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Effect of frother type and operational parameters on nano bubble flotation of quartz coarse particles

S. Nazari[1], S.Z. Shafaei[1*], M. Gharabaghi[1], R. Ahmadi[2] and B. Shahbazi[3]

1. School of Mining Engineering, College of Engineering, University of Tehran, Tehran, Iran
2. Department of Mining Engineering, Imam Khomeini International University of Qazvin, Qazvin, Iran
3. Department of Mining Engineering, Faculty of Engineering & Technology, Tarbiat Modares University, Tehran, Iran

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**Corresponding author: zshafaie@ut.ac.ir (S.Z. Shafaei).*

Abstract

In this work, the effects of the types of frother (MIBC, pine oil, and A_{65}) and operational parameters (impeller speed and air flow rate) on the flotation of quartz coarse particles was investigated using nano bubbles (NBs). Quartz particles of the size of -425+106 μm and three types of frother were used for the flotation experiments. Also the impeller speed was 600 to 1300 rpm, and the air flow rates were 30 and 60 L/h. In the absence of NBs, the maximum recovery was achieved with the pine oil frother, an impeller speed of 1000 rpm, and an air flow rate of 60 L/h. In the presence of NBs, the maximum recovery was achieved using pine oil at an impeller speed of 900 rpm and an air flow rate of 30 L/h. However, increasing the recovery in the presence of NBs, compared to the absence of NBs for MIBC, was more than the other two frothers, and the recovery using this frother to increase up to 25% but using pine oil, the recovery increased up to 23%. The lowest recovery in the presence of NBs was obtained using A_{65}. Also the use of NBs increased recovery in all the three fractions compared to the absence of NBs but the presence of NBs increased the recovery of particles with size of -212+106 μm more than the particle size in the ranges of -300+212 and -425+300 μm.

Keywords: *Flotation, Nano Bubbles, Frother Type, Particle Size, Operational Parameters.*

1. Introduction

Flotation is a process based on the physical-chemical properties of the surface. In this process, air bubbles attach to the surface of the desired particles in the pulp and form bubble-particle aggregates but some particles detach from the air bubbles during the transfer of bubble-particle aggregates to the froth zone. On the other hand, some hydrophobic particles, due to their very large size or very small size, are not attached to the air bubbles, and thus the recovery of the flotation process is reduced. The maximum efficiency of the flotation process is in the size range of 10-100 μm [1-6].

One of the factor affecting the flotation process is the consumable chemical during the process. Frothers are very important due to their role in the flotation process. These materials are the compounds that help changing the size and stabilize the produced bubbles, prevent bubbles from coalescence, and attach particles-bubbles. Therefore, they are well-dispersed in the slurry, and form a layer of stability froth. They also have a very important role in the recovery, grade, and kinetics of the flotation process. The frother action in the floatation process is simple. Frothers are active surface molecules that are absorbed at the gas-liquid interface and reduce the surface tension of the interface. On the other hand, one of the most important factors involved in the process of flotation is the operational parameters. Optimal adjustment of these parameters will increase the flotability capability of fine and coarse particles [5, 7, 8].

Research works have been conducted by researchers to increase the flotability of coarse and fine particles. Shahbazi et al. (2009) have investigated the effect of the type and dosage of frothers on the micro bubble flotation of quartz coarse particles and flotation experiments carried out without using nano bubbles [9]. Shahbazi (2015) has examined the effect of the type of frother type on the probability of a particle-bubble collision on fine particles. The results obtained have shown that the type and concentration of the frother were effective in the probability of the particle-bubble collision [5]. Awatey et al. (2014) have studied the flotation of coarse sphalerite particles and surface chemistry particles. Also optimization of the operating parameters of coarse sphalerite particles in the fluid bed separator has been investigated [10-12]. Newcombe et al. (2012) have studied the effective factors in coarse particle flotation such as collector concentrate, impeller speed, froth depth, and air flow rate [13]. Oteyaka et al. (1995) have investigated the coarse particle flotation and modeling of the column floatation process. In this work, the particle size was 100 to 700 μm, and the results obtained with quartz and calcite had a high compatibility with the predicted values. They also showed that the recovery of particles depended on the size of the bubbles, the bubble stability, and the particle size [14].

One of the methods recently used to increase the recovery of fine and coarse particles is the use of NBs in the flotation process. NBs are bubbles smaller than 1 μm that are produced by various methods such as hydrodynamic cavitation, ultrasonic, solvent exchange, and temperature variations [15-18]. Investigations have been carried out on the flotation of fine and coarse particles using NBs, which improves the recovery of these particles. Zhang and Seddon (2016) have investigated the flotation of gold nano particles using NBs, and found that the main reaction was carried out through the nucleation of NBs onto particles [19]. Ahmadi et al. (2014) have examined the flotation of fine chalcopyrite particles and increased the recovery of fine particles by up to 21% [20]. Sobhy and Tao (2013) also studied the flotation of coal particles, and increased the recovery of particles by 50% [21]. Maoming et al. (2010) have studied the coarse-grained particles of phosphate and coal using NBs, and the presence of NBs increased the recovery of these particles [6, 22-24]. Recently, the effect of nano bubbles on the flotation of coarse particles has been studied but the effect of the frother type and operational parameters on the nano bubble size and thus the flotation response of coarse particles has not been considered although that could be very important [25].

In general, it can be said that the improvement of coarse particle flotation has a great benefit in the separation of minerals, especially industrial minerals. So far, many attempts have been made to improve the floatation of coarse particles. In this regard, improvement of hydrodynamic conditions, froth specification, and geometric characteristics of the cell have been used but the attempts made did not have enough success. In this work, to improve the recovery of coarse particles, the surface specification of the particles is improved using nano bubbles. Therefore, according to the authors' knowledge, for the first time, the effect of the type of frother on nano bubble production and hence the improvement of coarse particle floatation was investigated. The results of this work indicate a significant increase in the recovery of coarse particles, which can be very interesting for other researchers.

Furthermore, in this research work, the effects of three different types of frothers (MIBC, Pine oil, and A_{65}) on the flotation performance were investigated in the presence and absence of NBs considering the operational parameters. The use of a proper frother for generating NBs and a proper setting of operational conditions improves the collision and attachment probability of bubble-particle, and ultimately increase the recovery. In this regard, the effects of MIBC, pine oil, and A_{65}, and operational parameters such as impeller speed and air flow rate on particle recovery in a Denver mechanical flotation cell in the presence and absence of NBs were investigated.

2. Materials and methods

2.1. Materials

In this work, MIBC (methyl isobutyl carbonyl), pine oil, and A_{65} (poly propylene glycol) with a concentration of 22.4 mg/L were used as the frother and for generation of NBs. The collector was dodecyl amine with the dosage of 50 g/t. Quartz particles (purity ~ 99%) in three size classes of -212+106, -300+212, and -425+300 μm were used for the flotation experiments. All of the experiments were performed at the natural pH of 8.5 using local tap water.

2.2. Methods

2.2.1. NBs generation and measurement

An NB generator device is available at the Iranian Mineral Processing Research Center (Figure 1).

NBs were generated using a hydrodynamic cavitation process, water, and a specific amount of frother at a natural pH of 8.5. First, the solution in a conditioning tank was pumped using a centrifuge pump into a specified diameter of the Venturi tube. The filtered air was injected into the solution. Using static mixers, the dissolution of air at the inlet of the Venturi tube increases and leads to an increase in the static pressure. Eventually, when the air-saturated water reaches the Venturi tube, the reduction in pressure of the air-saturated water results in the production of NBs [19]. A laser particle size analyzer (LPSA) was used to measure the size of the bubbles used in the flotation process. The measurements were repeated five times and the results obtained were confirmed. The Sauter mean diameter of the bubbles, d_{32}, was used for the NB size calculation. For all the three kinds of frother, with a constant dosage of frother (22.4 mg/L) and changing the air flow rate (0.2-0.4 L/min) and pressure (250 to 400 Kps), the size of NBs were 171 nm.

2.2.2. Flotation experiments

A Denver 1 L mechanical cell was used to perform the flotation experiments. The flotation experiments were carried out under the operational conditions including an impeller diameter of 7 cm, air flow rates of 30 and 60 L/h, and impeller speeds of 600, 700, 800, 900, 1000, 1100, 1200, and 1300 rpm. In each experiment, the air flow rate and the impeller speed were adjusted. Initially, the feed was prepared for 3 minutes. After adding the collector, 2 minutes of preparation were considered. Then the frother was added and prepared for 1 minute. Addition of the frother was done in two ways:

I. In the absence of NBs, two minutes after addition of the collector, the frother was introduced directly into the cell through direction A (Figure 1).

II. In the presence of NBs, two minutes after addition of the collector, 23% of the frother was introduced into the cell through direction A, and 77% of the remainder was introduced into the cell through a direction of B (Figure 1) to form NBs.

Finally, flotation was started by opening the air inlet valve into the flotation cell, and the froth was collected after 2.5 minutes. These procedures were performed for all the three types of frothers with the same conditions. In the flotation experiments, all the particle size fractions were floated together and the depth of the frother was low. After the flotation experiments, the concentrates and tailings were collected, filtered, dried, and finally, weighed for calculation of particle recovery.

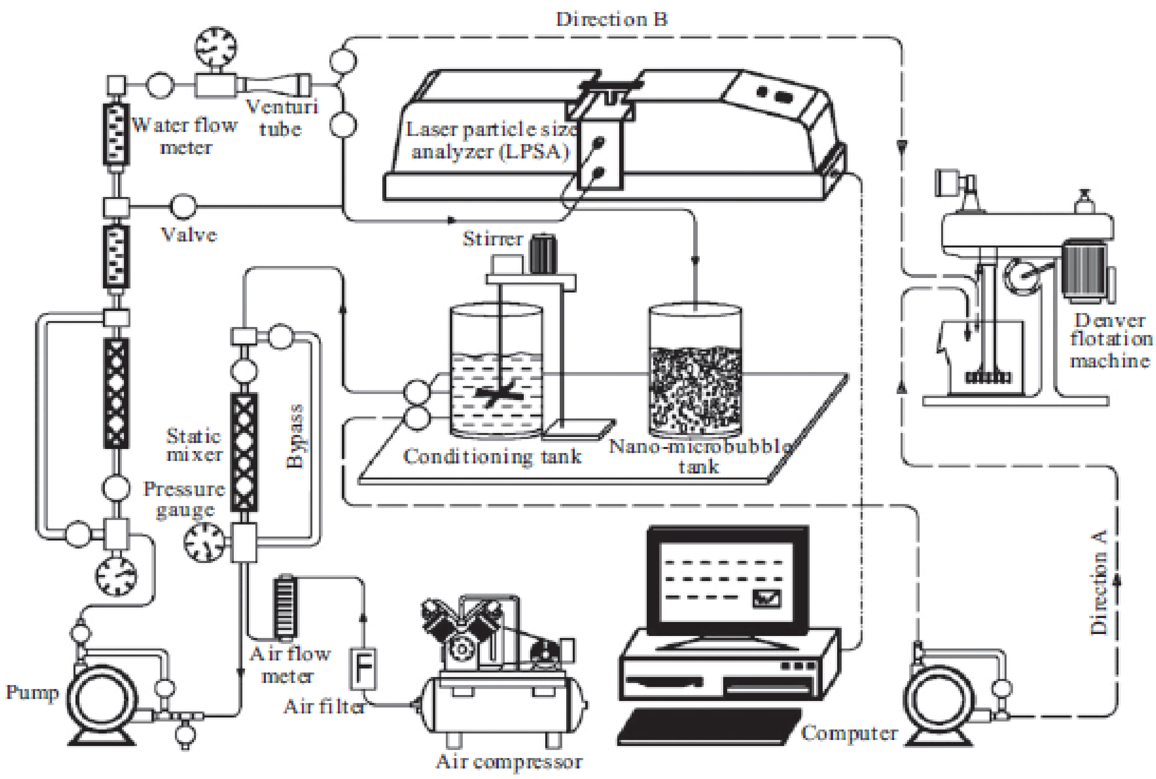

Figure 1. Schematic representation of NB generator and laser particle size analyzer [19].

3. Results and discussion

3.1. Effects of various parameters on flotation of quartz coarse particles in the absence of NBs

Flotation recovery was obtained for different operational conditions and the three types of frother, i.e. MIBC, pine oil, and A_{65} (Figures 2, 3 and 4). Also the Sauter mean diameter of the common air bubbles, d_{32}, for the three frothers at different operational parameters are shown in Table 1. The effects of four parameters were investigated according to the items below.

3.1.1. Effect of frother type

As it can be seen in Figures 2, 3 and 4, the maximum recovery, 90.84%, was obtained using the pine oil frother, and the minimum recovery, 2.54%, was obtained using the A_{65} frother. The low recovery with A_{65} can be attributed to the small size of the bubbles produced by this frother (Table 1). Production of the smaller bubbles by A_{65} can be related to the surface tension, surface zeta potential, and higher frother power. Therefore, due to the high surface area of the bubbles and coarse-sizes of the particles, the ability to attach between the particles and the bubble decreases and leads to increases in the separation of particles from the bubbles. In other words, the probability of collision of small bubbles with a high surface area is higher with these particles but due to the coarse particle sizes, the probability of detachment of the particles from the bubble is high. However, in the case of the MIBC and pine oil frothers, the size of the produced bubbles is coarse and they can carry coarse particles. Thus a successful collision and attachment happens between the particles and bubbles.

3.1.2. Effect of particle size

The highest recovery was obtained in all the three types of frother in the particle size of -212+106 μm, and the recovery decreased with increase in the particle size from the range of -212+106 to the ranges of -300+212 and -425+300 μm. The reason for decrease in the recovery for coarse particles is the reduction in the ability of air bubbles to carry coarse particles.

3.1.3. Effect of air flow rate

Flotation recovery was determined based on the particle size at different air flow rates. The highest recovery was obtained to be 90.84% in the air flow rate of 60 L/h using the pine oil frother. With increase in the air flow rate, the amount of dissolved gas in the solution increases, which causes bubble stability. Therefore, using this frother, recovery decreased with decrease in the air flow rate from 60 to 30 L/h.

3.1.4. Effect of impeller speed

The bubble size decreased when the impeller speed increased. The maximum recoveries for the MIBC, pine oil, and A_{65} frothers were obtained at the impeller speeds of 1100, 1000, and 1000 rpm respectively. Recovery decreased for impeller speeds more and quiescence. Decrease in the recovery in less impeller speeds is due to particle settling in the pulp. Also decrease in the recovery at the higher impeller speeds is due to the detachment of particles from bubbles. Therefore, at an optimum impeller speed, bubble-particle aggregates are formed, and they are destroyed at higher impeller speeds.

Table 1. Bubble diameters for three frothers at different operational parameters.

Frother	Air flow rate (L/h)	Impeller speed (rpm)	d_b	Frother	Air flow rate (L/h)	Impeller speed (rpm)	d_b	Frother	Air flow rate (L/h)	Impeller speed (rpm)	d_b
MIBC	30	600	802	Pine oil	30	600	945	A_{65}	30	600	754
		700	721			700	903			700	650
		800	657			800	856			800	601
		900	623			900	823			900	587
		1000	551			1000	756			1000	540
		1100	465			1100	698			1100	456
		1200	392			1200	602			1200	376
		1300	371			1300	565			1300	360
	60	600	850		60	600	1010		60	600	776
		700	754			700	970			700	664
		800	687			800	920			800	623
		900	625			900	878			900	605
		1000	572			1000	808			1000	565
		1100	495			1100	754			1100	470
		1200	423			1200	656			1200	392
		1300	382			1300	606			1300	369

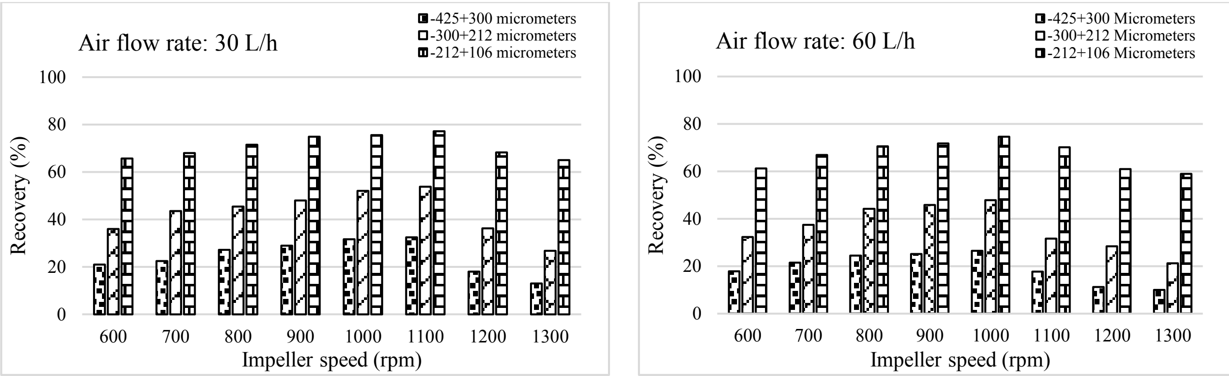

Figure 2. Recovery of quartz coarse particles *vs.* impeller speed in the absence of NBs using MIBC frother.

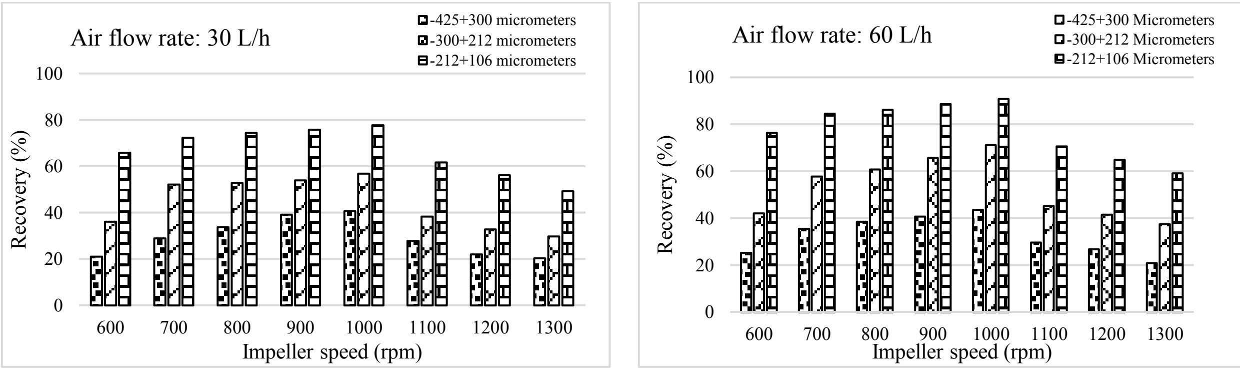

Figure 3. Recovery of quartz coarse particles *vs.* impeller speed in the absence of NBs using pine oil frother.

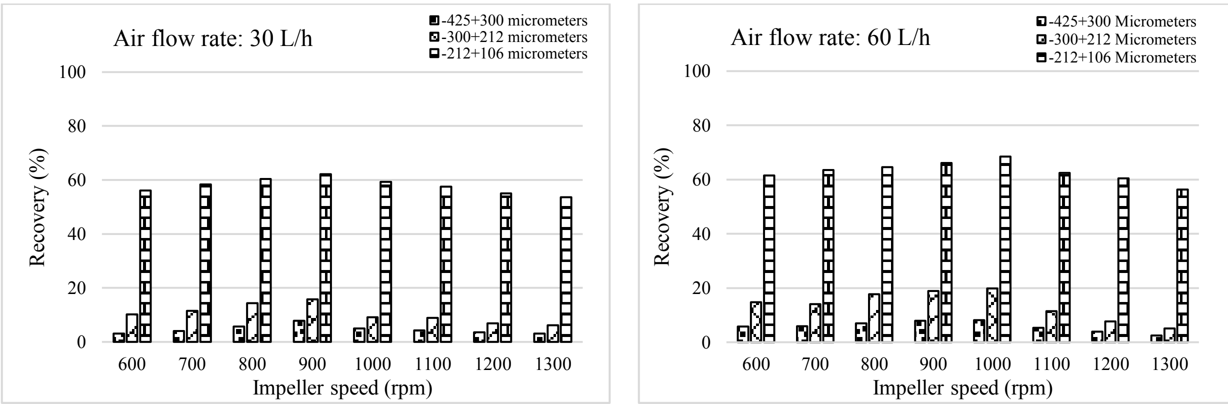

Figure 4. Recovery of quartz coarse particles *vs.* impeller speed in the absence of NBs using A_{65} frother.

Thus investigating the effective parameters in the flotation of quartz coarse particles showed that the best frother for the operations and achieving desirable recovery was pine oil. Therefore, the use of pine oil frother led to the best results at the impeller speed of 1000 rpm, air flow rate of 60 L/h, and particle size of -212+106 µm.

3.2. Effect of various parameters on flotation of quartz coarse particles in the presence of NBs bubbles

Flotation recovery was obtained under different operating conditions for the three types of frothers (MIBC, pine oil, and A_{65}) in the presence of NBs with the size of 171 nm (Figures 5, 6 and 7). In this section, the impacts of four parameters were also investigated.

3.2.1. Effect of frother type

The presence of frother like as its effect on the size of common air bubbles in the flotation cell in the NB generators leads to a reduction in the size of NBs. Also the type of frother is effective on the amount of zeta potential of the bubble surface. Although they are non-ionic, they have the ability to change the zeta potential by reducing the bubble's electrical two-layer thickness. On the other hand, increasing the frother power increases the absolute amount of surface zeta potential, and, consequently, increases the bubble surface charge.

Increasing the amount of surface zeta potential of NBs results in an increase in the superficial repellency, and thus prevents the coalescence and integration of NBs. Thus the maximum increase in recovery is in the presence of MIBC, which shows that the recovery of coarse particles increases up to 25%, which is more than pine oil and A_{65}. However, the maximum recovery in the presence of NBs is related to pine oil, and the minimum recovery is related to A_{65}. The use of A_{65} is not recommended due to the lower recovery than the other two frothers.

3.2.2. Effect of particle size

The use of NBs increased recovery in all the three fractions in comparison with the absence of NBs but the presence of NBs increased the recovery of particles with size of -212+106 µm more than the particle size in the ranges of -300+212 and -425+300 µm. Thus due to the high and low surface area of NBs and common air bubbles, respectively, and also coarse sizes of the particles, the ability to attach between the particles and bubbles increases, which leads to increase the attachment of particles to bubbles.

3.2.3. Effect of air flow rate

With increasing air flow rate in the flotation cell, the amount of dissolved gas in the solution increases. Increasing the dissolved gas while reducing the concentration of gas at the interface of the bubble-solution lead to increase in the stability of NBs and decrease in the bubble sizes. Thus the maximum recovery was observed in the presence of NBs and at the air flow rate of 30 L/h and pine oil. In all the three frothers, the maximum recovery was obtained at the air flow rate of 30 L/h, and the recovery decreased with increase in the air flow rate due to decrease in the bubble sizes.

3.2.4. Effect of impeller speed

The maximum recovery for MIBC, pine oil, and A_{65} was obtained at the impeller speeds of 900, 900, and 800 rpm, respectively, and the recovery decreased for lower and higher impeller speeds. Lower recovery at the impeller speeds less than these values is due to the fact that the particles are not attached to the bubbles and the particles are settled in the pulp. Also decrease in recovery at the impeller speeds more than these values is due to the separation of particles from bubbles. In other words, at appropriate speeds, NBs cover the surface of the particles and cause attachment to larger bubbles. In other words, NBs act like a secondary collector.

Studies show that in the presence of NBs and with these three types of frothers, the best frother for coarse particles is pine oil, which has the highest recovery in the flotation. However, the maximum increase in recovery is obtained with the MIBC frother, which represents an increase in recovery of up to 25%.

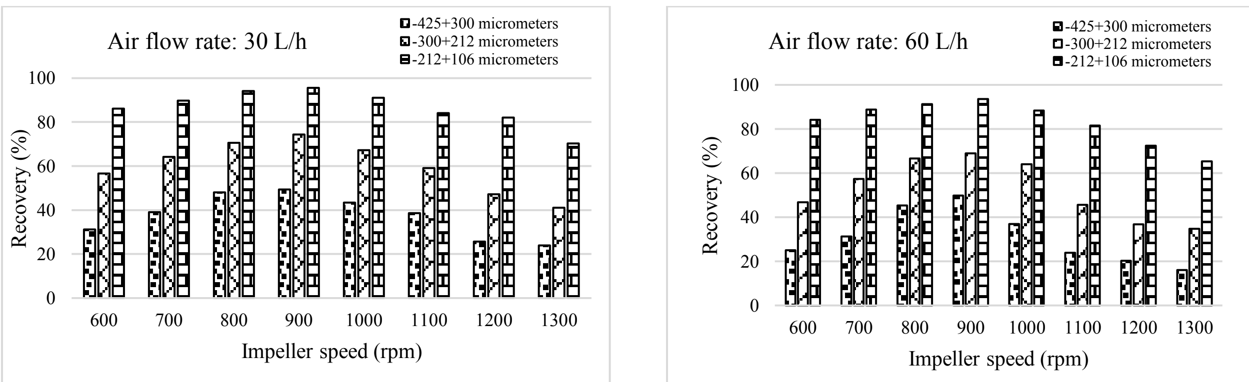

Figure 5. Recovery of quartz coarse particles *vs.* impeller speed in the presence of NBs using MIBC frother.

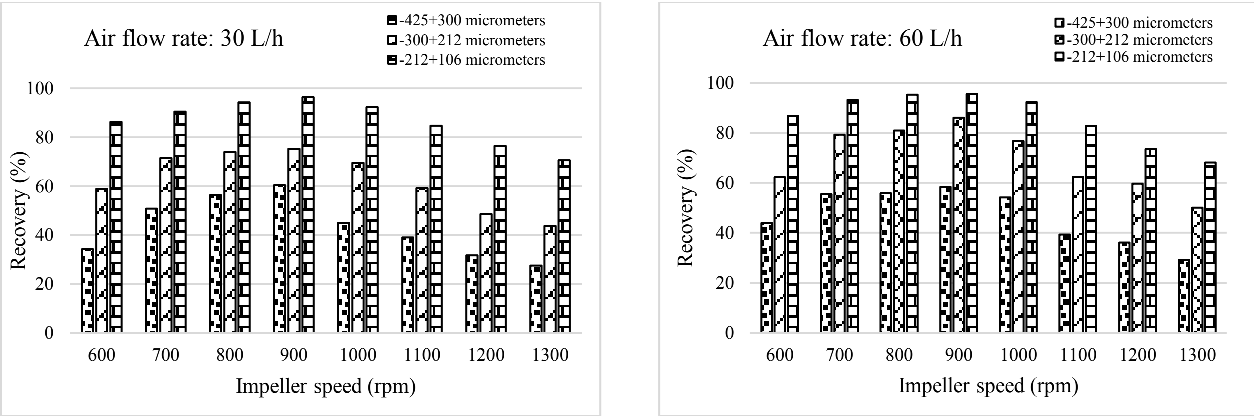

Figure 6. Recovery of quartz coarse particles *vs.* impeller speed in the presence of NBs using pine oil frother.

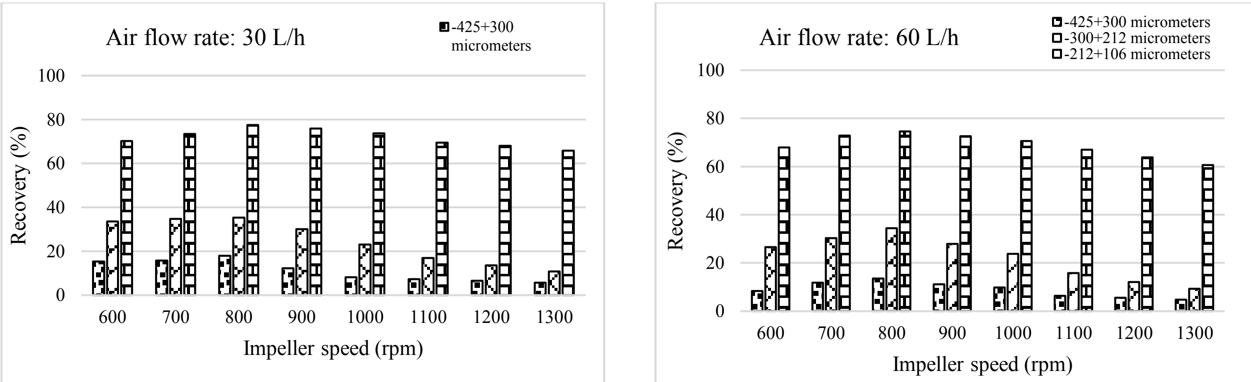

Figure 7. Recovery of quartz coarse particles *vs.* impeller speed in the presence of NBs using A_{65} frother.

4. Conclusions

The results of this work showed that the use of an appropriate frother and operational parameters would have a very good effect on the flotation process.

In the absence of NBs, the maximum recovery was obtained with pine oil at the impeller speed of 1000 rpm, air flow rate of 60 L/h, and in the range of -216+106 μm. The minimum recovery was obtained with A_{65}. The recovery decreased with increase in the particle size. The reason for the decrease in recovery at an impeller speed more than 1000 rpm is the detachment of the bubbles from the particles. At lower speeds, the recovery decreased due to the fact that the bubbles were not attached to the surface of the particles.

In all the three types of frother, the use of NBs increased recovery but increasing the recovery for MIBC was more than the other two frothers. Increasing the recovery in the presence of NBs compared with the absence of NBs for MIBC was more than the other two frothers, and the recovery using this frother increased up to 25% but using pine oil, the recovery increased by 23%. The minimum recovery in the presence of NBs was obtained with A_{65}. In the case of pine oil, the maximum recovery was achieved at the impeller speed of 900 rpm and an air flow rate of 30 L/h. Recovery for more and less speeds decreased by detachment of particles from bubbles.

Acknowledgments

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تأثیر نوع کفساز و پارامترهای عملیاتی بر روی فلوتاسیون ذرات درشت کوارتز با استفاده از نانوحباب‌ها

صابره نظری[۱]، سید ضیاءالدین شفائی[۱*]، مهدی قراباغی[۱]، رحمان احمدی[۲] و بهزاد شهبازی[۳]

۱- بخش مهندسی معدن، دانشکده فنی، دانشگاه تهران، ایران

۲- بخش مهندسی معدن، دانشکده فنی، دانشگاه بین‌المللی امام خمینی قزوین (ره)، ایران

۳- بخش مهندسی معدن، دانشکده فنی، دانشگاه تربیت مدرس، ایران

ارسال ۲۰۱۷/۱۱/۶، پذیرش ۲۰۱۷/۱۱/۲۸

* نویسنده مسئول مکاتبات: zshafaie@ut.ac.ir

چکیده:

در این تحقیق تأثیر سه نوع کفساز (متیل ایزوبوتیل کربونیل (MIBC)، روغن کاج (Pine oil) و پلی پروپیلن گیلیکول (A_{65})) و پارامترهای عملیاتی (سرعت همزن و نرخ هوادهی) بر روی فلوتاسیون ذرات درشت کوارتز در حضور و عدم حضور نانوحباب‌ها بررسی شد. برای آزمایش‌های فلوتاسیون از ذرات کوارتز در ابعاد ۱۰۶+۴۲۵- میکرومتر استفاده شد. همچنین سرعت همزنی ۶۰۰ تا ۱۳۰۰ دور در دقیقه و نرخ هوادهی ۳۰ و ۶۰ لیتر بر ساعت بود. نتایج نشان داد که در عدم حضور نانوحباب‌ها، ماکزیمم بازیابی با استفاده از روغن کاج در سرعت همزنی ۱۰۰۰ دور در دقیقه و نرخ هوادهی ۶۰ لیتر بر ساعت به دست آمد. از طرفی در حضور نانوحباب‌ها، ماکزیمم بازیابی با استفاده از روغن کاج در سرعت همزنی ۹۰۰ دور در دقیقه و نرخ هوادهی ۳۰ لیتر بر ساعت به دست آمد. با این وجود افزایش بازیابی در حضور نانوحباب‌ها در مقایسه با عدم حضور نانوحباب‌ها برای کفساز متیل ایزوبوتیل کربونیل بیشتر از دو کفساز دیگر بود و بازیابی با استفاده از این کفساز تا ۲۵ درصد افزایش یافت اما با استفاده از کفساز روغن کاج، بازیابی تا ۲۳ درصد افزایش نشان داد. پایین‌ترین بازیابی در حضور نانوحباب‌ها با استفاده از کفساز A_{65} به دست آمد. همچنین استفاده از نانوحباب‌ها باعث افزایش بازیابی در هر سه فراکسیون ابعادی در مقایسه با عدم حضور نانوحباب‌ها شد اما در حضور نانوحباب‌ها، افزایش بازیابی در ذرات با ابعاد ۱۰۶+۲۱۲- میکرومتر بیشتر از ابعاد ۲۱۲+۳۰۰- و ۳۰۰+۴۲۵- میکرومتر بود.

کلمات کلیدی: فلوتاسیون، نانوحباب‌ها، نوع کفساز، ابعاد ذرات، پارامترهای عملیاتی.