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Development of a new generation flotation cell and monitoring of air bubbles

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ABSTRACT

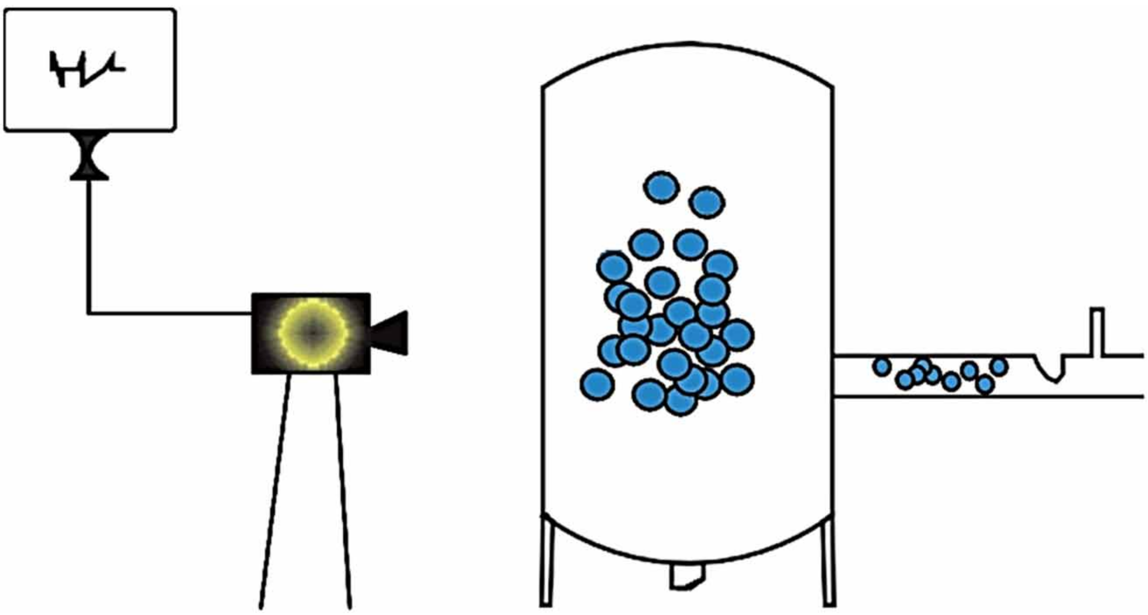
The flotation process allows particles and oil to separate from wastewater with high efficiency. Therefore, it is widely used in engineering and is a multidisciplinary field of study. In this study, a new generation flotation method is developed as an alternative to conventional flotation methods. Some experiments are conducted to determine the performance of this new system. It is known that the air-demand rate in the flotation process directly improves flotation performance. For this purpose, maximum aeration efficiency and bubble properties in the flotation cell supported by the newly developed head gated conduit are examined. A pilot-scale flotation system is installed for the experimental study. With the help of high resolution and high-speed cameras, parameters such as air bubble density, air bubble size, dead zone volume and penetration depth are determined. In addition, the images recorded during the flotation process are examined with professional image processing techniques. Experimental results showed that the Froude number, jet plunge angle and cell water levels have a significant impact on air-demand in the new system.

Key words: air bubble, air-demand ratio, flotation cell, Froude number, head gated conduit, hydraulic structures

HIGHLIGHTS

- Bubble size, dead zones and penetration depth were obtained by image analysis at the flotation cell.
- The amount of bubbles was monitored during flotation different experiments.
- The size of the Froude number has a significant effect on the amount of air bubbles.
- Flotation system with a cell supported by conduit will be an alternative to the conventional flotation methods.

GRAPHICAL ABSTRACT



SYMBOLS

Fr Froude number (–)
V Water velocity
E_{20} Aeration efficiency at 20 °C
H The cell water level (m)
R The cell diameter (m)
Q Flow rates (m^3/s)
Q_a Air flow absorbed into the conduit (m^3/s)
Q_w Flow through conduit (m^3/s)
d The diameter of the conduit air hole (m)
g Acceleration of gravity (m/s^2)
h_c Vena contracta region (m)
h The amount of gate opening (m)
y_e The effective depth (m)
α The air–water jet plunge angle
φ Ratio of the water flow area to the conduit section area

1. INTRODUCTION

In recent years, with the rapid growth of the industry, various studies have been carried out using different disciplines to evaluate waste caused by existing underground resources or domestic and industrial resources. Materials engineering, mining, environmental and civil engineering carry out joint research on these subjects. One of the most well-known of these collaborative studies is the flotation method. Flotation can be defined as the process of transferring fine solid particles to the liquid surface by holding the air or gas bubbles to be provided by liquid aeration. This method is used for a variety of purposes, including processing metallic and non-metallic ores, disposal of domestic and industrial wastewater, and ore flotation in mining facilities (Aytac 2017).

Some of the features such as very thin bubble diameter, high capacity, low cost and energy saving are expected in flotation cells. Studies on flotation cells are mainly concentrated in three points: high capacity, low energy consumption and reduction of environmental problems. These studies are in continuous development (Degner 1990; Koivistoinen 1991). Flotation cells that can achieve higher efficiency are tried to be produced with various innovations (Bentli 2000).

Aeration is the basis of the flotation process. The aeration process can be described as the transfer of oxygen from the air to the water. The performance of aeration units in flotation plants is important (Aytac 2017). In the conventional flotation process, aeration is usually carried out using air compressors and jets. With the help of a compressor, the flotation process is carried out with the air injected into the cell. In addition, bubble size is the most important dependent variable in air flotation mechanisms. The amount and dimensions of air bubbles that occur in a certain volume of water are correlated with both the physical system and chemical content of wastewater.

This study uses head gated conduits with high aeration performance in the flotation process. The main reason for this is the principle that the flotation process is based on aeration. In the cell developed for this purpose, the aeration work in the flotation process was combined with conduit, which is widely used in water engineering and has high aeration capability. As a result, a new generation flotation cell was manufactured.

In this new method, a two-phase high-pressure flow is formed by conduit. In this flow system, homogeneous dispersed, dense and small air bubbles entering the flotation cell are projected to directly improve flotation performance. The system can be easily applied to very large-scale cells. The innovation of the system is that the aeration process in the flotation cell is carried out using the head gated conduit, which is a hydraulic structure without the need for a compressor.

The principle of operation of this new method is as follows. A two-phase high-pressure current is generated by the section narrowing cover placed in the conduit. In this flow system, homogeneous dispersed, dense and small air bubbles entering the flotation cell are projected to directly improve flotation performance. In addition, in conventional systems, compressors require a high amount of energy. In the newly developed system, the air is drawn from the atmosphere is injected into the cell with the help of low pressure formed by the conduit cap. Therefore, there is no additional energy consumption. In addition, this system will minimize environmental concerns with high efficiency and low energy consumption. There is no flotation system using conduit in the literature.

In this system, the relationship between aeration and flotation performance was demonstrated by a series of experimental and observational studies. These studies are carried out in the experimental set established at

Firat University Hydraulic Laboratory. In this study, the effects of parameters such as different Froude numbers (Fr), flow rates, cell diameters and water jet plunge angles on air-demand rate and aeration efficiency are examined. The number, size and distribution of bubbles within the cell are also observed. The results revealed that the new generation system developed could be a good alternative to conventional systems.

1.1. Literature review

Aeration performance in conduits has been studied by various researchers. Speerli & Hager (2000), Escarameia (2007), Unsal *et al.* (2008, 2009), Oveson (2008), Mortensen (2009), and Ozkan *et al.* (2010, 2014, 2015) have worked on air-demand rate and aeration efficiency.

Tuna *et al.* (2014) examined aeration and oxygen transfer efficiencies in the conduits. They developed the following Equation (1):

$$E_{20} = 1 - \tanh\,(6.02\varphi^{-0.68}\mathrm{Fr}^{-1.22}) \tag{1}$$

where E_{20} is the aeration efficiency at 20 °C, φ is the ratio of the water cross-sectional flow area to the conduit cross-sectional area and Fr is the number of Froude based on the effective depth of the conduit.

Yianatos *et al.* (2016) developed a new method for flotation processes. They noted that the mineral record in this method is associated with the bubble flow rate and level in the flotation cell.

Shammas & Bennett (2010) stated that flotation processing time depends primarily on the rate of elevation of air bubbles. They also found that the rate of liquid ascension can be calculated using the Stoke Law (the equation that governs bubble movement in flotation).

Miskovic & Luttrell (2011) used various methods to investigate the regional bubble size distributions in the pilot-scale flotation cell. As a result of the experimental data they obtained, they achieved significant differences in bubble sizes under different conditions throughout the cell.

Sekerci & Tuna (2020) examined the effect of conduit physical properties on aeration performance in the flotation cell supported by conduit. They developed the following Equation (2):

$$Q_a/Q_w = 0.0082\mathrm{Fr}^{1{,}786} + \exp(-1.455K^{-0{,}608} + 1.344H_L^{4{,}56} + 8.75d^{2{,}253})^{3{,}475} \tag{2}$$

in which, the Froude number Fr is dimensionless, the air intake hole diameter d is in meters, the air intake hole length H_L is in meters, the conduit gate opening ratio K is in degrees and Q_a/Q_w ratio is dimensionless.

Miskovich (2011) investigated the gas distribution performance of two commercial mechanical flotation cells in a comprehensive pilot and industrial size experimental research (compressed air and self-ventilated).

Zhang (2014) used imaging technology to determine the size of the bubbles. In his study, he stated that the bubble size varies with the temperature of the water in the flotation process.

According to Bailey (2004) and Besagni *et al.* (2018) study, there should be a strong association between the size distribution of particles and bubbles. Bubbles should also have an adequate size distribution. As a result, air bubbles have a very important function in the flotation system.

Ahmed & Jameson (1985) showed that the bubble size distribution in the flotation process has a significant effect on the mineral recovery rate. Yoon & Luttrell (1989) reported that by reducing the bubble size tenfold, the flotation rate increased almost a hundredfold.

Measurement of bubble size is crucial for controlling the flotation process. Hu *et al.* (2020) various techniques such as X-ray technic and Chen *et al.* (2020) ultrasound technic have been used to determine the size of the bubbles produced in flotation.

To estimate the distribution of bubble and micro-bubble sizes, numerous researchers have used the image analysis method.

1.2. Aeration

There are many parameters that affect flotation efficiency. The most important of these parameters is the amount of air drawn into the cell using various pathways for flotation. The process of taking this air from the atmosphere and giving it to water is called aeration. In classical flotation cells, air compressors are used to give air to the system. Hydraulic structures have been widely used in wastewater treatment plants for aeration in recent years.

Hydraulic structures used for aeration improve aeration performance as they cause a turbulence situation in which air bubbles flow. Considering the role of hydraulic structures in the aeration process, air–water ratio and aeration efficiency, it is thought that appropriate results can be obtained within the flotation process.

1.3. Head gated conduit

When a conduit cross-section is partially closed by a gate, high-velocity and low-pressure flow occurs downstream of the gate, and pressure below atmospheric can occur within the conduit. These pressures might theoretically be as low as the pressure at which water vapor exists. Air suction happens in the suction pipe when an atmospheric connection is formed by positioning a suction pipe after the gate (Figure 1). The carrying and entraining capacities of the flow affect how much fluid is suctioned within. The Froude number (Fr), water flow, gate opening percentage, conduit length and viscosity all influence the pressure drop downstream of the gate (Aydın *et al.* 2022).

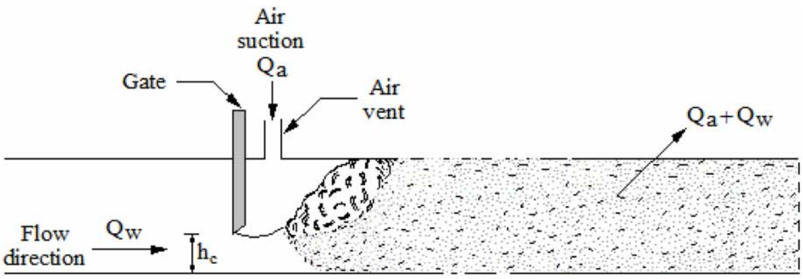


Figure 1 | Highhead gated conduit flow (Tuna *et al.* 2014).

2. METHODS

The production of air bubbles in flotation varies in various ways depending on the type of flotation cell established. As a result of detailed examinations on this subject, the air bubbles that will affect flotation the most are emphasized. The overall view of the experimental set and the components is depicted in Figure 2.

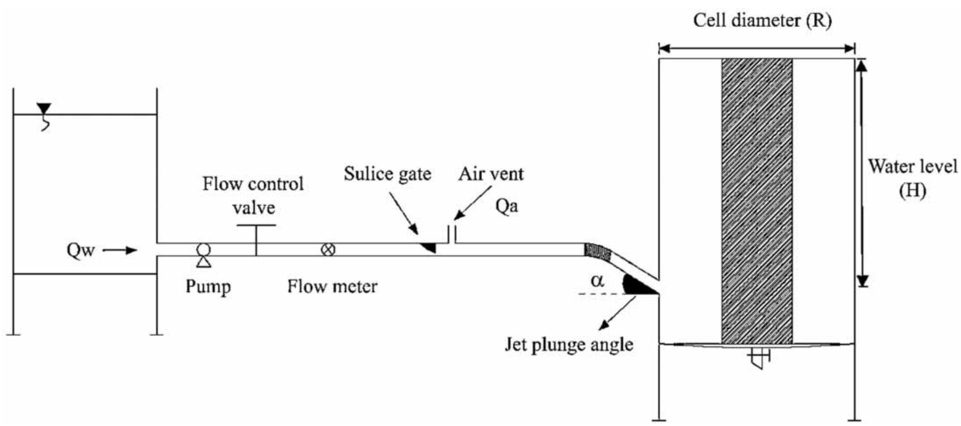


Figure 2 | General view of the experimental setup.

In order to examine in more detail the amount of air bubbles to occur in the flotation cell, three experimental devices with a diameter of $R = 0.92$ m, $R = 1.30$ m and $R = 1.60$ m and a height of 1.5 m were manufactured, as shown in Figure 3. Flotation cell diameters and the amounts of water in which air bubbles are intended to be formed; $R = 0.92$ m cell diameter is determined by taking into account 1 m^3, $R = 1.30$ m cell diameter 2 m^3 and $R = 1.60$ m cell diameter 3 m^3 water. Continuous water ingress was provided to the cells from the outside and the current was cut off after reaching the desired volume value. Then, the water, the volume of which is known, is constantly overturned.

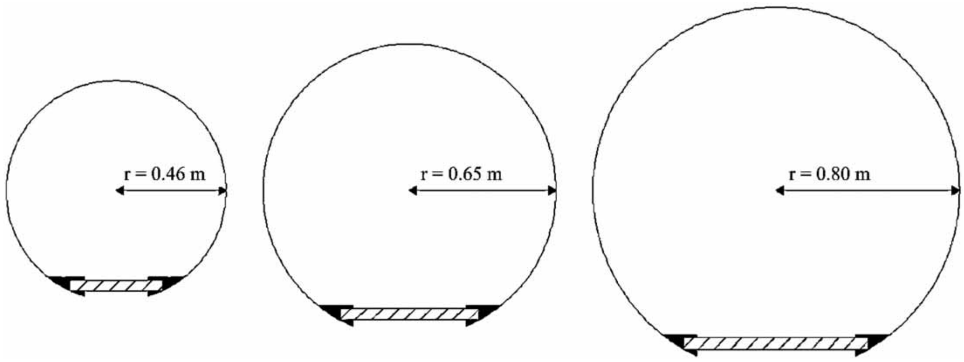


Figure 3 | The schematic view of the flotation cells' diameters.

An opening has been left in each experimental mechanism to observe the air bubbles that are intended to be created optically and to determine the pathways these bubbles follow. This opening is one-fourth of that cell diameter in each flotation cell. This opening along the flotation cell height is covered with transparent glass with 10 mm temper.

In addition, as shown in Figure 4, there are three separate connections that are stuck at angles of 30°, 45° and 60° at an altitude of 0.75 m from the cell base. These connections were manufactured to adjust the plunge angle of the air–water jet entering the flotation cell and the penetration depth of the jet. In addition, each flotation cell is 50 cm above the laboratory floor and three U profile feet boiled into the flotation cell to allow waste evacuations.

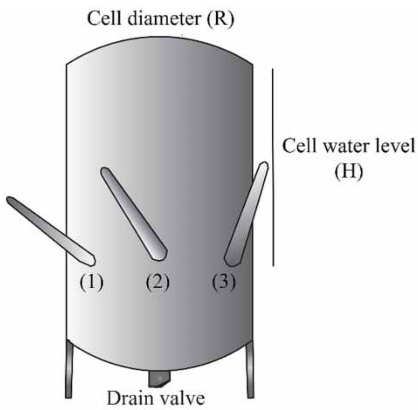


Figure 4 | Inputs 1–2 and 3 that provide different air–water jet plunge angles in the flotation cell.

In order to experimentally investigate the effect of flotation cell size or cell height, three different cell sizes were determined based on the center of the jet plunge angle and water was filled up to these levels in the cells. The first level was studied as non-sunken $H = 0$ cm, the second level $H = 25$ cm was sunken and the third level was worked as $H = 50$ cm.

In the experiments, a galvanized metal pipe with circular section, diameter 8.09 cm and length 200 cm was used as the head gated conduit. The opening rate of the conduit cover is 10%. In other words, only 10% of the circular section water pipe is left open. Therefore, the depth of water in the conduit is designed as 0.875 cm. An air pipe with a diameter of 14.00 mm was opened in the downstream of the conduit cover and the air in the external environment was allowed to enter the pipe from here. A high-precision anemometer was used to measure the speed of air absorbed into the pipe (%1.5 mv $\pm$ %). The data were collected for 60 s to calculate the airspeed drawn to the system. A calibrated electromagnetic flowmeter was used to measure the water flow.

Froude numbers (Fr) are in the range of 25.70 and 83.79. Depth of flowing water in the conduit (y_e) and the Equation (3) Froude number formula:

$$\mathrm{Fr} = \frac{V}{\sqrt{g y_e}} \tag{3}$$

Water velocity at bottom of conduit gate is represented by V, and g denotes gravity acceleration. y_e represents the ratio of the width of the water surface to the cross-section of the water flow area. Previously, it has been the vena contract that determines the Fr. In this study, Fr was determined by the y_e in the conduit. This was done with the purpose of making the determination of flow depths and velocities at the vena contract, a section where the flow has a mixture of air and water with a high velocity.

Monitoring and recording were carried out in the tempered glass part of the flotation cell surface area (25%). Parameters such as air bubble density, air bubble size and dead zones, which are sections where air bubbles do not reach the cell, penetration depth, which is the last vertical distance reached by air bubbles, foam layer thickness formed on the surface were recorded with the help of high resolution and high-speed cameras. These images were detected by professional image processing techniques.

2.1. Monitoring bubbles

Different techniques are used to determine the size, number and distribution of air bubbles. These techniques are acoustic methods and optical (photography, holography, scattering, radiography), methods (Leighton 2012).

It is very important to determine the size of a bubble or other suspended particle in the flotation cell. Because the aeration method has a very effective place in the flotation process. In this study, optical methods were used to determine the physical properties of bubbles. The resulting photographic images focus on determining the actual bubble diameter.

In the experimental setup (Figure 5), the water jet formed by the conduit (1) is transported into the cell by pipes (2). Bubbles (3) are formed within the cell. The high-speed camera connected to the computer was mounted on the tripod (84 next to the cell). With this camera, the images taken during the experiment were transferred to the computer and the data was processed by the program.

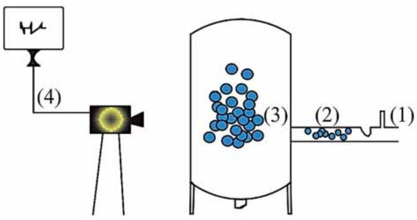


Figure 5 | Monitoring bubbles scheme.

The experiment was carried out as follows: The valve that provided water input to the system was opened enough to achieve the desired number of Fr. Due to the narrowing of the conduit cover, the increased speed allowed the pressure to decrease and thus air to enter the system. For different test alternatives, the number, size and distribution of air bubbles were recorded with high-speed cameras and a large database was created. ImageJ and Phyton programs were used to obtain images from the database. Thus, the physical characteristics of the bubbles were determined.

3. RESULTS AND DISCUSSION

3.1. Monitoring and detecting air bubbles for different parameters in flotation cells

Alternative Figure 6(a) shows that the cell water level is $H = 50$ cm, the air–water jet plunge angle is $\alpha = 30°$ and the cell diameter is $R = 0.92$ m. When this pattern was examined, it was observed that air bubbles could not reach the lower regions of the flotation cell, so largely dead zones occurred. The penetration depth of the air–water jet was measured as 12 cm. In this alternative, since the jet plunge angle is more horizontal, the air bubbles could not reach the deep parts of the flotation cell. The thickness of the foam area formed on the surface was measured as

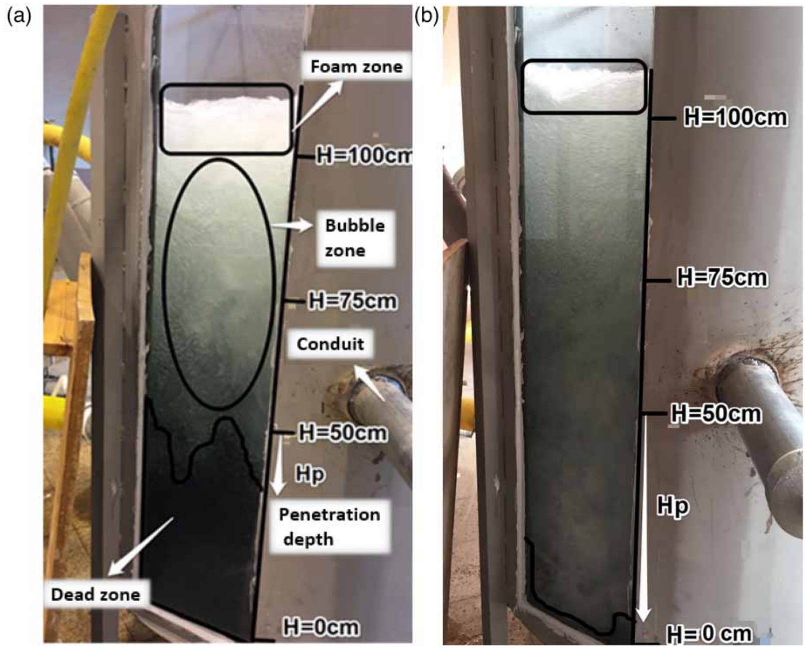


Figure 6 | Images of $R = 0.92$ m, $\alpha = 30°$ (a) and $\alpha = 60°$ (b) test alternative.

10 cm. The volume of dead zones was calculated as 38% of the total cell volume. It was observed that 70% of the total air bubbles were larger than 1 mm in diameter (Figure 7(a)).

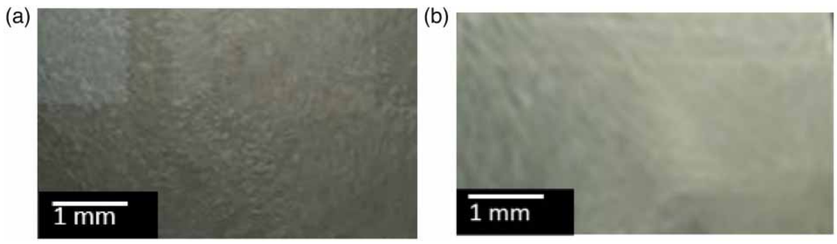


Figure 7 | Zoomed bubble views of $R = 0.92$ m, $\alpha = 30°$ (a) and $\alpha = 60°$ (b) test alternative.

When Figure 6(b) test alternative with cell water level $H = 50$ cm, air–water jet plunge angle $\alpha = 60°$ and cell diameter $R = 0.92$ m is examined, the air bubbles are very dense and very small in size. Air bubbles are densely and homogeneously distributed throughout the entire flotation cell. Therefore, dead zones are quite small. When the penetration depth was 45 cm, it was observed that the air bubbles reached the deep areas of the flotation cell. The thickness of the foam area here was measured as 3 cm. The volume of dead zones was observed as 3% of the total cell volume. 90% of the total air bubbles are less than 1 mm in diameter (Figure 7(b)).

Some results were obtained when the test images with an air–water jet plunge angle of $\alpha = 60°$ were examined. According to these results, the formation of dead zones has been minimal. It can also be said that air bubbles are evenly distributed within the cell. Based on the results, the optimal jet plunge angle for flotation is $\alpha = 60°$.

Alternative Figure 8(a) shows that the cell water level is $H = 50$ cm, the air–water jet plunge angle is $\alpha = 30°$ and the cell diameter is $R = 1.30$ m. The air bubbles that occurred in this experimental alternative could not reach the deep regions of the cell. The penetration depth of the flotation cell was recorded on average around 15 cm. The thickness of the foam area formed on the surface was measured as 8 cm. The volume of dead zones was calculated as 35% of the total cell volume. 50% of the total air bubbles were larger than 1 mm in diameter (Figure 9(a)).

When the cell water level is $H = 50$ cm, the air–water jet plunge angle is shown in Figure 8(b), where $\alpha = 60°$ and the cell diameter is $R = 1.30$ m. In this alternative, the air bubbles that occur reach the entire cell, including the deep regions of the cell. However, dead zones occurred in the deep parts of the left side of the cell. But the

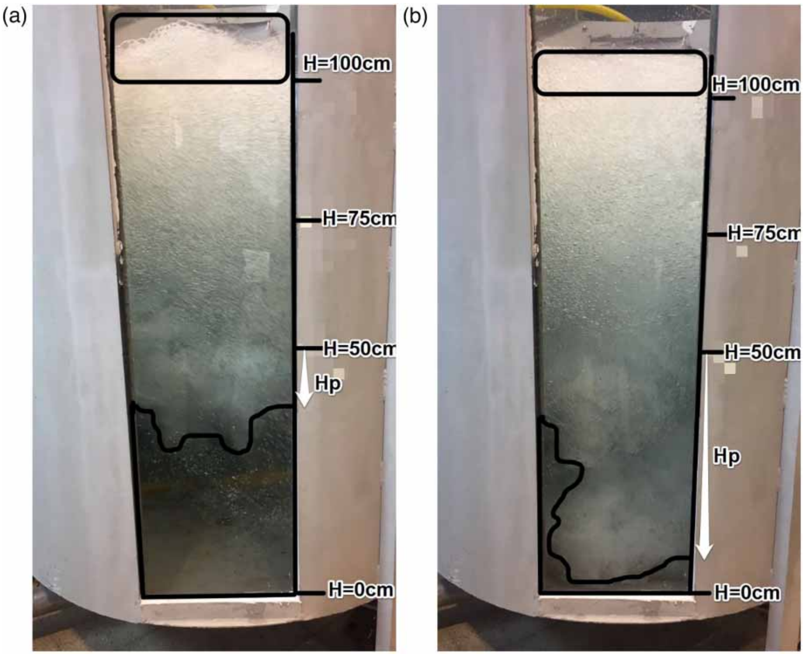


Figure 8 | Images of $R = 1.30$ m, $\alpha = 30°$ (a) and $\alpha = 60°$ (b) test alternative.

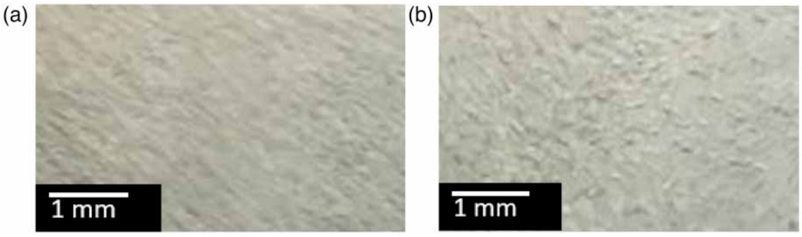


Figure 9 | Zoomed bubble view of $R = 1.30$ m, $\alpha = 30°$ (a) and $\alpha = 60°$ (b) test alternative.

resulting air bubbles are small in diameter and dense. The penetration depth formed in this alternative is 45 cm. Therefore, the resulting air bubbles reach deep into the flotation cell. The thickness of the foam area on the surface of the flotation cell was measured as 6 cm. The volume of dead zones was calculated as 15% of the total cell volume. It was determined that 60% of the total air bubbles were less than 1 mm in diameter (Figure 9(b)).

In Figure 10(a), an experimental alternative was studied in which the cell water level was $H = 50$ cm, the air–water jet plunge angle was $\alpha = 30°$, and the cell diameter was $R = 1.60$ m. In this alternative, air bubbles barely reached the deep areas of the flotation cell and dead zones were formed. Accordingly, it can be said that the dead zone increases with increasing cell diameter. The penetration depth reaches 8 cm below the air–water jet. The thickness of the foam zone formed on the surface was measured as 4 cm. The volume of dead zones was calculated as 35% of the total cell volume. It is observed that 55% of the total number of air bubbles have a diameter greater than 1 mm (Figure 11(a)).

The cell water level is shown in Figure 10(b), where the air–water jet plunge angle is $\alpha = 60°$ and the cell diameter is $R = 1.60$ m. In this test alternative, the penetration depth was measured as 20 cm and the thickness of the foam area was 2 cm. The volume of dead zones was calculated as 12% of the total cell volume. It was observed that 75% of the total air bubbles were less than 1 mm in diameter (Figure 11(b)).

3.2. Effect of the water jet plunge angle on aeration performance

The effect of the water jet plunge angle on aeration performance in terms of cell diameter is shown in Figure 12(a)–12(c). Cell water level (H) was kept constant and aeration performance of three different water jet plunge angles was examined.

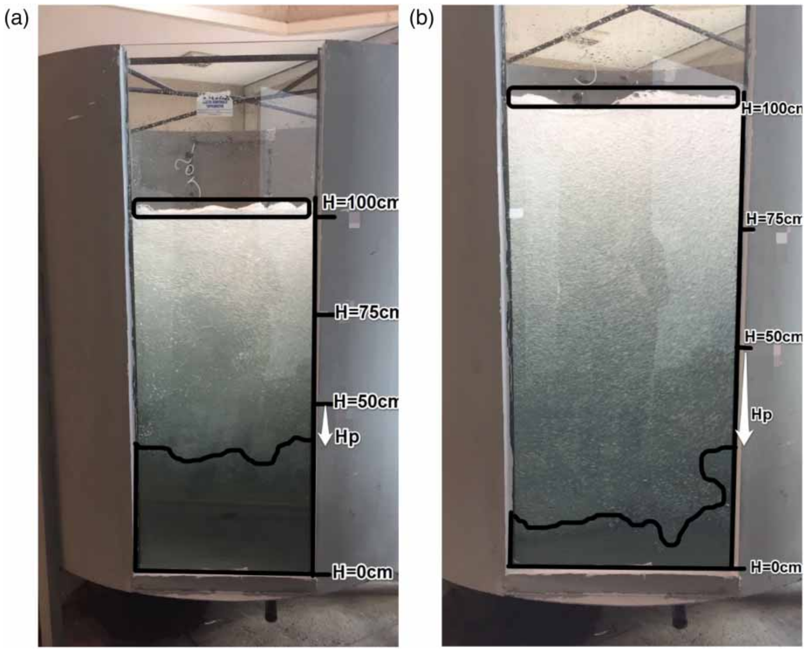


Figure 10 | Images of $R = 1.60$ m, $\alpha = 30°$ (a) and $\alpha = 60°$ (b) test alternative.

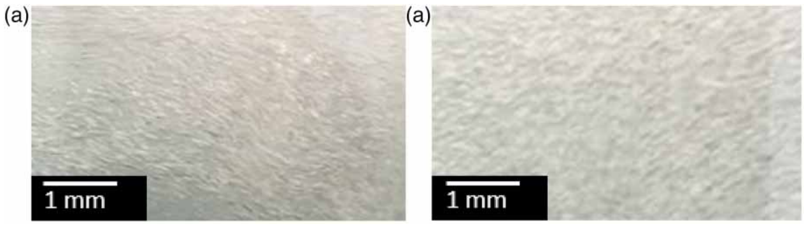


Figure 11 | Zoomed bubble views of $R = 1.60$ m, $\alpha = 30°$ (a) and $\alpha = 60°$ (b) test alternative.

The test parameters for Figure 12(a) are jet plunge angle $\alpha = 60°$ and cell diameter $R = 0.92$ m. In this experimental alternative, the maximum Q_a/Q_w value was calculated as 3.25.

The lowest aeration performance compared with other alternatives is shown in Figure 12(b). In this alternative, the jet plunge angle is $\alpha = 30°$. When Figure 12(b) and 12(c) are examined, it shows that the Q_a/Q_w value tends to increase sharply after the number of Fr exceeds 40 in water jet alternatives with $\alpha = 60°$.

When all the test groups in the shapes are examined, it was determined that the aeration performance reached the highest value in alternatives where the water jet plunge angle was $\alpha = 60°$. Therefore, there is an accurate ratio between the water jet plunge angle and aeration efficiency.

3.3. Effect of the flotation cell diameter on aeration performance

The effect of different cell water levels ($H = 0$ cm, 25 cm and 50 cm) and different flotation cell diameters ($R = 0.92$ m, 1.30 m and 1.60 m) on aeration performance is seen in Figure 12(a)–12(c).

The water jet plunge angle ($\alpha = 60°$) was kept constant and the aeration performance of three different flotation cell diameters was examined. The water jet plunge angle is selected as $\alpha = 60°$ because it has the highest aeration performance in all experimental groups.

In these experiments for the same water jet plunge angle, it can be said that flotation efficiency varies depending on different cell diameters.

As shown in Figure 13(a) and 13(c), maximum aeration performance occurred at cell diameters of $R = 0.92$ m and minimum aeration performance $R = 1.60$ m, respectively.

When the graphs showing the effect of cell diameter are examined, it is seen that Q_a/Q_w is maximized with 3.20, the cell water level is $H = 0$ cm and the water jet plunge angle is $\alpha = 60°$. When the experimental groups

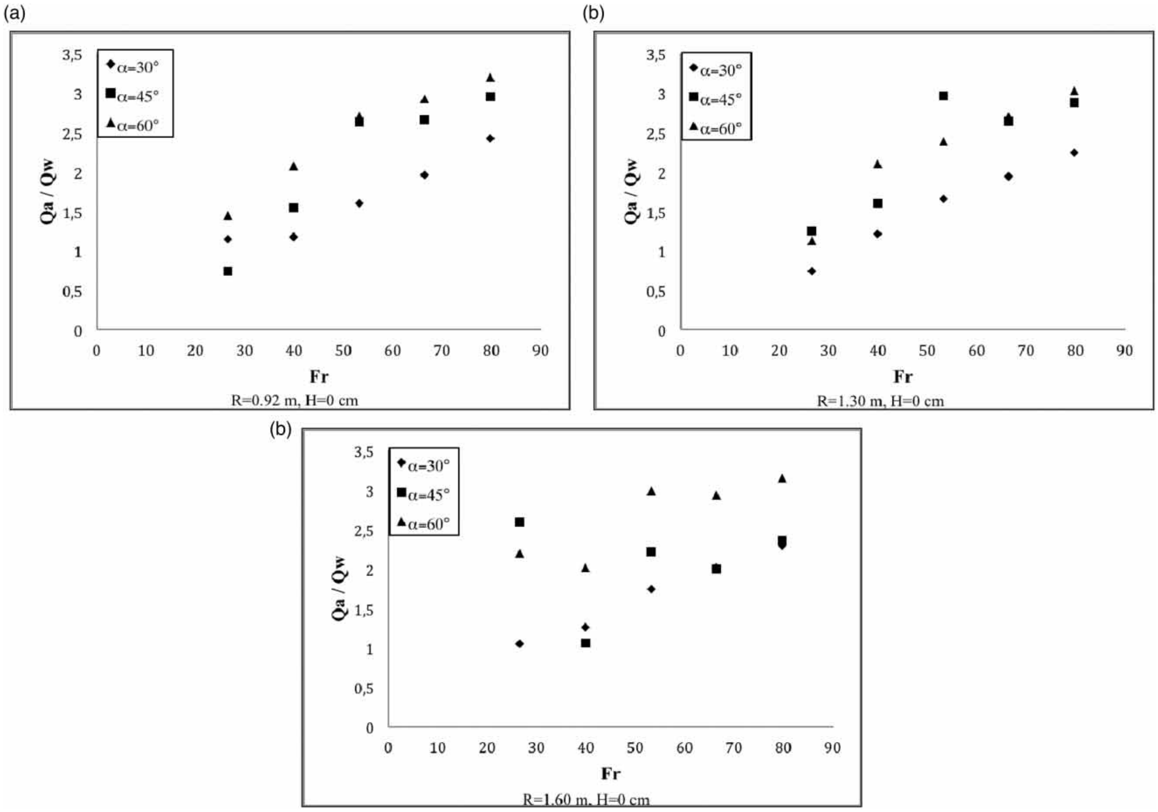


Figure 12 | Q_a/Q_w and Fr relationship with the effect of jet plunge angle in different cell diameters (a, b, c).

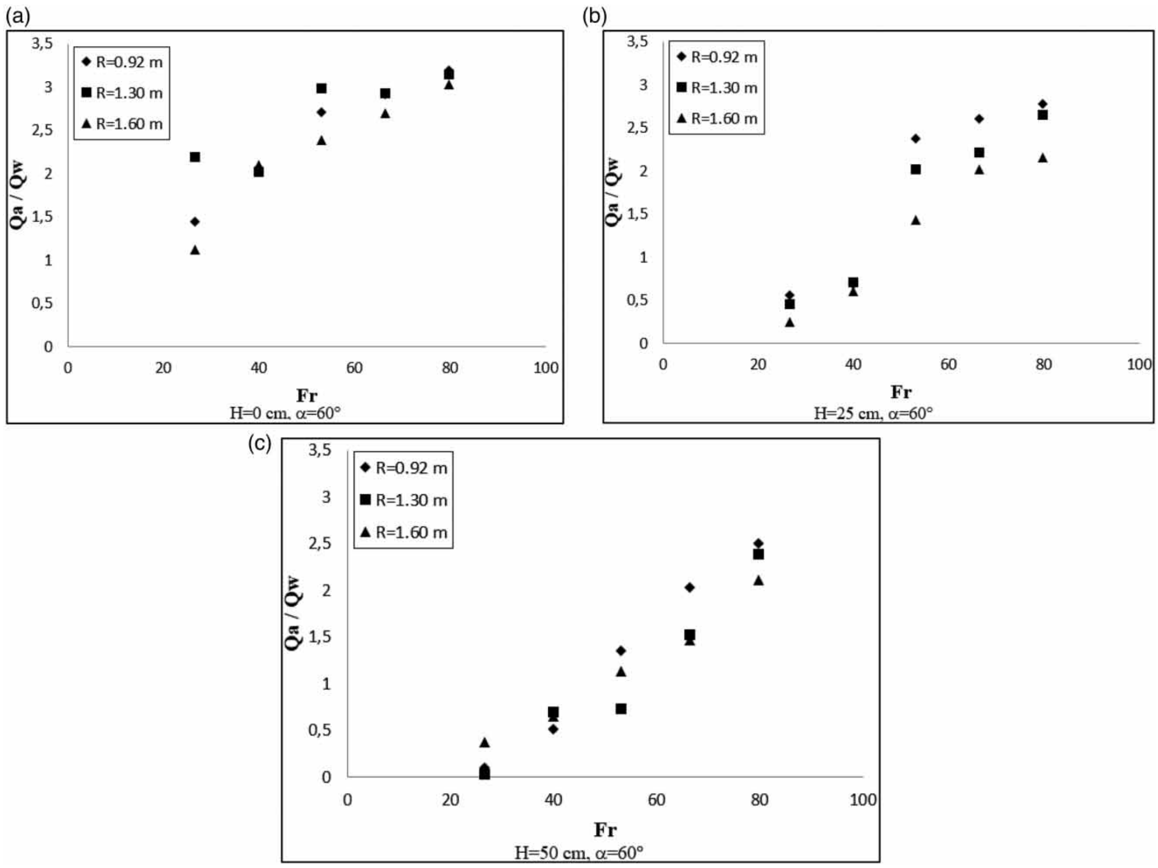


Figure 13 | Q_a/Q_w and Fr relationship with the effect of cell diameter at different water levels (a, b, c).

of these alternatives are compared, it is concluded that there is an inverse ratio between cell diameter and flotation efficiency. Because as the cell diameter increases, the penetration depth decreases and in parallel the aeration and flotation efficiency decreases.

3.4. Effect of the flotation cell water level on aeration performance

The effect of flotation cell water level on aeration performance in terms of different water jet plunge angles is shown in Figure 14(a)–14(c). Flotation cell diameter was kept constant and aeration performance of three different flotation cell water levels was examined.

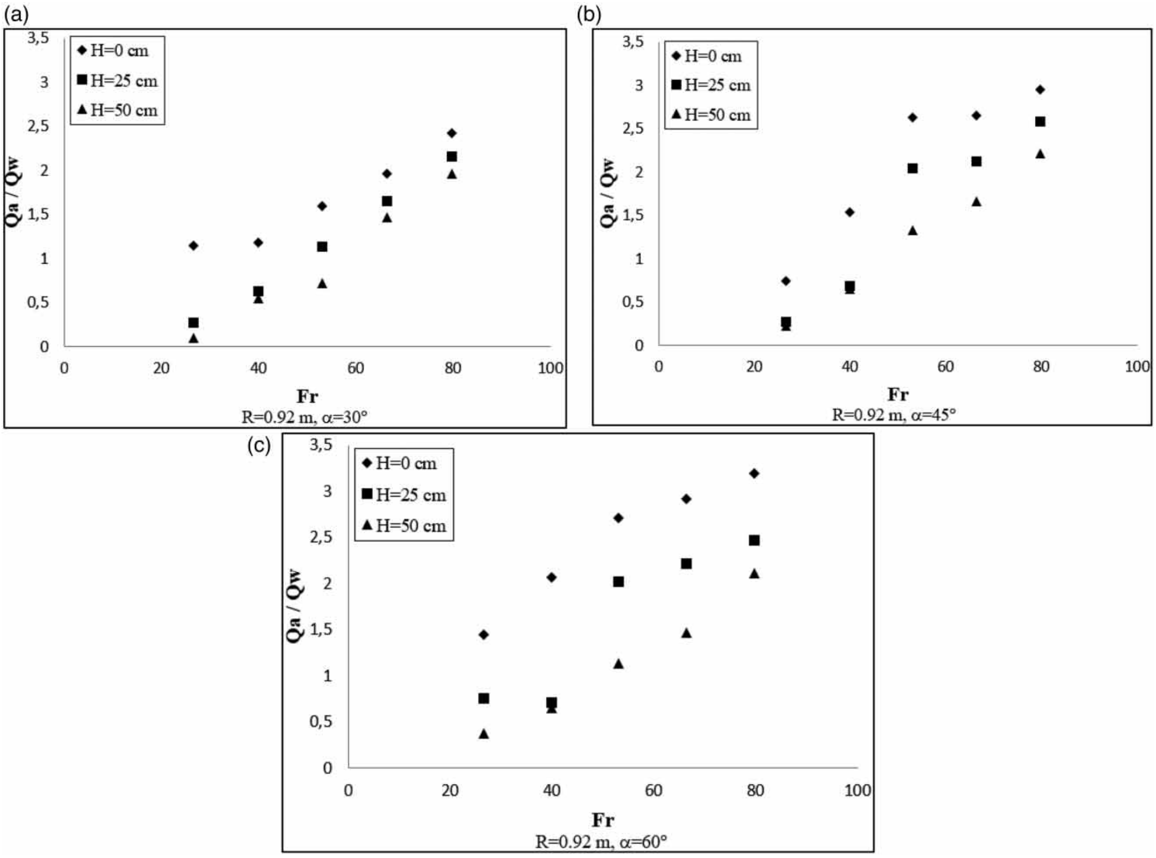


Figure 14 | Q_a/Q_w and Fr relation to the effect of cell water level at different jet plunge angles (a, b, c).

When all experimental groups were examined, it was observed that the cell water level was $H = 50$ cm and there was no aeration in low flow test alternatives.

Increasing the water level of the flotation cell reduces aeration efficiency. In other words, there is an inverse ratio between cell water level and aeration efficiency (Figure 14). The increase in cell water level and in parallel decreased aeration performance can be explained as follows: As the static water level on the water jet that plunges into the flotation cell increases, pressure builds up on the jet. As a result of this suppression, the aeration rate decreases. Therefore, aeration performance is adversely affected and reduced by this situation.

4. CONCLUSION

In this study, the effects of the change in the physical parameters of the cell on aeration performance were investigated. These parameters are cell diameter, air–water jet plunge angle and flotation cell water level. A number of experiments were carried out on flotation cells supported by the head gated conduit. The number of Froude under the conduit cover was calculated by experiments. The results obtained in the experimental study are given below.

Q_a/Q_w increases with the increase in the number of Froude in all experimental groups. In large Froude numbers, maximum values are reached for aeration performance. In parallel with the high aeration performance, a large number of air bubbles have entered the flotation cell. Therefore, it is understood that these cells, supported by the head gated conduit, can be used with high efficiency for flotation. Because according to the literature, the increase in the efficiency of the flotation process is directly proportional to the number of air bubbles entering the cell and the small size.

- Due to the increased water speed, aeration performance has increased significantly.
- In all experimental groups, the best air bubble distribution and the highest penetration depth in the flotation cell were seen in alternatives where the jet plunge angle was $\alpha = 60°$. The spread of air bubbles throughout the cell is desirable in the flotation process.
- As the flotation cell diameter increases, the efficiency of aeration decreases. As the cell diameter increases, the dead zones increase. The formation of a large amount of dead zones during the flotation process is undesirable. According to the literature, air bubbles should be distributed as homogeneously as possible inside the flotation cell. Already in those parts where air bubbles are not distributed homogeneously, dead zones occur. This is undesirable. Because the flotation process cannot take place in areas without aeration.
- Increasing the water level of the flotation cell reduces aeration efficiency.
- Images of situations where the jet plunge angle was $\alpha = 30°$ showed that the foam layer formed on the surface was thicker.
- When the jet plunge angle is $\alpha = 60°$ and images of high-flow experimental alternatives are examined, the diameter of the air bubbles has generally shrunk.
- When the number of Fr exceeds a certain value, it is found to cause turbulence within the cell.

According to experimental analyses, some empirical correlations have been developed to calculate Q_a/Q_w. The resulting correlations are given in Equation (4):

$$Q_a/Q_w = 0.1822 \cdot \text{abs}(\log(R)^{2,889} + 0.992 \cdot \text{Fr}^{0,0426} + 1.0076 \cdot \tan(\alpha)^H \quad (4)$$

in which, the flotation cell diameter is in R meters. The angle of water jet plunge is in α degrees. The water level of the flotation cell is in H meters. Froude number Fr and Q_a/Q_w ratio is sizeless. Correlation coefficient criteria were used to evaluate the accuracy of estimates obtained using nonlinear equations. The correlation coefficient for Equation (4) is 0.846. As a result, a successful match was achieved between the experimentally measured Q_a/Q_w values and the values calculated by the formula.

In this method, the principles of civil engineering were used for flotation. A series of experimental and observational studies were carried out on a flotation cell supported by conduit with a new generation flotation and aeration system. This system provides a very high amount of air bubble input into the flotation cell. Thus, the significant amount of air bubbles intended in the flotation method is easily provided with this system.

This newly developed method can be an alternative to existing systems for flotation, which is the subject of materials, mining and environmental engineering. It can be used especially in vertical flotation tanks to get rid of high energy costs. It can be used for aeration process in wastewater treatment plants in environmental engineering. It can be effectively used in pond aeration. It can be used effectively especially against accidents at sea and human-induced marine pollution. In general, the system has a high cleaning capacity of suspended substances in polluted water. Specifically, it can be used as an alternative to compressor plants and all flotation plants using chemical methods.

Today's technology aims to optimize profitability and efficiency in working conditions in all areas. Therefore, this next-generation flotation system, which has a cell supported by head gated conduit, will be a good alternative to traditional flotation methods in terms of simple structure, low initial investment cost and ease of use.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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