Floatability and Bubble Behavior in Seawater Flotation for the Recovering Copper Mineral

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Currently, feasibility studies of seawater flotation for copper recovery from ores have been carried out in the mineral processing field. In this study, we investigated the influence of seawater on behavior of particle and bubbles of the copper flotation. Samples of crude copper sulfide ore mainly containing chalcopyrite (CuFeS₂), magnetite (Fe₃O₄) and quartz (SiO₂) were used in this study. The results showed that copper recovery by flotation with methyl iso butyl carbolin (MIBC) in distilled water and seawater reached 97% and 86%, respectively. It was observed that when DOW froth 250 was used as a frother in flotation in distilled water, copper (Cu) recovery didn’t change obviously, whereas the copper recovery increased up to 97% in flotation in seawater. It can be seen that diameter of bubbles in the seawater was increased when use the frother (DOW froth 250) in the flotation. The froth layer generated from the flotation in seawater is thicker than that flotation in distilled water. The thickness of froth layer which may be the reason why the copper recovery was higher in seawater flotation.

Key Words : Seawater, Flotation, Copper mineral

1 INTRODUCTION
Copper (Cu) is an essential metal used in various industrial fields such as electric wire, copper products and casting. In the Cu production process, Cu ore is concentrated to Cu (Cu 30 mass%) by mining and mineral processing and the Cu concentrate carried out to Cu refining process. Numerous researches have been investigated the flotation method which is widely used technique in mineral processing.

The flotation separation process of chalcopyrite and pyrite which are combined with sodium humate and lime was examined [1]. The concentration of the copper ore from porphyry copper ore was examined using N-propyl N-ethoxy carbonyl thiourea (PECTU) as a frother [2]. Muganda et al investigated the effect of particle diameter and contact angle on the flotation of chalcopyrite in a laboratory batch flotation cell [3]. The influence of different water quality on froth stability and valuable mineral recovery in the flotation of a borate salt ore was investigated by Peng and Bradshaw [4]. The effect of iron, copper, and cadmium on the flotation of a mock lead was also investigated [5].

Many researchers have studied the flotation separation process and they reported the effect of many factors on the froth flotation, but there are a few reports on the flotation in seawater. Nowadays, it is very important to develop sustainable technologies in order to improve water conservation management and to reduce water consumption because most mineral processing requires high water use. Therefore an idea on the use of seawater instead of fresh water in froth flotation is considered as the water source for mineral processing.

In some mining, practice of flotation has been made using seawater [6]. Buffering the seawater, hard pH and difficultly to maintain the bubble on surface of liquid are main problems when use seawater in mining operation. Furthermore, it is difficult to understand that mechanism.

In this study, we investigated the effect of seawater quality on the flotation of copper ore due to demanding requirements on water conservation management and development of the flotation process. Bubble formation in froth flotation with fresh water and sea water was also observed, respectively. The improvement of Cu recovery from Cu sulfide ore by flotation and floatation behavior of mineral particles as well as generation of bubbles in fresh water and seawater flotation were discussed in this paper.

2 EXPERIMENTS

2.1 Experimental samples
Chemical content and mineral composition of the ore sample used in this study are shown in Table 1 and Figure 1. The XRD result confirmed that the sample contains chalcopyrite (CuFeS₂), quartz (SiO₂) and magnetite (Fe₃O₄) as main constituents (Figure 1). The Cu sulfide ore sample was crushed to a particle size below 180 μm by using a vibration mill and jaw crusher. Potassium amyl xanthate (PAX) was used as a collector. Methyl iso butyl carbolin (MIBC, C₆H₁₄O) and DOW froth 250 (DF250, C₈H₁₈O₃) were used as the frother. Calcium hydroxide (Ca(OH)₂) used as a pH adjuster. We used distilled water and seawater as the flotation medium.

2.2 Experimental method
400 g distilled water or seawater and a 100 g ore sample were
applied into 500 mL MS-type flotation machine (pulp density 20%) and stirred the sample solution at 1500 rpm. A part of the ore sample subjected to flotation and conditioned in distilled water or seawater for 24 hours, respectively.

After adjusted a solution pH using calcium hydroxide, PAX was added and conditioned for 5 minutes. Fixed amount of frother was added to the conditioned solution and the froth flotation was performed during 15 minutes. After each experiment, Cu concentration in froth and tail was measured using inductively coupled plasma – optical emission spectroscopy (ICP-OES). Each component’s grade and recovery rate was calculated.

The generation action of air bubbles from solid-liquid suspension into the flotation cell and height of the froth layer formed were observed by high speed camera using the 1000 mL measuring cylinder.

### 3 EXPERIMENTAL RESULT

#### 3.1 Effect of pH on the flotation in distilled water

Figure 2 shows the influence of the pH on the Cu recovery. Flotation was conducted at various pH conditions from pH 7.5-10.0 while PAX and MIBC dosage was 50 and 250 g/t-ore. As shown in Figure 2, about 95% of Cu was floated during 10 minutes when the flotation time increased up to 15 minutes. Cu recovery reached 97% under pH 8.5, whereas the Cu recovery rate was 92% at pH of 7.5.

#### 3.2 Effect of PAX dosage in distilled water flotation

Figure 3 shows the influence of PAX dosage on the Cu recovery. The flotation experiment was carried out at fixed pH (pH 8.5) and fixed MIBC dosage (250 g/t-ore) and fixed time (15 minutes) while PAX dosage was changed from 25 g/t-ore to 75 g/t-ore. It can be seen from Figure 3 that about 97% Cu was floated when added 25 g/t-ore of PAX to the sample solution in the flotation cell. When PAX dosage increased in the flotation, any significant change in Cu recovery did not observed.

#### 3.3 Flotation of copper sulfide ore in seawater

A comparison of the results of Cu recovery from crude copper sulfide ore by flotation in distilled water and seawater in the presence of frothing agent (MIBC, DF250) can show from Figure 4. Each experiment was done at fixed condition as pH of 8.5, PAX dosage 25 g/t-ore, and frother dosage of 250 g/t-ore and used different water and different frother. When used MIBC as a frother, the Cu recovery increased until 86% with increasing the flotation time, whereas DF250 was used as a frother, Cu recovery reached 90% during 5 minutes. The Cu recovery was increased up to 95% when the flotation time increased further. The result showed that
high rate of Cu can be recovered from the Cu ore by flotation using seawater and DF250. Cu grade in the froth was 16.8 mass%, 31.4 mass% and 16.7 mass% when used the distilled water, seawater with MIBC and seawater with DF250 in the flotation, respectively.

3.4 Effect of particle size on flotation in seawater

Flotation experiment in seawater was done at the condition of pH 8.5, PAX amount of 25 g/t-ore and frother amount of 250 g/t-ore with varying particle size distribution from -38 µm to +100µm and flotation time from 5 to 15 minutes, respectively. Effect of particle size on the Cu ore flotation is shown in Figure 5. The rate of Cu recovery was 98% when particle size was -75+38 µm and -100+75 µm, respectively. Cu recovery was 81% when particle size of -38 µm and a flotation time of 5 minutes, but after 15 minutes the Cu recovery reached 96%. At -180+100 µm, the recovery rate of Cu in the flotation for 15 minutes became lower (93%) compared with -75+38 µm and -100+75 µm particle size. It is considered that a high Cu recovery can be obtained by adjusting the particle size about -100 µm or less.

3.5 Effect of floatability of pulp condition on flotation in seawater

The effect of the floatability of pulp condition on flotation in seawater was investigated during 24 hours soaking. As shown in Figure 6, Cu recovery was 87% when flotation time and particle size was 5 minutes and -38 µm. Increasing the flotation time until 15 minutes the Cu recovery was reached about 99%. The copper in the sample with particle size of -75+38 µm and -100+75 µm was recovered 97% for 5 minutes flotation. There was no change in the Cu recovery afterwards. In -180-100 µm part, the froth layer could not be formed in seawater condition, therefore Cu did not able to be collected. When particle size is more than 100 µm, sufficient froth layer could not form, whereas stable froth layer can form while the particle size lower than 100 µm at the condition for 24 hours conditioning the sample into the seawater. Therefore the -100 µm particle is easily floated than that of particle more than 100 µm by flotation process.

3.6 Effect of floatability and Cu grade on flotation in seawater

The effect of floatability and Cu grade on the flotation of the copper ore samples which conditioned and unconditioned into seawater during 24 hours was investigated and results obtained are compared in Figure 7 and 8, respectively. It can be seen from Figure 7 that the floatability rate in the conditioned sample was lower than that of unconditioned sample in seawater. The floatability in the conditioned and unconditioned sample with -38 µm particle size was 4% and 15%, respectively. It was observed that the floatability rate decreased in the both samples increasing with the particle size. On the other hand, Cu grade increased greatly in the sample conditioned into seawater during 24 hours. Cu grade reached to 50 mass% in the conditioned sample with particle size of -100+75 µm, whereas the grade was 14 mass% in the unconditioned sample with same particle size as shown in Figure 8. It can also be seen that the Cu grade increased with increasing of the particle size of the both samples, especially for the sample conditions.
conditioned into seawater during 24 hours. It expected that the gangue minerals in the sample suppressed by the seawater during the conditioned time which promote the value of Cu grade in the flotation.

3.7 Bubble behavior in flotation in seawater and distilled water

The state of the bubble in the column with MIBC and DF250 in distilled water and seawater are shown in Figure 9. Average diameter of bubbles was calculated by counting technique. The average diameter of bubbles in each condition was 0.95 mm in distilled water, and 1.17 mm in seawater with MIBC addition. When DF250 was added, the average diameter of bubbles was 1.31 mm in distilled water, and 1.4 mm in seawater, respectively. Moreover, the height of the froth layer was 1.62 cm when MIBC was added in seawater, whereas that was 2.42 cm in seawater with DF250 addition. It has shown that thick froth layer can be form when use the DF250. The adhered time of minerals is longer when bubbles diameter increase, which can improve the Cu recovery from the sample by flotation.

4 CONCLUSION

(1) Cu recovery rate in the flotation in seawater was 86%, whereas the rate was 10% lower in the flotation in distilled water when used the MIBC as a frother. However, the rate of Cu recovery reached 97% in the flotation in distilled water in the presence

![Figure 7](image1.png)  Effect of conditioning time in seawater flotation. (Test condition: Seawater, pH8.5, PAX dosage 25 g/t-ore, DF250 dosage 250 g/ t-ore, flotation time 5 min.).

![Figure 8](image2.png)  Effect of Cu grade of pulp conditioning on seawater flotation. (Test condition: Seawater, pH8.5, PAX dosage 25 g/t-ore, DF250 dosage 250 g/t-ore, flotation time 5 min.).

![Figure 9](image3.png)  Generation behaviour of bubbles in each condition. (Conditions: (a) Distilled water, Air flow rate 300 mL/min (b) Distilled water, MIBC dosage 50 mg/L, Air flow rate 300 mL/min (c) Distilled water, DF250 dosage 50 mg/L, Air flow rate 300 mL/min (d) Seawater, Air flow rate 300 mL/min (e) Seawater, MIBC dosage 50 mg/L, Air flow rate 300 mL/min (f) Seawater, DF250 dosage 50 mg/L, Air flow rate 300 mL/min)
of a frother as DF250.

(2) The Cu recovery can be improved by adjusting the particles less than 100 \( \mu \text{m} \) in size.

(3) It was observed that conditioning of the sample into seawater during 24 hours can improve the Cu grade in the flotation.

This work explains the possibility of the use of seawater in the flotation of crude copper sulfide ore. Difference in the floating behavior of copper mineral, generation of bubbles in seawater and in distilled water were studied.

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References


