-1} and 2852.72 cm^{-1} is found in the IR spectrum of auriferous pyrite after adsorbed by SIAX. C=S and C-O-C stretching vibration peaks are found in 1027.89 cm^{-1} and 1207.20 cm^{-1} , respectively. Analysis results of IR spectrum show that SIAX may absorb on auriferous pyrite surface in the form of chemical adsorption.

As shown in Fig. 11, stretching vibration peaks of C-H in 2956.35 cm^{-1} and 2869.72 cm^{-1} is found in the IR spectrum of auriferous pyrite after adsorbed by Y89. C=S and C-O-C stretching vibration peaks are found in 1012.99 cm^{-1} and 1267.20 cm^{-1} , respectively. Compared spectra in Fig. with Fig. , stretching vibration peaks is much apparent, which indicates that collector Y89 can much strongly absorb on the surface of auriferous pyrite.

When the collector mixture of SIAX and Y89 was at a mass ration of 1:2, the infrared spectral patterns of auriferous pyrite before and after interaction with mixed collector was studied. As shown in Fig. 12, stretching vibration peaks of C-H in 2955.78 cm^{-1} and 2869.76 cm^{-1} is found in the IR spectrum of auriferous pyrite after adsorbed by mixed collector. C=S and C-O-C stretching vibration peaks are found in 1016.73 cm^{-1} and 1267.05 cm^{-1} , respectively. Compared spectra of Fig. 10, Fig. 11 and Fig. 12, stretching vibration peaks has greater intensity in Fig. 12. It indicates that mixed collector can much strongly absorb on the surface of auriferous pyrite and improve the recovery of auriferous pyrite.

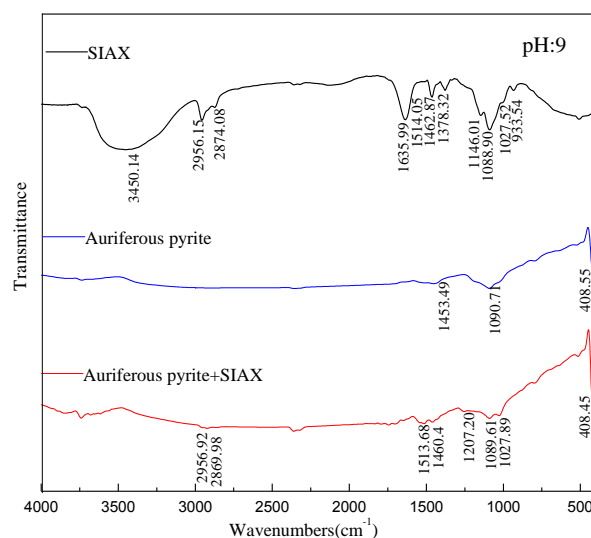


Fig. 10. IR spectrum in the absence and presence of pure SIAX

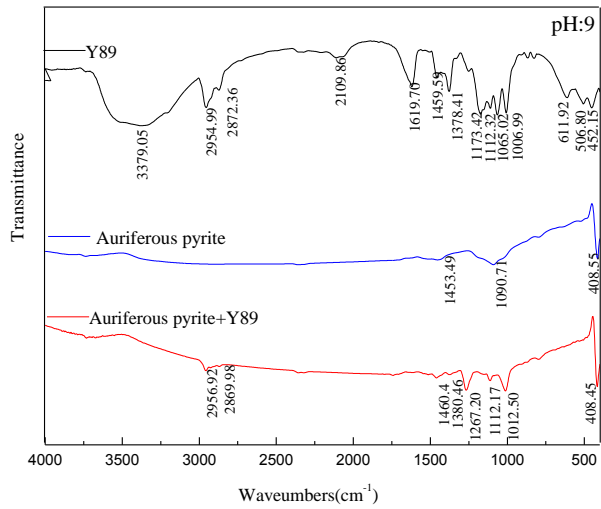


Fig. 11. IR spectrum in the absence and presence of pure Y89

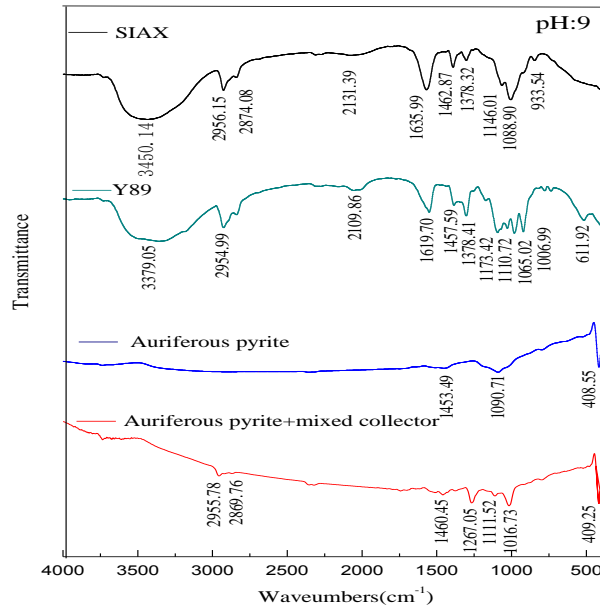


Fig. 12. IR spectrum in the absence and presence of mixed collector

3.4. Flotation tests on materials

The materials containing auriferous pyrite in the flotation were obtained from Xinjiang, China. Chemical composition analysis was carried out X-ray fluorescence spectrometry (XRF) technique by using a Philips spectrometer. Phase composition of the ore was investigated by Powder X-ray diffraction (XRD). XRF and XRD results of the experiment sample are shown in Table 1 and Fig. 13 respectively.

Table 1 Chemical composition of the ore sample (mass fraction, %).

Composite	Au (g/t)	S	As	CaO	MgO	SiO ₂	Al ₂ O ₃	TFe
Grade	3.44	2.78	0.32	6.82	2.63	61.74	10.75	5.23

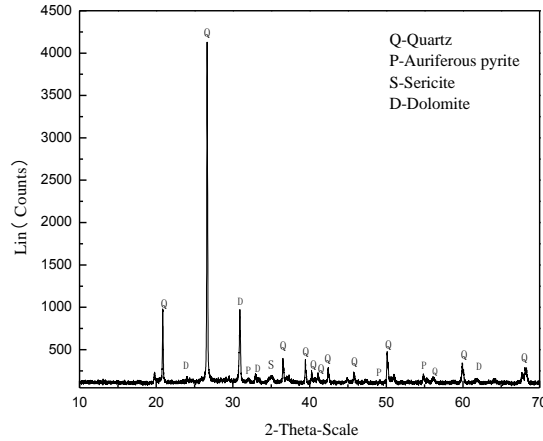
**Fig. 13.** X-ray diffraction of materials

Table 1 suggests that the main value elements in the materials is Au with a grade of 3.44g/t. And the XRD result indicates that Au mainly exist in auriferous pyrite, and quartz, sericite and dolomite are the dominate gangue minerals, as shown in Fig. 13.

Based on the results of microflotation experiments, adsorption measurements and Fi-IR analyses, the raw ore flotation tests were investigated under the condition of different collector. In raw ore flotation, 500 g of sample was used for each test. The pH was adjusted to 9 with NaOH, and the dosage of terpenic oil was 30 g/t. The results of the raw ore flotation experiments are listed in Table 2. When the collector mixture of SIAX and Y89 was at a mass ration of 1:2, an Au concentrate assaying 12.79 g/t Au was produced at a Au recovery of 84.24%. Comparing SIAX or Y89 as alone collector, the Au recovery has a significant improvement at the same reagent consumption. The 1:2 collector mixture SIAX+Y89 shows great potential for industrial application.

Table 2 Results of flotation tests performed on materials using pure and collector mixture

Collector	Products	Yield/wt%	Au	
			Grade (g/t)	Recovery(%)
SIAX	Concentrate	19.94	12.77	74.03
	Tailings	80.06	1.12	25.97
	Feed	100.00	3.44	100.00
Y89	Concentrate	21.20	12.95	79.82
	Tailings	78.80	0.88	20.18
	Feed	100.00	3.44	100.00
SIAX:Y89 =1: 2	Concentrate	22.63	12.79	84.24
	Tailings	77.37	0.70	15.76
	Feed	100.00	3.44	100.00

4. Conclusions

(1) In this study, the flotation of fine auriferous pyrite was studied with a collector mixture of Sodium iso-amylxanthate (SIAX) and its isomeride (Y89). It can be noted that, when the two strong collectors was mixed for recovering auriferous pyrite, the higher recovery can be obtained than alone collector. There exist an optimal mass ratio between two collectors.

(2) Adsorption measurements show that the adsorption density of collector on auriferous pyrite slightly decreases increasing pH from 4 to 9 and greatly decreases with from 9 to 12. Comparing to use collector alone, the mixed collector has greater adsorption density on the surface of auriferous pyrite under condition of the same collector concentrations in the whole pH range.

(3) The infrared spectral analysis suggests that mixed collector can much strongly absorb on the surface of auriferous pyrite, and the stretching vibration peaks has greater intensity. This is the reason that collector mixture can improve the recovery of auriferous pyrite. The collector mixture SIAX+Y89 exhibits great potential for industrial application in fine auriferous pyrite flotation.

Acknowledgements

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