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Effect of radiation on wettability and floatability of sulfide minerals

Huaifa Wang[1,2], *Shouci Lu*[1], *and Liqing Xie*[3]

1) Civil and Environmental Engineering School, University of Science & Technology Beijing, Beijing 100083, China
2) Mining Engineering School, Taiyuan University of Technology, Taiyuan 030024, China
3) The Key Laboratory of Beam Technology and Material Modification of Ministry of Education, Beijing Normal University, Beijing 100875, China
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Abstract: The feasibility for modifying the wettability and floatability of sulfide minerals by electron beam irradiation has been studied experimentally. The wettability of crystalline pyrite and floatability of some sulfide as pyrite, arsenopyrite, chalcopyrite and marmatite after irradiation were examined by flotation in a modified Hallimond tube. Experimental results show that the hydrophobicity of crystalline pyrite enhances with the increase of irradiation dose in a low dose range. And the flotation responses of sulfide minerals on irradiation dose vary with the mineral species and particle size. The floatability of minerals can be regulated by altering irradiation dose. An explanation for the mechanism has been suggested based on the principle of radiation chemistry.

Key words: electron beam; irradiation; wettability; foatability; sulfide mineral; mechanism

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The idea of using ionizing radiation treatment for study of mineral floatability was firstly proposed and applied in 1970s. Subsequently, numerous researchers adopted this method and used it in flotation study. Hitherto, various radiation sources like fast neutrons, gamma, beta or X rays from radionuclide sources were used for treatment of minerals as rutile, quartz, feldspar, scheelite and so on. The experiment results have shown a substantial modification of floatability of those minerals [1-4]. Unfortunately, the high investment in radiation source establishment, high cost of operation and difficulty in waste source disposal become a barrier for its industrial application.

At present, with the development of nuclear industry, industrial high energy electron accelerators have been developed and widely used in radiation processing technology. Bochkarev, Chanturia and Florek have conducted comprehensive research works for the application of electron beam irradiation in mineral processing [2, 5-8]. Achievements acquired in mineral flotation shows that surface properties of minerals could be changed by electron beam irradiation observably. Therefore, ionizing radiation treatment appears a promising alternative in strengthening mineral flotation process.

1 Experiment materials and methods

1.1 Contact angle measurement

(1) Preparation of specimen.

Crystalline pyrite specimen from Leiyang, Hunan province of China was selected for contact angle measurement. The specimens were roughly polished on a series emery papers, and then followed by two wet polishes on a low-spin lap using levagated polishing powder chromium hemitrioxide in canvas millstones and magnesia in worsted millstones. After polishing, the samples were washed vigorously to remove any adhering powder and then stored under the protection of nitrogen gas. Rubber gloves were used for the entire polishing sequence and all specimens were handled to avoid contamination. Eleven specimens with the size of 2 cm×1.5 cm×0.5 cm were prepared for experiments.

(2) Irradiation.

Crystalline pyrite specimens were subjected to irradiation by model BF-5 electrostatic linear electron accelerator in the Key Laboratory of Radiation Beam Technology and Materials Modification of Beijing Normal University. Beam energy of accelerator was given as 1.5 MeV in irradiation. The beam density was altered according to experiment parameters.

(3) Test method and principle.

The contact angle measurement were carried out using model JY-1 contact angle goniometer. Principle used for contact angle measurement is illustrated in **figure 1**. In procedure of experiment, the specimen was immerged in distilled water and the small bubble made by a capillary was followed, the contact angle of bubble

Corresponding author: Huaifa Wang, **E-mail**: h-fwong@163.com

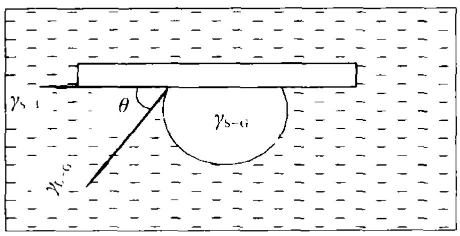

Figure 1 The priciple of contract angle measurement.

and mineral surface in distilled water was measured using protractor through a magnifier. Contact angles were measured on two opposite sides of the bubble. Several bubbles were measured to ensure reproducibility. The standard deviation in measuring single contact angle was about ±2°. Arithmetical mean of measured values was regarded as experimental data.

When the bubble adhering to polished mineral surface, the contact periphery of three phases is formed. Make tangent line at arbitrary point of contact periphery, the inclination which includes liquid is called contact angle, commonly expressed as θ. The relation of equilibrium contact angle with free energy of gas-solid, liquid-solid and gas-liquid interfaces can be expressed by the Young's equation:

$$\gamma_{S\text{-}G} - \gamma_{S\text{-}L} = \gamma_{L\text{-}G} \cos\theta \qquad (1)$$

where θ is the equilibrium contact angle, $\gamma_{S\text{-}G}$, $\gamma_{S\text{-}L}$ and $\gamma_{L\text{-}G}$ are the free energy of gas-solid, liquid-solid and gas-liquid interfaces, respectively.

Magnitude of contact angle is a measurement of wettability of solid surface. The bigger the contact angle is, the more hydrophobic the solid surface will be.

1.2 Flotation experiment

Some sulfide minerals like pyrite, arsenopyrite, chalcopyrite and marmatite were used in floatability experiments. The pure minerals were milled to −75 μm and classified into size fractions of 75-53 μm and −53 μm. Each size fraction was separated into samples. Every sample was weighted and put in weighing disk for irradiation.

Irradiation was carried out using model GJ-15 electron accelerator according to scheduled irradiation dose in Tianjin Institute of Technical Physics of China. The irradiated samples were sealed for flotation experiments.

Flotation experiments were conducted in distilled water with a modified Hallimond tube. The Butyl-xanthate was used as collector in the flotation of all minerals. The flotation conditions were as follows.

Volume of flotation pulp: 100 mL;

Preconditioning time: 3 min;

Aeration rate: 66 mL/min;

Aeration time: 3 min;

Dosage of flotation reagent: 2 mg/g.

2 Experiment results and discussion

2.1 Effect of electron beam irradiation on wettability of pyrite

The measured contact angle data of pyrite before and after irradiation by electron beam are illustrated in **figure 2**. The experimental data showed that the contact angle after irradiation rose with the increase of irradiation dose at beam current 120 μA. In the range of irradiation dose tested, the contact angle of crystalline pyrite was increased from 24.2° before irradiation to 33.54° after irradiation at dose 10 kGy. When the beam current was 150 μA, the contact angle after irradiation was increased rapidly in the range of irradiation dose of 2-8 kGy, beyond that the increase slowed down. After irradiation of dose 10 kGy at beam current 150 μA, the contact angle was changed to 40.24°.

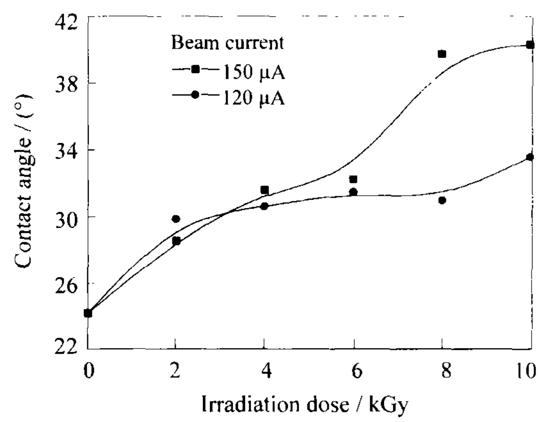

Figure 2 Effect of electron beam irradiation on contact angle (θ) of crystalline pyrite under different beam current.

By comparison of results of irradiation tests at beam current 120 and 150 μA, one can find that effect of irradiation on contact angle of crystalline pyrite is similar at different beam current. And in the range of irradiation dose of 4-10 kGy, the higher beam current can change the contact angle of crystalline pyrite remarkably.

2.2 Effect of electron beam irradiation on the floatability of sulfide minerals

Flotation results of arsenopyrite, pyrite, chalcopyrite and marmatite after irradiation are shown in **figures 3-6**, respectively.

The arsenopyrite flotation recovery of −53 μm rose with the increase of irradiation dose and reached it's

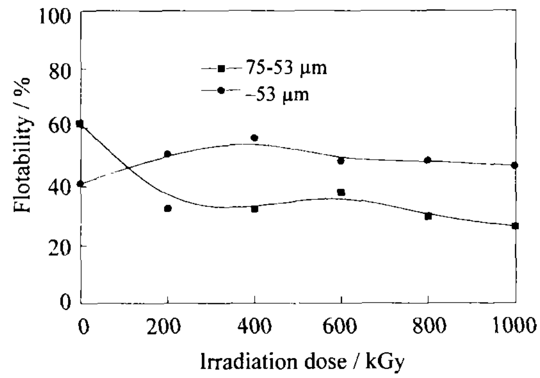

Figure 3 Flotability of arsenopyrite as a function of irradiation dose.

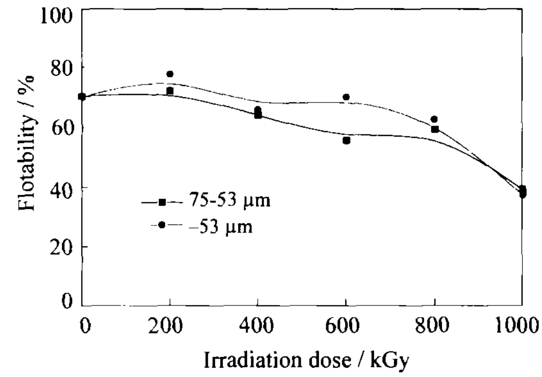

Figure 4 Flotability of pyrite as a function of irradiation dose.

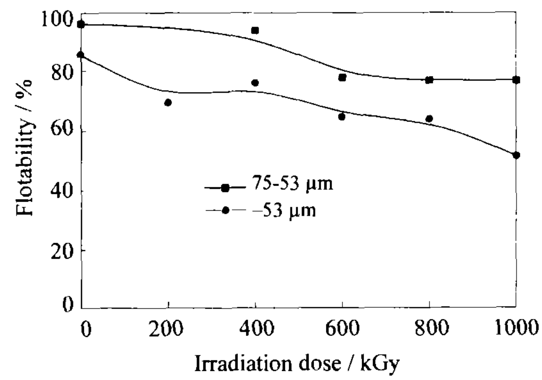

Figure 5 Flotability of chalcopyrite as a function of irradiation dose.

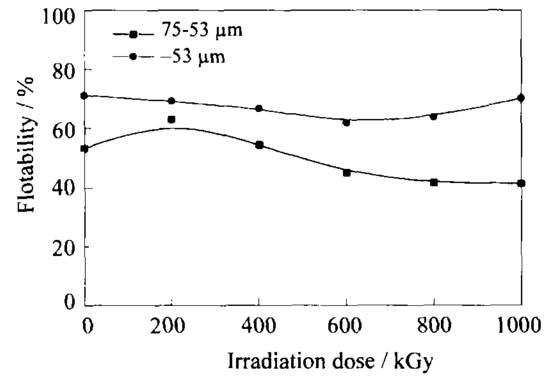

Figure 3 Flotability of marmatite as a function of irradiation dose.

maximum at radiation dose 400 kGy, further increase of irradiation dose had negative effect. The maximum recovery after irradiation was higher than that of unirradiated by 15.17%. In general, electron beam radiation has a positive effect on flotation of arsenopyrite with size of −53 μm. Whereas, it has negative effect on flotation of arsenopyrite with size of 75-53 μm.

The effect of irradiation on flotation of pyrite is similar with that of arsenopyrite. Recovery of pyrite with size of −53 μm reached maximum at irradiation dose 200 kGy, and then declined. The recovery after 200 kGy irradiation was increased by 7% than that of untreated. After 1 000 kGy irradiation, the flotation recovery of pyrite with size of 75-53 μm and −53 μm was decreased by 30% and 32.36%, respectively.

Irradiation by electron beam negatively influences the flotation of chalcopyrite. Recovery at all irradiation doses is descended than that of untreated.

The response of marmatite flotation on irradiation is a little different from others. After 200 kGy irradiation, the flotation recovery of marmatite with size of 75-53 μm was increased by 10%, and then descended. Whereas, recovery of −53 μm descended with the increase of irradiation dose.

By comparison of flotation response of minerals, one can find that electron beam irradiation can activate the floatability of arsenopyrite, pyrite with size of −53 μm and marmatite with size of 75-53 μm. Others are depressed because of irradiation. This will make irradiation an alternative for activation and depression of minerals in flotation.

2.3 Discussion

In the process of electron beam irradiation, the incident electron releases its energy in irradiated material due to inelastic collision with crystal lattice of the irradiated material. The majority of energy is transformed into heat. The heat will result in the increase of crystal lattice oscillation and cause a rise of temperature in the irradiated spot to such a degree that a thermic decomposition is taking place. Under certain conditions, a new crystalline phase will occur [8].

Furthermore, the interaction of the accelerated electrons with crystal lattice of the irradiated material initiates the excitation and ionization of molecules, and induces defects and damages in the surface irradiated. The heterogeneity of surface is intensified. These radiation-induced surface defects act as centers of adsorption and surface chemical activity for components in flotation solution.

In the presence of air, the decomposition and oxidation reaction will happen on surface of minerals because of thermal effect of electron beam irradiation, and the radiation-induced defects will stimulate the reactions. The following reaction route may be postulated in the case of pyrite according to the principle of radiation chemistry and metallurgy [9,10,12].

$$2FeS_2 \rightarrow 2FeS + S_2 \quad (2)$$

$$7FeS_2 + 6O_2 \rightarrow Fe_7S_8 + 6SO_2 \quad (3)$$

$$3Fe_7S_8 + 38O_2 \rightarrow 7Fe_3O_4 + 24SO_2 \quad (4)$$

In situation of low dose irradiation, the decomposition of pyrite occurs firstly, the partial sulphur vapor is thus formed on surface. It is known from floatation theory that presence of element sulphfur on surface will enhance the hydrophobicity of sulfide, hence the floatability of sulfide mineral is increased [6,11]. If irradiation at a high dose, the pyrite surface oxidation proceeds. The resultants like Fe_7S_8 and Fe_3O_4 appear on surface and cause surface more hydrophilic. This may be responsible for the decrease of floatability of some minerals when irradiated at a high dose.

3 Conclusions

(1) The hydrophobicity of crystal pyrite was enhanced by electron beam irradiation when the irradiation dose was lower than 10 kGy at beam current 120 and 150 μA. After irradiated by electron, the contact angle of crystalline pyrite was increased by 16°.

(2) Electron beam irradiation positively influences the floatability of arsenopyrite, pyrite with size of −53 μm and marmatite with size of 75-53 μm before the optimum irradiation dose, but negatively influences others.

(3) The radiation-induced defects in surface, the decomposition and oxidation of sulfide minerals surface might be responsible for the changes of floatability.

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