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The monitoring process of column flotation using ECVT system with the effect of percent solid and frother dosage to recovery

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ABSTRACT

Flotation is a separation process that exploits differences in the surface properties of minerals and their impurities when exposed to a solution medium. To effectively observe and monitor the flotation process, Electrical Capacitance Volume Tomography (ECVT) has emerged as a valuable monitoring technology. By employing ECVT, the performance of flotation can be successfully monitored, particularly in relation to the dosage of frother and the percentage of solids. In this study, a laboratory-scale flotation column, equipped with 32 capacitance sensors located in the collection zone section, was employed to facilitate the monitoring process. The measurements of capacitance values were conducted at level 5, which represents the steady-state region of the flotation process. By varying the dosage of frother and the percentage of solids, the study explored the impact of these variables on the flotation performance. The experiments encompassed different solid percentage variations, including 7.5%, 10%, 12.5%, and 15% solid, in conjunction with varying frother dosages of 10, 20, 30, 40, and 50 ppm. The experimental results demonstrated that both the recovery and the signal capacitance exhibited a tendency to increase up to a maximum point as the frother dosage and solid percentage were varied. Notably, the changes in the signal capacitance and recovery displayed a parallel pattern, which was further confirmed through the three-dimensional images obtained using ECVT. These images visually depicted alterations in color concentration in accordance with the variations in frother dosage and solid percentage. The study identified the lowest recovery of 12.34% under the condition of a 10 ppm frother dosage and 12.5% solid, corresponding to a capacitance value of 1.177. Conversely, the highest recovery achieved was 49.91% when using a 40 ppm frother dosage and 15% solid, with a corresponding capacitance value of 1.270.

ABSTRAK

Flotasi adalah proses pemisahan mineral berharga dan pengotornya berdasarkan perbedaan sifat permukaan mineral dengan media larutan. Salah satu teknologi monitoring yang dapat digunakan sebagai observatorium proses flotasi adalah Electrical Capacitance Volume Tomography (ECVT). ECVT memantau kinerja flotasi yang dipengaruhi oleh dosis frother dan persen padatan. Penelitian ini menggunakan kolom flotasi skala laboratorium yang dilengkapi dengan 32 sensor kapasitansi di bagian zona koleksi. Pengukuran nilai kapasitansi dilakukan pada level 5 yang merupakan daerah steady-state. Penelitian dilakukan dengan memvariasikan dosis frother dan persen padat. Variasi persen padat 7,5; 10; 12,5; dan 15% dan variasi dosis buih 10, 20, 30, 40, dan 50 ppm. Hasil percobaan menunjukkan bahwa perolehan kembali dan kapasitansi sinyal pada berbagai dosis persentase buih dan padat cenderung meningkat hingga mencapai titik maksimum. Kapasitansi dan recovery sinyal memiliki kecenderungan yang sama dan citra tiga dimensi ECVT membuktikan adanya perubahan konsentrasi warna dengan variasi dosis buih dan persen padat. Recovery terendah sebesar 12,34% pada kondisi dosis buih 10 ppm dan persen padatan 12,5% dengan nilai kapasitansi sebesar 1,177, sedangkan recovery tertinggi sebesar 49,91% pada kondisi dosis buih 40 ppm dan persen padatan 15% dengan nilai kapasitansi. dari 1,270.

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1. Introduction

In Indonesia, sulfide minerals are among the valuable mineral reserves [1]. These minerals, including Fe, Ag, Cu, Pb, Zn, and Hg, play a significant role in various industries [1]. For instance, sphalerite (ZnS), a sulfide mineral, serves as the primary source of zinc (Zn), a non-ferrous metal widely used for galvanizing steel, manufacturing batteries, and as an element in brass alloys [2]. To maximize the value-added potential of minerals, Minister of Energy and Mineral Resources Regulation No. 11 of 2018 emphasizes the importance of mineral processing and refining activities in Indonesia [2].

In the context of sulfide minerals, flotation techniques are commonly employed to concentrate sulfide ore [3]. Flotation is a separation process that exploits differences in the surface properties of minerals in the presence of a solution medium [3]. Two main types of flotation cells are used: mechanical flotation and column flotation. Mechanical flotation relies on an impeller to generate bubbles, whereas column flotation utilizes gas injection via a compressor, which homogeneously distributes bubbles through a sparger [4].

Flotation processes typically involve three stages: rougher, scavenger, and cleaner, which collectively enhance separation efficiency [4]. Column flotation, often employed during the cleaner stage, offers distinct advantages due to its three distinct zones: froth zone, collection zone, and cleaning zone [5]. In the cleaning zone, hydrophilic particles are raised to the froth zone but eventually pushed back to the collection zone by the wash water [5]. This characteristic of column flotation contributes to its superior selectivity compared to mechanical flotation [6].

Flotation efficiency depends on the probability of collisions, attachments, and detachments between mineral particles and air bubbles [7]. Several factors influence the process efficiency, including froth depth, air rate, and wash water rate [8]. The addition of a frother, for example, can influence the formation of froth depth and stabilize bubbles, allowing particles to rise to the surface and form a froth layer before the bubbles burst [3]. Optimal dosage of the frother is essential for improving recovery and grade in the flotation process [9].

Process optimization can be done by monitoring the process. The flotation process can be monitored with Machine Vision technology. Machine Vision is a technology to observe froth surfaces by high-speed cameras [10,11]. The collection zone is the area of interaction between particles and air bubbles in the column, so it is important to be monitored. Observation in the collection zone is expected to occur in real-time, which can obtain a bubble image that is useful for observing flotation dispersion variables that related to recovery. The limitation of Machine Vision is the reason for the development of monitoring technology using sensors.

Electrical Capacitance Volume Tomography (ECVT) is a sensor that has successfully monitored the flotation process in the collection zone area on the z-axis. ECVT is a promising non-intrusive imaging technology that can provide real-time 3-dimensional images of the sensing domain [12]. The 3-dimensional image of the ECVT will display interactions between bubbles and particles. ECVT monitoring is expected to be able to see the effect of adding frother dosages with solid percent variations on metallurgical performance, which is recovery. Solid percentages and frother dosages can affect the ability of air bubble attachments with mineral particles in the collection zone that affect recovery. Thus, it is important to monitor column flotation in the collection zone to determine the effect of frother dosages and percent solid using the ECVT system.

2. Experimental Detail

The stages of this research are the preparation of samples and preparation of the ECVT system and then the monitoring of the column flotation process.

2.1. Sample Preparation

The feed, which is the ore that enters the flotation column, contains sphalerite as the primary mineral of interest, along with other minerals and impurities. The ore has undergone grinding in a ball mill to reduce its particle size. The size reduction process ensures that the ore particles are finely ground, allowing for better liberation of the valuable minerals.

After grinding, the ore is sieved, and a specific size fraction, typically between -140 mesh and +230 mesh (#), is selected for the flotation process. This size range ensures that the particles are of suitable size for efficient flotation. Before flotation, the ore sample undergoes washing and drying to remove any slime or fine particles that may hinder the flotation process. The removal of slime helps improve the separation efficiency by reducing the interference from fine particles. To understand the mineral composition of the ore, X-Ray Diffraction (XRD) analysis is performed. XRD provides information about the mineral compounds present in the ore sample, helping to identify the minerals of interest and their relative abundance. Additionally, X-Ray Fluorescence (XRF) analysis is conducted to determine the elemental composition of the ore. This analysis provides insights into the concentration levels of different elements present in the ore, including zinc (Zn) from sphalerite and other elements that may impact the flotation process.

In the flotation process, several reagents are employed to facilitate the separation of valuable minerals from the gangue material. These reagents include potassium amyl xanthate (PAX) as a collector, OrePrep® F-583-OZ as a frother, copper sulfate (CuSO4) as an activator, and soda ash (Na2CO3) as a pH regulator. The feed and the product of flotation can be seen in Figure 1.

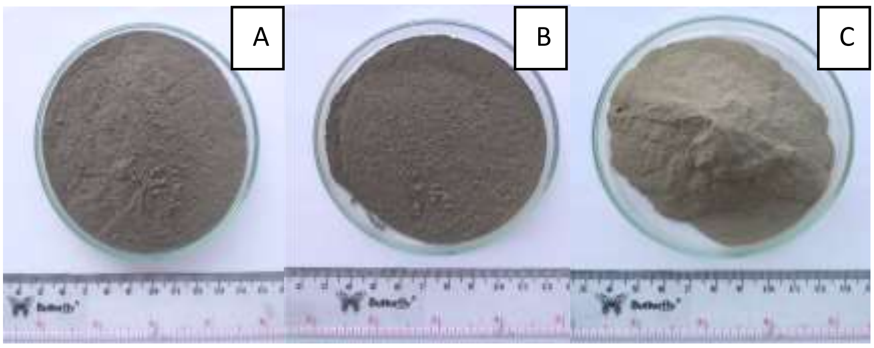

Figure 1. (A) Sphalerite ore as feed (B) Concentrate (C) Tailing

2.2. Column Flotation Process

Figure 2 presents a schematic representation of the laboratory-scale flotation column cells utilized in this study. These cells are custom-made in the lab, with a height of 150 meters and a diameter of 5 cm. The flotation column is equipped with 32 capacitance sensors strategically placed in the collection zone. Each sensor is connected to a data acquisition system (DAS) and a computer to process the acquired signals.

To ensure the proper functioning of the flotation column and the Electrode Contact Voltammetry (ECVT) monitoring system, preliminary experiments were conducted. These experiments involved two-phase systems (air and liquid) and three-phase systems (air, liquid, and solid) at varying dosages of frother, specifically 10, 20, 30, 40, and 50 parts per million (ppm). The main experiment was then carried out using a gas injection rate of 2.5 L/m and a reagent dosage (PAX, CuSO4, Na2CO3) of 500 grams per ton of ore. The conditioning time was set at 5 minutes, followed by aeration for 10 minutes. Frother dosages were varied at 10, 20, 30, 40, and 50 ppm, while the percent solid ranged from 7.5% to 15%.

After the flotation process, the concentrates and tailings were subjected to drying, weighing, and analysis using XRF (X-Ray Fluorescence) to determine their composition and elemental concentrations. Before initiating the monitoring process, the capacitance sensors were calibrated by acquiring signals in two conditions: an empty column condition (filled with air) and a full condition (filled with water). Once the slurry is fed into the flotation column, the monitoring process begins and continues until the aeration process is complete.

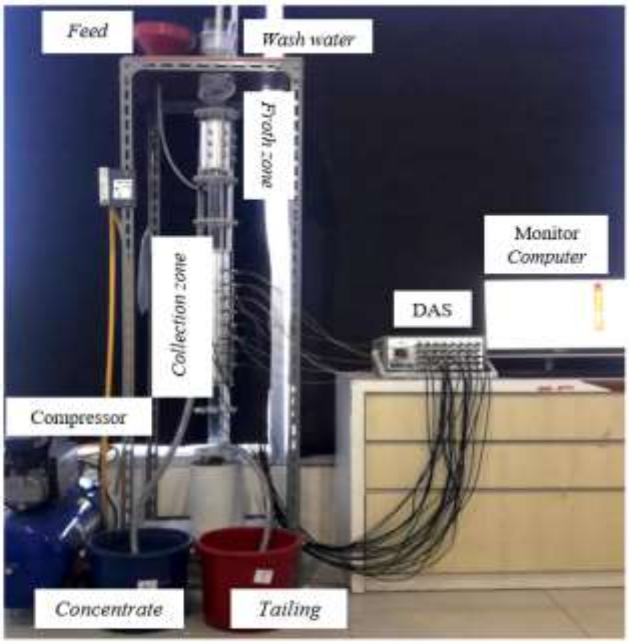

Figure 2. Laboratory-scale column flotation cell and ECVT system set-up

3. Result and Discussion

3.1. Initial Characterization of Ore

The content of sphalerite ore compounds used as a sample in this study was tested using X-ray Diffraction (XRD). The XRD results show that the sphalerite ore used is associated with SiO2, FeS, and PbS (Figure 3).

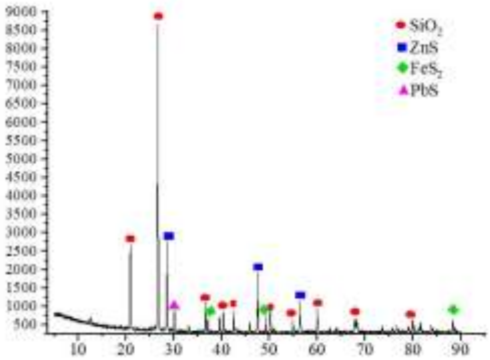

Figure 3. XRD test results of sphalerite ore

The content of sphalerite ore was tested using an X-ray fluorescence portable analyzer (XRF) with results as in Table 1. The analysis showed that the Zn in sphalerite ore was 27,6%.

Tabel 1. XRF test results of sphalerite ore

The content	Zn	S	Si	Fe	Al	Pb	Cu	Mg
compotition(%)	27,6	8,5	9,2	18,7	1,5	10,3	1,3	0,4

3.2. Characterization of Capacitance Signals

Two-phase (gas and liquid) and three-phase (gas, liquid and solid) characterization experiments were carried out to determine that the sensor and flotation column design was functioning properly.

The frother is a compound that has a polar and nonpolar group structure. The potential difference in the sensor electrode pair can cause polar molecules to polarize so that the influence of the electric field on the sensor electrode pair is reduced. The following are the results of capacitance measurements at various dosages of frother (Figure 4). Figure 3 shows that the normalized signal capacitance increases with increasing dosage frother. The capacitance value has increased from 1.089 in 10 ppm frother to 1.134 in 50 ppm frother.

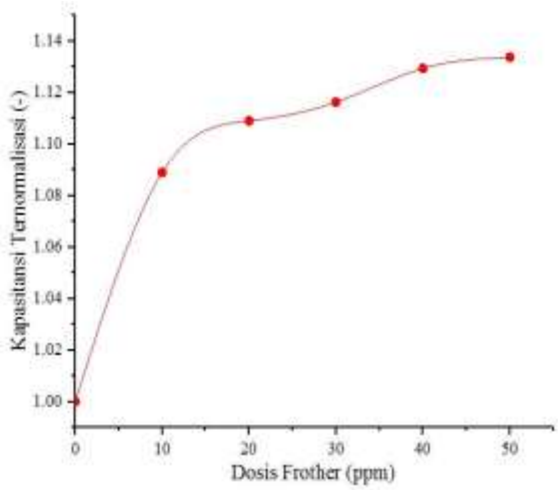

Figure 4. Effect of frother dosage on two-phase capacitance value

After characterizing the 2-phase signal capacitance, then the characterization of the 3-phase signal capacitance. Preliminary trials of the 3-phase system were carried out with varying frother dosages of 10.20,30,40 and 50 ppm with 7.5 percent solid. Figure 5 shows the effect of frother dosages on percent recovery and capacitance normalized values. Percentage recovery and normalized signal capacitance are responses to variations given in the flotation process. Figure 4 shows the percent recovery increased from 66.68% in 10 ppm frother conditions to 86.97% in 50 ppm frother conditions, while the signal capacitance decreased from 1,111 in 10 ppm frother conditions to 1,027 in 50 ppm frother conditions. The increase in dosage frother affects the number and the distribution of bubbles increases. An increase in the number of bubbles results in an increase in the number of particles carried to the concentrate outlet thereby increasing recovery, and an increase in signal capacitance indicates the system is dominated by particles carried by the bubble. This shows that ECVT can monitor 3-phase interactions in the flotation column during the process.

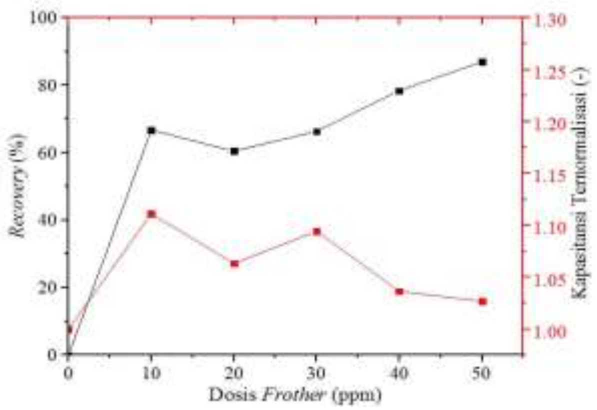

Figure 5. Graphic of influence of frother dosage (ppm) on recovery (%) and capacitance normalized value (-)

3.3. Effects of Dosage Frother and Solid Percentage on Recovery

The metallurgical performance of the flotation process can be expressed by the recovery. In flotation, the recovery value is affected by the process of attachment valuable minerals to the air bubbles. Surfactants in the flotation process are mainly used to increase the probability of bubble-particle collision by means of producing small bubbles and provide foam stabilization [13]. Frother are heteropolar surface-active compounds containing a polar group and a hydrocarbon radical, capable of adsorbing in the air-water interface [14]. Recovery as a function of the frother dosage is shown in Figure 6.

Figure 6 shows the lowest percent recovery is 12.34% at 10 ppm frother and the highest percent recovery is 49.91% at 40 ppm frother conditions. The experimental results show that an increase in frother affects the percent recovery increased. The increase of the frother has increased the formation of bubbles and stabilized the froth. This is made an increase in the mineral particles of ZnS that are hydrophobic in the concentrated outlet. Increasing the frother dosage has also reduced the diameter of the air bubbles resulting in an increase in the surface area of the bubbles so that more solid particles are carried to the concentrate outlet. The percent recovery of the experimental results fluctuates, but it produces a tendency that increases with increasing frother dosage under various percent solid conditions.

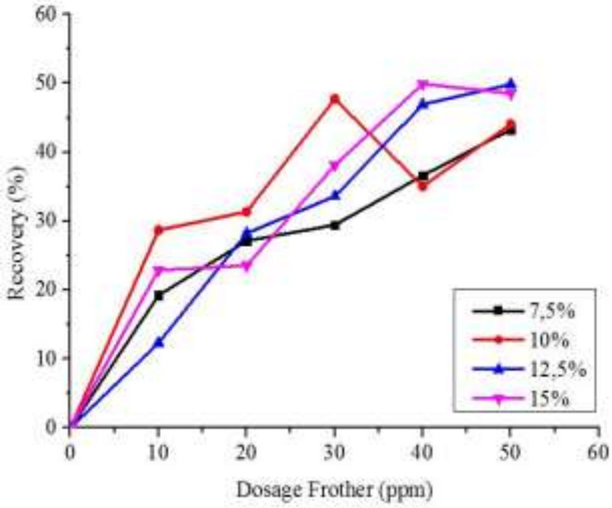

Figure 6. Effect of increasing dosage frother on recovery

Percent solid can affect the recovery of the flotation process. A solid percent that increases will increase the recovery value to the maximum point. The effect of solid percent on recovery is shown in Figure 7. Figure 7 shows the lowest recovery value of 12.34% at 12.5% solid with 10 ppm frother and the highest percent recovery is 49.91% at 15% solid condition and 40 ppm frother. More solids in the process affect the number of particles that stick to the bubbles and become concentrated affect the increasing the percent recovery. The increase in the mass of the concentrate is influenced by entrainment. But an increase in solid percent can also reduce recovery due to the bubble overloading phenomenon. This phenomenon occurs when particles attached to a bubble exceed the bubble's capacity. When the particle exceeds the bubble capacity, the bubble becomes unstable and breaks before it gets to the concentrate outlet. This results in detachment thereby reducing the mass of the concentrate as the solid percent increases. Bubble overloading occurs as a solid percent increase can affect the recovery value and flotation ZnS levels. Increased solid percent can also increase pulp viscosity which decreases bubble rise velocity. The effect of solid percent on the ZnS level contained in the concentrate is shown in Figure 8.

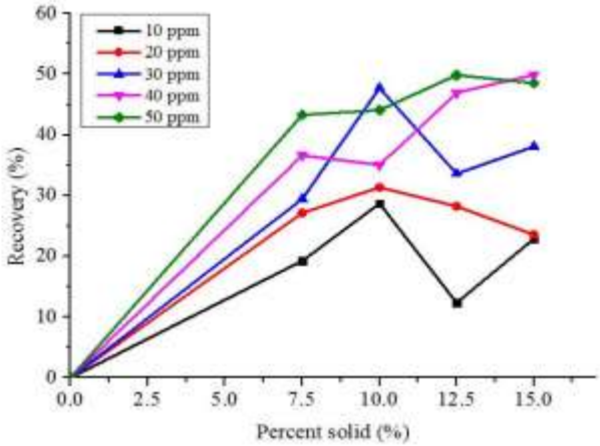

Figure 7. Effect of solid percent increase on recovery (%)

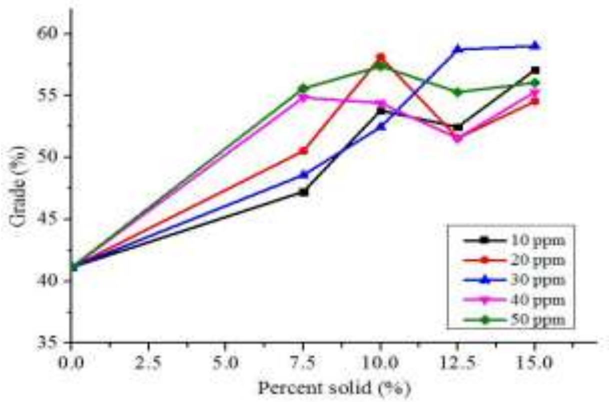

Figure 8. effect of solid percent on a grade of ZnS (%)

Figure 8 shows that the grade of ZnS in the concentrate increases with the increase in solid percent. Percentage of ZnS concentrations at the lowest concentrations were obtained at a 7.5% solid condition with a 10 ppm frother of 47.13%. Whereas the highest concentration of ZnS in the concentrate was obtained in the condition of 15% Solid with a frother dosage of 30 ppm which is 59.02%.

3.4. Monitoring of the ECVT System Flotation Process

The principle of monitoring Electrical Capacitance Volume Tomography (ECVT) is to display 3D images in real-time by measuring the measured capacitance values. ECVT is based on utilizing nonliniear distribution of electric field lines to reconstruct a volume image of different materials in the imaging domain [12]. ECVT sensors are installed in the collection zone which includes 32 channels with 8 sensor levels (Figure 9), where each level has 4 electrodes surrounding the flotation column.

Figure 9. The levels of sensor for *monitoring* column flotation

Observations were at level 5 because in this area is steady-state. This level is used to analyze signal capacitance from interactions of water, bubbles, and mineral particles in the collection zone area. The calibration process is carried out to obtain system limitations. The relative permittivity value 1 is used as the upper limit which is limited by water and the relative permittivity value of 0 for the lower limit by air.

This research carried out variations in frother dosage and percent solid to determine its effect on recovery and monitoring results using ECVT. The effect of the frother dosage on capacitance normalized is shown in Figure 10.

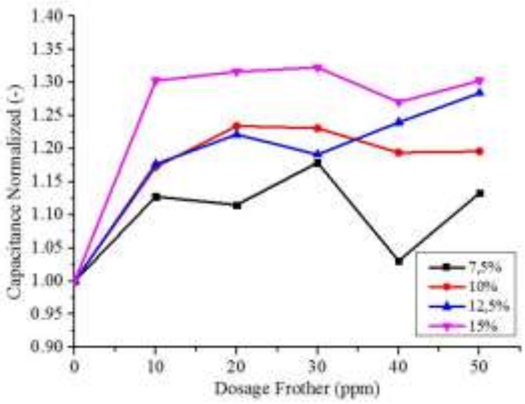

Figure 10. Effect of dosage frother on capacitance signals

The monitoring results show that increasing the dosage frother in every percent solid does not significantly influence the capacitance normalized value. This can be seen in the graphic that has a flat tendency. But the increase in frother dosage affects the diameter of the bubble in flotation. The function of the frother is to reduce the size of the bubbles and increase the surface area of the bubbles, to increase the number of particles attached to the bubbles. This makes the frother dosage more and more the system is dominated by solid particles attached to the bubble, thus affecting the results of monitoring.

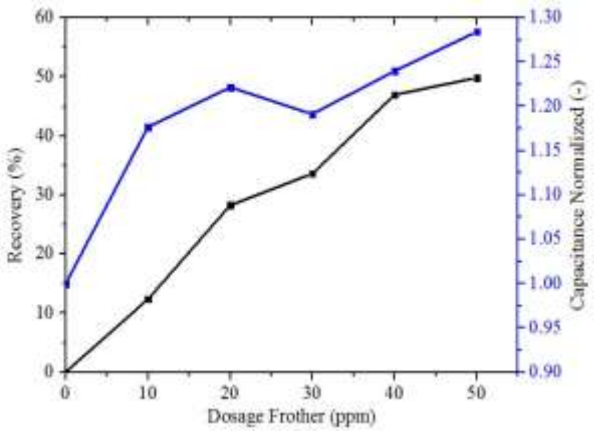

Figure 11. The effect of dosage frother on recovery and capacitance normalized at 12.5% solid

Figure 11 is observed to show that the phenomenon of flotation that occurs can be monitored using ECVT. From the graphic, in condition 12.5% solid process shows that as the frother dosage increases, the recovery and average capacitance normalized during aeration increases. This is because stable bubbles increase the amount of raised mineral particles thereby increasing recovery and capacitance values. But at 30 ppm, a decrease in the value of capacitance and an increase in recovery is not significant. Therefore, observations of phenomena that occur specifically at 30 ppm are observed capacitance in every minute during the process at 30 ppm.

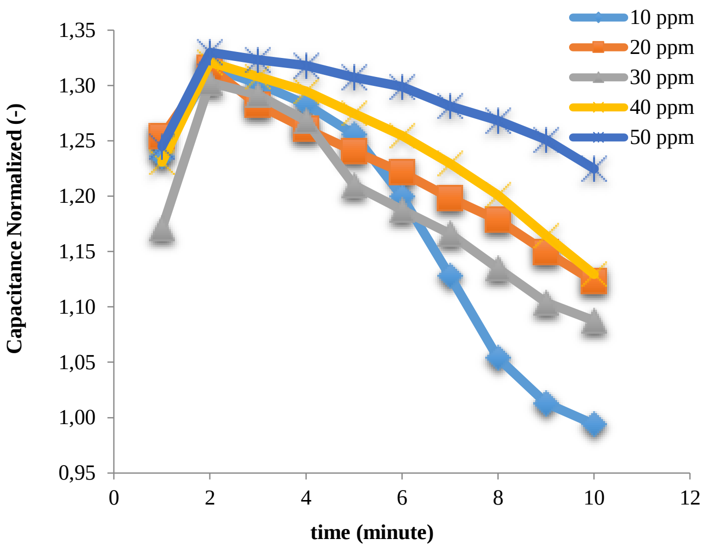

Figure 12. Capacitance normalized value during process at 12.5% solid

Figure 12 shows the change in the value of the signal capacitance every minute for 10 minutes. The curve above shows that the capacitance normalized value at 30 ppm is lower than 20 ppm. This decrease is due to the bubble coalescence phenomenon in the first minute. This phenomenon creates a large bubble that is unstable, resulting in a detachment that causes recovery does not increase significantly. Bubble coalescence also causes the air volume in the column to be relatively high. This decreases the relative permittivity of the entire column because air-dominated systems have lower capacitance than water systems and process capacitance. Therefore, the normalized value of process capacitance at 30 ppm decreases and recovery does not increase significantly. Figure 11 also shows that the capacitance normalized value in each variation decreases with processing time. This is because the number of solid particles in the flotation column decreases during the aeration time due to the presence of concentrated and tailings output. A decrease in capacitance value at 10 minutes indicates that the solid particles are depleted, or the flotation process is complete.

Capacitance normalized data is then used for the image reconstruction process by calculating the permittivity distribution. The image is indicated by 3 basic colors namely blue, green, and red. Image changes that occur with changes in dosage frother are shown in Figure 13. The slice image taken at level 5 area. The blue and the red colors represent low and high phase concentrations [12]. The blue color represents an air system that has the lowest permittivity distribution, and the red color represents a slurry system that has a higher permittivity distribution. The green color represents the system with the value of the permittivity distribution between solids and fluid.

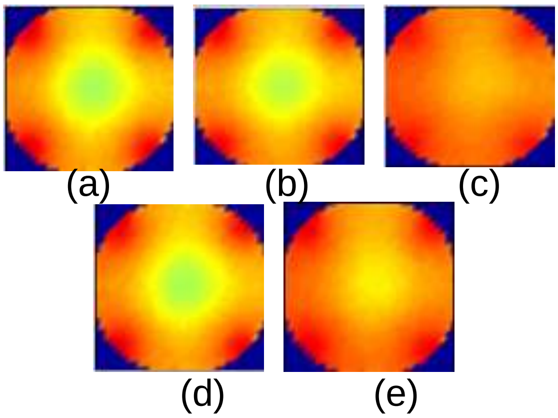

Figure 13. Image changes in the frother dosage (a). 10 ppm; (b). 20 ppm; (c). 30 ppm; (d). 40 ppm; and (e). 50 ppm

Figure 14 shows the image change with an increasing dosage frother in 15% of solids. At 10 ppm frother, the image shows a green color which means the system is dominated by air. Unlike the 50 ppm, the image is still red, meaning the system is still dominated by water and mineral particles. Not only the dosage frother affects the capacitance value, but also the percent solid shown in Figure 14.

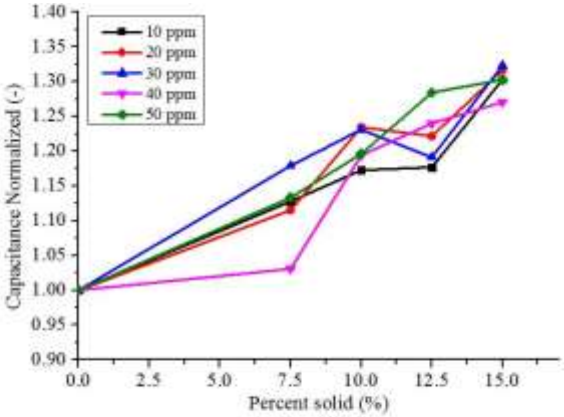

Figure 14. Effect of a solid percent on signal capacitance

The effect of percent solid on capacitance normalized is that the increase in solid percent increases relative permittivity and capacitance normalized values increase. This is due to the increase in the value of solid percent, the number of solid particles in the pulp increases. The increasing number of solid particles will affect the measured capacitance and voltage values. This is consistent with the results of monitoring in Figure 10. The monitoring results show that an increase in the percentage of solids at each dosage of the frother increases the capacitance normalized value. The maximum capacitance value is 1,242 at 50 ppm frother and 15% solid. This increase in capacitance value is due to the amount of solid phase that increases with the increase in solid percentage. As a result, the average normalization capacitance value during the process is relatively high. The more solid particles the permittivity distribution increases and the influence of the electric field between the electrodes decreases so that the value of the capacitance or the measured voltage increases.

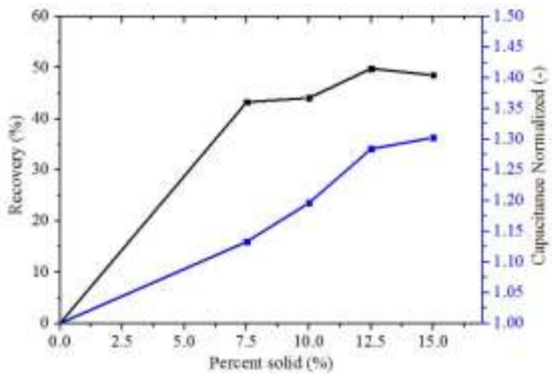

Figure 15. The effect of percent solid on recovery and capacitance normalized at 50 ppm.

Figure 15 shows the relationship of percent solid with the recovery value and the capacitance normalized value at a 50 ppm. The figure above shows that as solid percent increases, the recovery and capacitance normalized also increases. This is because the increased amount of feed can increase the amount of lifted particle mass and make the column system dominated by solid particles so that the measured capacitance increases. The image at level 5, after the aeration process is complete is shown in Figure 16.

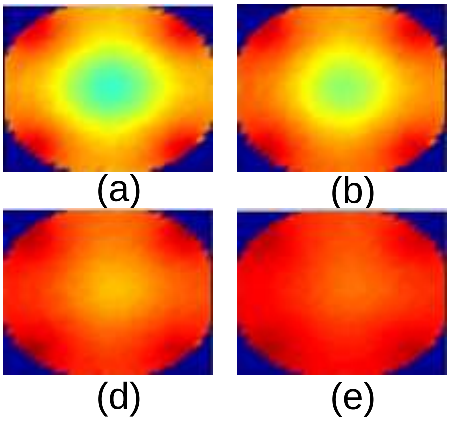

Figure 16. Image change on solid percent (a). 7.5%; (b). 10%; (c). 12.5%; and (d) .15%

Based on Figure 16 the increase in recovery is followed by a blue image, which shows the air phase increasing in the measurement area because the mineral particles have been lifted to the outlet of the concentrate. At 10 percent solid, recovery has increased followed by an image that is also blue. In contrast to the solid percent of 12.5 and 15, the recovery has decreased. This is due to detachment due to bubble overloading when the percent solid continues to increase.

4. Conclusion

The analysis of the flotation process, monitored through the Electrical Capacitance Volume Tomography (ECVT) system, revealed a correlation between the dosage of frother and the recovery value. The experimental data demonstrated that as the frother dosage increased, the recovery value also increased up to an optimal dosage, beyond which it showed no significant changes. Additionally, the increase in the percentage of solid in the system had a positive impact on the recovery percentage.

In this study, the maximum recovery achieved was 49.91% when using 40 ppm frother dosage and 15% solid percentage. Notably, the observed increase in both frother dosage and solid percentage led to higher recovery values, which were further supported by the measured capacitance signal values during the flotation process. These changes in recovery were visualized through three-dimensional imaging, reinforcing the relationship between the frother dosage, solid percentage, and the observed recovery improvement.

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