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INVESTIGATION OF THE ENTRAINMENT OF FINE SIZED CALCITE AND CHROMITE PARTICLES BY A FLOTATION COLUMN WITH NEGATIVE BIAS REGIME

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Keywords

Flotation column
Negative bias
Entrainment
Calcite
Chromite

Abstract

Negatively Biased Flotation Column (NBFC) is a tool, which is developed for the flotation of coarse-sized ores. Unlike the conventional flotation column, in this column, there is no froth zone, and wash-water is usually not used. Therefore, hydrodynamically entrainment of fine-sized particles into the concentrate is possible, and this may result in a decrease in the grade or yield of the concentrate.

In this study, operating parameters that can affect the entrainment of fine-sized particles were investigated. Calcite with a grade of 99.4% ($CaCO_3$) and chromite concentrates with a grade of 54.8% (Cr_2O_3) were used in the experiments. Parameters such as superficial water flowrate, particle size, air flow rate, frother dosage and particle density were used in the experiments. As a result of the experiments, it was determined that the amount of entrainment increased as the particle size and density decreased, and decreased with increasing superficial water flowrate, air flow rate and frother dosage.

NEGATİF BİAS REJİMİNE SAHİP BİR FLOTASYON KOLONU İLE İNCE BOYUTLU KALSİT VE KROMİT TANELERİNİN SÜRÜKLENMESİNİN ARAŞTIRILMASI

Anahtar Kelimeler

Flotasyon kolonu
Negatif bias
Sürüklenme
Kalsit
Kromit

Öz

Negatif Biaslı Flotasyon Kolonu (NBFK), iri boyutlu cevherlerin flotasyonu için geliştirilmiş bir araçtır. Klasik flotasyon kolonundan farklı olarak bu kolonda köpük bölgesi yoktur ve genellikle yıkama suyu kullanılmaz. Bu nedenle, ince boyutlu parçacıkların konsantreye hidrodinamik olarak sürüklenmesi mümkündür ve bu, konsantrenin tenöründe veya veriminde bir düşüşe neden olabilir.

Bu çalışmada, ince boyutlu taneciklerin sürüklenmesini etkileyebilecek çalışma parametreleri araştırılmıştır. Deneylerde %99.4 ($CaCO_3$) tenörlü kalsit ve %54,8 (Cr_2O_3) tenörlü kromit konsantreleri kullanılmıştır. Deneylerde yüzeysel su akış hızı, tanecik boyutu, hava akış hızı, köpürtücü dozajı ve tanecik yoğunluğu gibi parametreler kullanılmıştır. Deneyler sonucunda, tanecik boyutu ve yoğunluğu azaldıkça sürüklenme miktarının arttığı, artan yüzeysel su akış hızı, hava akış hızı ve köpürtücü dozajı ile azaldığı tespit edilmiştir.

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1. Introduction

There are many beneficiation methods for removing gangue minerals from valuable minerals. Froth flotation is one of the methods used for mineral beneficiation. Flotation is a physicochemical mineral processing method based on differences in surface properties between valuable and gangue minerals (Schulze, 1984;

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Wills and Finch, 2015). Flotation process can be performed in conventional flotation cells, flotation columns or Jameson cells.

Flotation cell is a flotation machine having mechanical and pneumatic properties. Turbulence in mechanical flotation cells is fairly high. It decreases the probability of collision between a coarse particle and air bubble and causes the detachment of coarse particles from the air bubbles. Therefore, flotation yield of minerals liberated in coarse sizes (>0.5 mm) is low in the flotation cells (Attia and Shaning, 1988; Finch and Dobby, 1990; Patil, Parekh, and Klunder, 2010; Schulze, 1977, 1984).

Flotation columns are pneumatic equipment with no mechanical agitation system, where turbulence is fairly low. They are divided into two subgroups as positive and negative bias. Flotation column with positive bias is preferred for the flotation of the fine-sized particles, and is used as an alternative to the flotation cell. Due to the positive bias, there is a downward liquid flow. Therefore, in these columns, the wash water must be used to ensure the stability of the system. Flotation of coarse-sized ores in the columns having a positive bias is also quite difficult. The latter, flotation column with negative bias, has almost the same operating principles with the former one, and can be used to improve the flotation performance of coarse particles. The direction of liquid flow in the flotation column having a negative bias is upward. The upward flow facilitates flotation of coarse-sized particles (Aliaga and Soto, 1993; Barbery, Bouajila and Soto, 1989; Bilir, 1997; Jameson, Cooper, Tang and Emer, 2020; Oteyaka and Soto, 1995; Soto, 1989; H. Soto and Barbery, 1991; Wills and Finch, 2015).

Bias is an expression defined as the difference between the feed and tailings flows. It plays an important role in the efficiency of column flotation (Azhin, Popli and Prasad, 2021). In the flotation column with a negative bias, feed flow is higher than tailings flow, and consequently, there is an upward liquid flow. Therefore, negative bias causes a reduction in the zone of froth or complete elimination of this zone (Oteyaka and Soto, 1995; Soto, 1989).

On account of the reduction of froth height and low turbulence, columns having a negative bias provide favorable conditions for the fast flotation of coarse particles (Bilir, 1997; Soto, 1989; Soto and Barbery, 1991; Aliaga and Soto, 1993; Oteyaka and Soto, 1995; Barbery, et al., 1989; Safari, Hoseinian, Deglon, Leal and Pinto, 2020). So, the column with negative bias was used by many researchers for the flotation of ores liberated in coarse sizes such as coal, potash and quartz (Bilir, 1997; Soto, 1989; Soto and Barbery, 1991; Aliaga and Soto, 1993; Oteyaka and Soto, 1995).

Column with negative bias is a device placed between the mill and the classifier to float the ores liberalized in coarse sizes or to prevent unnecessary fine grinding. This column is similar to the one with positive bias in terms of operating principles (Bilir, 1997; Soto, 1989; Soto and Barbery, 1991; Aliaga and Soto, 1993; Oteyaka and Soto, 1995; Barbery, et al., 1989;). Flotation column with negative bias has advantages, such as beneficiation of coarse-particle ores between 2 mm and 0.1 mm, lower column height, and lower operating cost. However, when coarse-sized particles are concentrated by flotation column with negative bias, some undesirable results like the entrainment of fine-sized particles into the concentrate, resulted in the changes of the grade of the concentrate can occur.

The aim of this study is to investigate the effects of the superficial water flowrate, particle size, air flowrate, frother dosage, and particle density on the entrainment of fine-sized particles, and to determine the relationship between entrainment of fine-sized particles and test parameters.

2. Materials and Methods

2.1. Materials

Calcite sample, supplied by Sahin Mineral Ltd., was crushed by jaw and roll crusher before being ground using the ceramic mill. Following comminution, the whole sample was sieved to obtain the size fractions needed for the experiments. Chromite was provided from the concentration plant of the Kavak Krom Inc., Eskisehir. Because the chromite sample had the required size properties for the experiments was sieved into desired size fractions without a comminution process. Calcite with a grade of 99.4% ($CaCO_3$) and chromite with a grade of 54.8% (Cr_2O_3) was used in the experiments. Table 1 displays the density values of the samples used in the entrainment experiments.

Table 1

Calcite and Chromite Densities According to Size Ranges

Sample size ranges (micron)	Density (g/cm^3)	
	Calcite	Chromite
-106 +75	2.69	4.00
-75 +53	2.70	3.95
-53 +38	2.69	3.67
-38	2.70	3.50

2.2. Flotation Column with Negative Bias Regime

The experiments were performed in a custom-designed column made of polyester, having a height of 205 cm and an internal diameter of 6 cm. Figure 1 shows the experimental setup, which includes the following pieces of equipment: Feed pump (1), sparger (2), tailing pump (3), solenoid valve (4), solenoid valve controller (5), flowmeter (6), air valve & Low-rpm motor (7), motor control unit (8), pressure regulator (9), air compressor (10), personal computer (11), capacitance-voltage transducer (12), capacitor (13), liquid level monitoring hose (14), and mixing tank (15).

In order to evaluate the effects of the tested parameters on the entrainment of fine-sized particles into concentrate, a series of experiments were carried out at varying superficial water flowrate, particle size, air flowrate, frother dosage, and particle density.

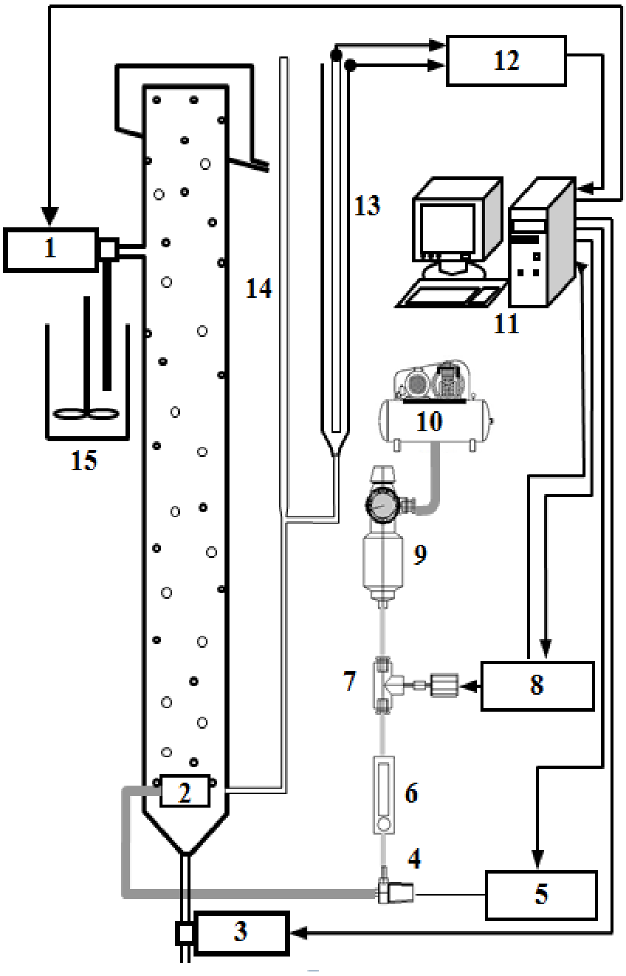

Figure 1 Schematic representation and experimental setup of the flotation column (Bilir, 1997)

The tested parameters and values used in the experiments are given in Table 2.

Table 2.

Experimental Conditions	
Feed flowrate	: 1282,1447, 1575 ml/min
Tailing flowrate	: 1020 ml/min
Superficial water flowrate	: 0.15, 0.25, 0.33 cm/s
Air flowrate	: 1000, 2000, 3000 ml/min
Mean bubble diameter	: 1-2 mm
Gas hold-up	: 8-20 %
Frother dosage	: 5, 10, 15 ppm
Frother type	: Aerofroth-88 (Cytec)
Solid ratio by weight	: 20 %
Sample densities, g/cm^3	: 2.69, 2.7, 3.5, 3.67, 3.95, 4.0
Sample quantity	: 500 g
Sample size ranges	: -0.106+0.075 mm
	-0.075+0.053 mm
	-0.053+0.038 mm
	-0.038 mm
Mean particle size	: 0.0905 mm
	0.064 mm
	0.0455 mm
	0.019 mm

3. Results and Discussion

3.1. The Effect of Superficial Water Flowrate (Jw)

Superficial water flowrate is obtained by dividing the difference between the feed flowrate and tailings flowrate by the column cross-sectional area. In flotation column with the negative bias, superficial water rate facilitates the upward movement of the bubble-hydrophobic particle aggregate. Despite that positive effect, superficial water flowrate can cause entrainment of fine-sized particles to concentrate. In terms of physical events, if superficial water flowrate is greater than the settling velocity of a particle, that particle drifts in the direction of the water flow. This variable is adjusted by changing the feed flowrate. A series of experiments were carried out to evaluate the effects of the changes at superficial water flowrate, and the test results obtained are shown in Figures 2 and 3 for calcite and chromite respectively.

According to the results given in Figures 2 and 3 show that the entrainment increases with an increasing superficial water flowrates, it is being more pronounced for calcite. This could be attributed to the fact that the density of calcite is lower than the density of chromite. At the same superficial water flowrate values, as the particle size decreases, the entrainment increases. There is a non-linear relationship between superficial water rate and entrainment.

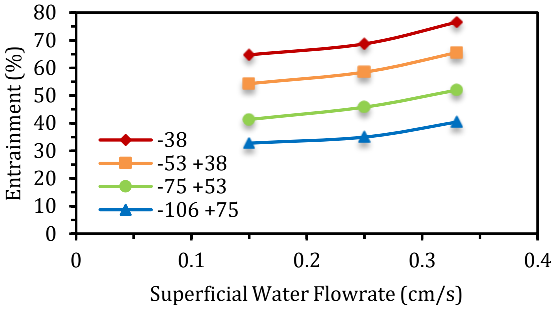

Figure 2. Relationship Between Superficial Water Flowrate and Entrainment at Different Particle Sizes for Calcite (Q_A: 2000 ml/min, Q_{fr}: 10 ppm)

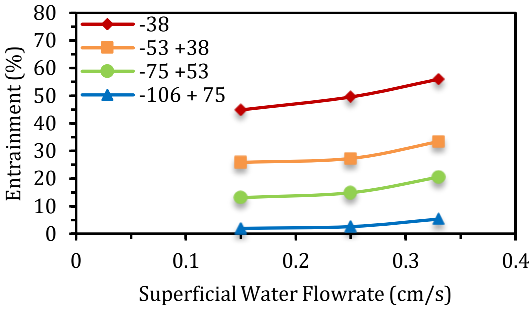

Figure 3. Relationship Between Superficial Water Flowrate and Entrainment at Different Particle Sizes for Chromite (Q_A: 2000 ml/min, Q_{fr}: 10 ppm)

3.2. The Effect of Particle Size (d_p)

In this part of the study, the effect of particle size on entrainment for calcite and chromite was investigated depending on different superficial water flowrates, air flowrates and frother dosages (Figure 4-9). As seen from the Figures 4-9, the entrainment increases with a decreasing particle size at all parameters tested. The results also show that the entrainment of calcite is higher than chromite at all parameters tested (Figure 4, Figure 6 and Figure 8). This could also be due to the density difference between calcite and chromite mineral samples. At the same mean particle sizes, as the particle size decreases, the entrainment increases resulting in a non-linear relationship between particle size and entrainment.

In Figure 4 and Figure 5, for the same mean particle sizes, it can be seen that there is a non-linear relationship between particle size and entrainment for both calcite and chromite mineral samples. As the superficial water flowrate increases, the entrainment increases for both mineral samples. However, as mentioned before the entrainment of calcite mineral samples is much more than those of chromite.

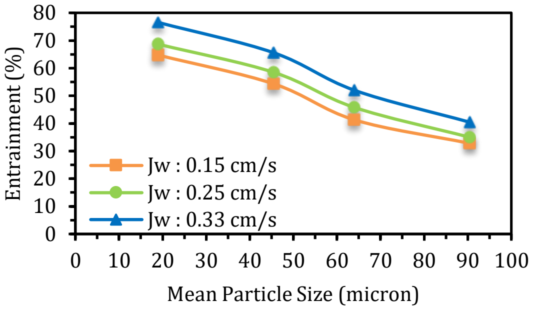

Figure 4. Relationship Between Particle Size and Entrainment at Different Superficial Water Flowrates for Calcite (Q_A: 2000 ml/min, Q_{fr}: 10 ppm)

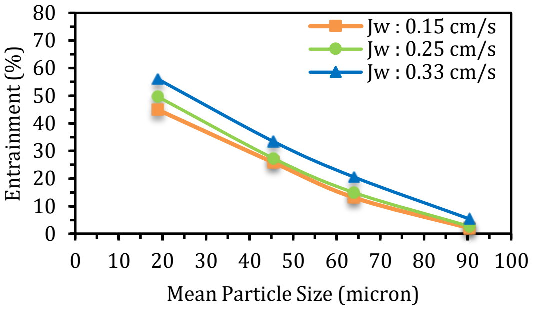

Figure 5. Relationship between mean particle size and entrainment at different superficial water flowrates for Chromite (Q_A: 2000 ml/min, Q_{fr}: 10 ppm)

In the case of different flowrates, the results given in Figure 6 and Figure 7 show similar trend with the different superficial water flowrates for both mineral samples. At the same mean particle sizes, as the air flowrate increases, the entrainment increases, resulting in a non-linear relationship between particle size and entrainment.

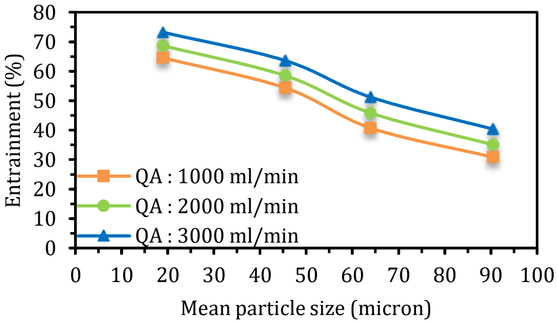

Figure 6. Relationship Between Particle Size and Entrainment at Different Air Flowrates for Calcite (J_w: 0.25 cm/s, Q_{fr}: 10 ppm)

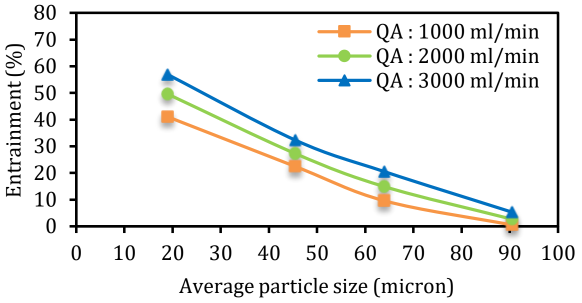

Figure 7. Relationship Between Particle Size and Entrainment at Different Air Flowrates for Chromite (J_w: 0.25 cm/s, Q_{fr}: 10 ppm)

As the frother dosage increases, the total surface area of air bubbles increases due to the decreasing the air bubble size for the same flowrate. Therefore, the results obtained with the both mineral samples given in Figure 8 and Figure 9 show that as the frother dosage increases, the entrainment increases for the same mean particles sizes, resulting in a non-linear relationship between particle size and entrainment.

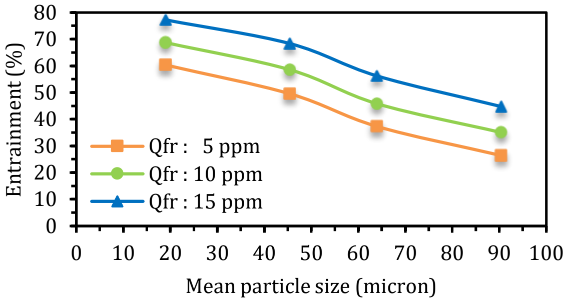

Figure 8. Relationship Between Particle Size and Entrainment at Different Frother Dosages for Calcite (Q_A: 2000 ml/min, J_w: 0.25 cm/s)

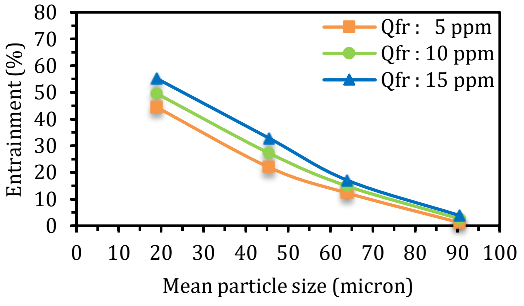

Figure 9. Relationship Between Particle Size and Entrainment at Different Frother Dosages for Chromite (Q_A: 2000 ml/min, J_w: 0.25 cm/s)

3.3. The Effect of Air Flowrate (Q_A)

The air flowrate is an important factor in the flotation column with the negative bias. It controls hold-up and air bubble diameter. Besides, it controls the turbulence created by air bubbles. Therefore, an increase in air flowrate may cause an increase in the entrainment of the fine-sized particles. Experiments were carried out at three different air flowrates, two different densities, and four different size ranges to determine the effect of air flowrate on the entrainment. The experimental results are shown in Figure 10 and 11.

According to the results obtained, as the air flowrate increases, the entrainment also increases. At the same air flowrate, as particle size decreases, the entrainment increases. There is a linear relationship between the air flowrate and the entrainment (Figure 10-11).

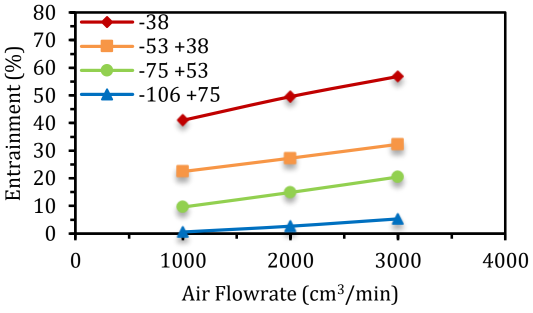

Figure 10. The Air Flowrate vs Entrainment Relationship for Chromite (Q_{fr}: 10 ppm, J_w: 0.25 cm/s)

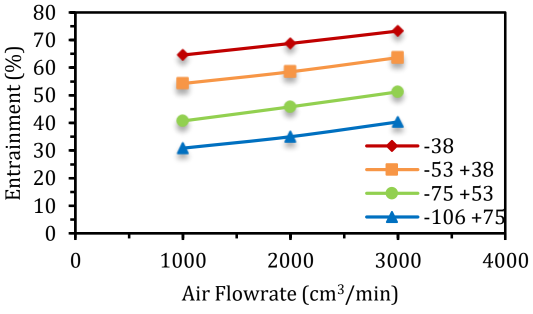

Figure 11. The Air Flowrate vs Entrainment Relationship for Calcite (Q_{fr}: 10 ppm, J_w: 0.25 cm/s)

3.4. The Effect of the Frother Dosage (Q_{fr})

The dosage of frother determines the diameter and number of bubbles. As the frother dosage increases, while the bubbles diameter decreases, the number of bubbles increases. As a result, hold-up, turbulence, and superficial water flowrate increase partially. Therefore, an increase in the frother dosage may cause an increase in the fine particle entrainment. Experiments were carried out at three different frother dosages, two different densities, and four different size ranges to determine the effect of frother dosage on the entrainment of fine-sized particles. The experimental results are given in Figure 12 and 13. As the frother dosage increases, the entrainment also increases. At the same frother dosage, as the particle size and density decreases, the entrainment increases. There is a linear relationship between the frother dosage and the entrainment.

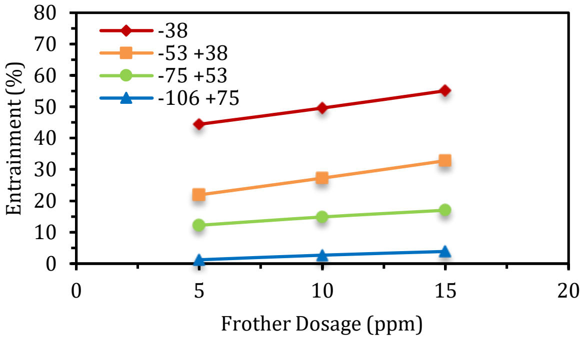

Figure 12. The Frother Dosage vs Entrainment Relationship for Chromite (Q_A: 2000 ml/min, J_w: 0.25 cm/s)

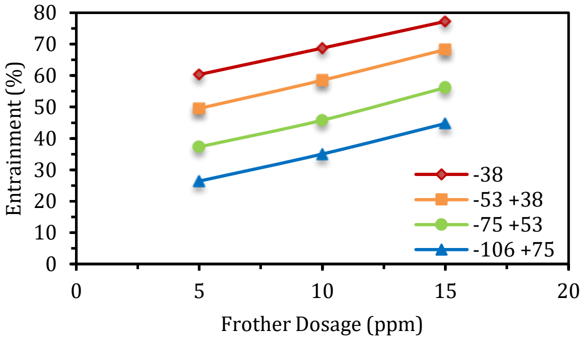

Figure 13. The Frother Dosages vs Entrainment Relationship for Calcite (Q_A: 2000 ml/min, J_w: 0.25 cm/s)

3.5. The Effect of Particle Density

Entrainment of the particles having a low density will be more easily than the particles having a high density. Therefore, the entrainment will vary depending on the change of the density. Experiments were carried out at two different densities. The experimental results are shown in Figure 14.

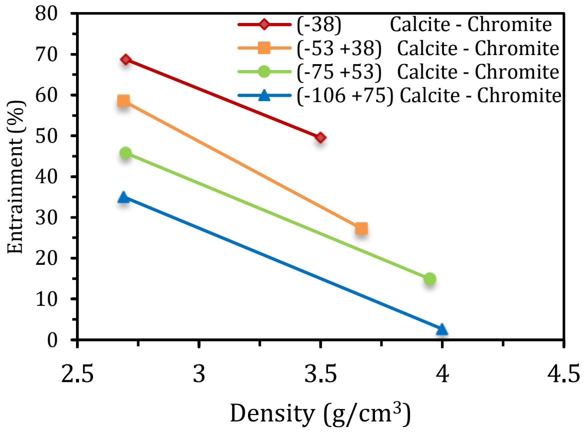

Figure 14. The Effect of the Density on The Entrainment (Q_A: 2000 ml/min, J_w: 0.25 cm/S, Q_{fr}: 10 ppm)

It is observed that as the particle density increases, the entrainment decreases as seen in Figure 14.

4. Conclusion

In this study, the parameters that can affect the fine particle entrainment in the flotation column with negative bias were investigated. The results of experimental studies showed that the entrainment is strongly dependent on the operating parameters including particle size, particle density, superficial water flowrate and air flowrate. Entrainment of fine-sized particles was observed which increased with an increasing superficial water flowrate, a decreasing particle size, an increasing air flow rate, an increasing frother dosage, and a decreasing particle density.

Contribution of Researchers

Kemal BİLİR contributed to the development of the article, preparing the samples, conducting the experiments, writing the article and evaluating the results.

The author declared that research and publication ethics were followed in this study.

Conflict of Interest

No conflict of interest was declared by the authors.

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