Optimization of flotation columns to provide added value of local sphalerite ore

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Abstract. Sphalerite is the most important mineral in the formation of zinc metal. According to regulation of Ministry ESDM No.5/2017 stated that the minimum grade of zinc concentrates to be exported is 51%. Therefore, it is necessary to do a beneficiation process for sphalerite ore to fulfil the requirements. Sphalerite is hydrophobic mineral, therefore it is the best way to processed sphalerite by flotation. Flotation is the process of concentrating valuable minerals from impurities based on the nature of the mineral surface. Column flotation is a flotation technology without an agitator as a producer of air bubbles like conventional flotation machines. Recovery is the most important factor in flotation and it shows the rate of acquisition of the flotation process. The purpose of this research was to determine the effect of air flow rates (2, 2.5, 3, 3.5, and 4 L / min.), percent solid (7.5%, 10%, 12.5%, and 15%), dose of reagent frother (10, 20, 30 and 40 ppm), and particle size of ore (−80 + 100 #, −100 + 140 #, −140 + 200 #, −200 #) on ZnS recovery. The research was carried out by using a laboratory scale flotation column with 4.6 cm in diameter and 150 cm column height. The flotation reagent used was activator (CuSO₄), pH regulator (NaCO₃), collector (PAX), and frother (dowfroth 1012). The highest recovery (90.29%) was achieved at a flow rate of 4.0 L / min, while on variation of particle size the highest recovery was 85.55% at (-100+140) #. The increase in percent solid or dilution of pulp is not always followed by an increase in recovery and the highest recovery ((71.26%) was achieved at 7.5% solid. In addition, recovery increases with increasing doses of frother, the highest recovery (86.04%) was achieved at 40 ppm doses of frother.

1. Introduction
Zinc currently the fourth most widely consumed metal in the world after iron, aluminium, and copper. It has strong anticorrosive properties and bonds well with other metals. Consequently, about one-half of the zinc that is produced is used in zinc galvanizing, which is the process of adding thin layers of zinc to iron or steel to prevent rusting. Zinc commonly found in mineral deposits along with other base metals, such as copper and lead. The most important ore of zinc is sphalerite. Sphalerite, a zinc sulfide mineral with a chemical composition of (Zn,Fe)S [1].

Sphalerite hydrophobic, therefore the best ore preparation process is flotation. Flotation is the process of ore concentration based on differences in the surface properties of minerals. Hydrophobic ores will float and are called concentrates while the hydrophilic ore will sink and be called tailings. Flotation can be done in three stages, namely rougher, scavenger and cleaner. Stage cleaner can be done using a mechanical or column flotation. The main difference in flotation of columns with mechanical flotation is the presence of wash water which serves to clean impurities of mineral particles that come with froth. Another difference is that the column flotation uses counter current flow which produces bubbles that
are relatively stable and thick, compared to bubbles produced by mechanical flotation that have a thinner and more easily broken texture [2].

The continuation of the flotation process involves several chemical and physical variables. Physical variables include air flow rate, solid percent and particle size while chemical variables include flotation reagents. These variables are flotation process parameters that affect the success/efficiency of the flotation process expressed in recovery [3]. In addition, the Flotation stage aims to increase the levels of Zn from sphalerite ore that can meet the requirements of ESDM RI NO. 25/2018 (Zn ≥ 51%) [4].

2. Experiment

Sphalerite ores are characterized first by XRD and XRF analysis. XRD analysis is performed to determine the compounds contained in sphalerite ore while XRF analysis to determine the levels of the elements. Before the flotation stage is carried out, the ore is reduced in size using a rod mill which is then followed by a sizing process to obtain the size as desired. Figure 1 shows the XRD analysis diagram and table 1 shows the result of XRF analysis. This research was conducted to determine the effect of water flow rate, solid percent, particle size and doses of frother on flotation recovery. Complete research variables can be seen in table 2. This research was conducted on a laboratory scale using column flotation 4.6 cm in diameter and 150 cm in height (figure 2). The flotation reagents used are CuSO₄ (activator), NaCO₃ (pH regulator), potassium amyl xanthate / PAX (Collector) and dowfroth 102 (frother). The Coning-Quartering process (figure 3) is carried out on ore that has been sieved to obtain ore samples that represent the ore as a whole.

![Figure 1. XRD Analysis Diagram.](image)

| Element | Wt (%) |
|---------|--------|
| Zn      | 52.8   |
| Si      | 9.7    |
| S       | 6.7    |
| Fe      | 5.4    |
| Al      | 2.7    |
| Pb      | 2.4    |
| Cl      | 2.1    |
| Cu      | 0.5    |
| Cd      | 0.4    |

Table 1. XRF Analysis.

After the sampling process, the conditioning process is carried out, i.e. the ore samples are mixed with flotation reagents and water and allowed to stand for 5-10 minutes. The next flotation process is carried out for 10 minutes. The concentrates and tailings produced from the flotation process were analysed by XRF.
3. Result and Discussion

3.1. Effect of air flow rate on flotation recovery

In general, ZnS recovery will increase to a certain maximum point by increasing the water flow rate, then its tendency to fluctuate. The highest recovery (90.29%) was achieved at a 3 L/min air flow rate and the lowest (57.64%) at 4 L/min (figure 4). The relationship between air flow rate and gas holdup determines flow regimes in the column, as illustrated in figure 5. Gas holdup increases linearly then deviate after passing a certain Ug range. The linear region is characterized by the bubbly flow regime, which is the homogeneous distribution of bubbles that are uniform in size and float at a relatively similar rate. Bubbly flow regimes are ideal characteristics in flotation column operations [5]. Increasing the flow rate of air and gas holdups while still producing the characteristics of bubbly flow can improve recovery because the possibility of contact between particles and bubbles increases.

![Figure 2. Column Flotation.](image)

![Figure 3. Coning and quartering.](image)

![Table 2. Variable process of Sphalerite Column Flotation.](image)

| No | Flotation Variable       | Variable Value         |
|----|-------------------------|------------------------|
| 1  | Air flow rate (L/min)   | 2; 2.5; 3; 3.5; 4      |
| 2  | Particle size (mesh)    | -80+100; -100+140; -140+200; -200 |
| 3  | Percent solid (%)       | 7.5; 10; 12.5; 15      |
| 4  | Dose of frother (ppm)   | 10; 20; 30; 40         |

![Figure 4. Effect of Air Flow Rate on Recovery.](image)

![Figure 5. Effect of Air Flow Rate on Gas Holdup [5].](image)
According to J. Finch et al., recovery increases with increasing air flow to a certain optimum point or during the bubbly flow regime. If it has passed the bubble flow regime, it will produce turbulent flow which creates large bubbles (slug). The larger the bubble size allows the phenomenon of coalescence and burst bubbles to occur. This phenomenon can reduce recovery value because it makes detachment of valuable mineral particles and is carried along with tailings [5-6]. In addition, the magnitude of the air flow rate will affect the amount of air bubbles produced. Increasing the flow rate of air will increase the production of the amount of air bubbles and also increase the likelihood of the number of particles raised to the surface of the froth. Recovery will continue to increase along with the faster air flow used [7]. However, an increase in air flow rate is not always followed by an increase in recovery value when the air flow rate has passed its optimal point.

3.2. Effect of percent solid or dilution of pulp on flotation recovery

Pulp density or commonly called percent solid is the ratio between the weight of the solid mineral and the overall weight of the pulp. The bigger percent is solid, the recovery will be even greater. The greater the percent solid value, the greater the number of particles in the Flotation Cell therefore the possibility of particles sticking to air bubbles is getting bigger [8]. The relationship between percent solid and recovery is not always directly proportional. It means, the increasing in solid percent value is not always followed by an increasing in recovery. Based on figure 6, it can be seen that the highest recovery is obtained at 7.5 percent solid which is equal to 71.26%, then the recovery value decreases with the increasing percent of solid value. This is due to a percent increase in solids which increases the amount of minerals in the pulp therefore small air bubbles cannot float valuable minerals to the surface of the froth. A high percent solid value can also cause a difficult flotation process due to the occurrence of bubble overloading or too much mineral attached to air bubbles which causes air bubbles to burst therefore the minerals are not raised to the surface of the froth [8].

![Figure 6. Effect of Percent Solid on Flotation Recovery.](image)

3.3. Effect of particle size on flotation recovery

Metallurgical performance is generally expressed in the form of recovery. Recovery is the percentage of valuable minerals contained in the ore obtained as concentrates [3]. Particle size has an important role that influences flotation performance because it deals with the interaction between particles and bubbles [9]. Based on the results of this research, variations in particle size affect the physical appearance of the pulp. Pulp with a fine particle size of -140 + 200 # and -200 # produces more concentrated froth and many sphalerites float on the pulp (figure 7.c, and 7.d), while particles that are roughly -80 + 100 # and -100 + 140 # the surface of the larger formed froth bubbles and floating sphalerites is only partially
compared with particle sizes -140 + 200 # and -200 # (figure 7.a, and 7.b). The float of sphalerite on the surface of the froth bubble at the pulp site indicates an interaction between particles and air.

Figure 8 shows a graph of the relationship between air flow rate to recovery in particle size variations. Based on the results of this research, it was found that the highest recovery was produced in the size of -100 + 140 # with an air flow rate of 3.5 L / minute which was equal to 85.558%. This proves that the particle size is best for the flotation process, which is at the medium size. The size of particles that are too smooth and light will cause particles to float onto the surface. While the particle size is too coarse, the individual mass of particles increases therefore the gravitational force will exceed the efficiency attachment and many particles will not be lifted by bubbles.

B. Shahbazi et al. investigating the effect of particle size FeS2 and bubble surface area flux on metallurgical performance. Optimal recovery is produced from eight size classes, namely at medium size (-140 + 200 mesh). Particle size is related to collision, attachment, detachment between bubbles and particles. Increasing particle size will increase collision efficiency and detachment efficiency but the particle bubble attachment efficiency decreases. Bubble and coarse particles often fail to form aggregates of bubbles therefore recovery decreases. As for particles that are too fine, the more entrainment occurs, the collision efficiency is very low, and the detachment efficiency between particles and bubbles is very high, causing low flotation speeds [9].

Figure 7. Conditioning on variation of particle size (a) -80+100#, (b) -100+140#, (c) -140+200 # and (d) -200#).
3.4. Effect of Frother Dose on Flotation Recovery

The effect of dose frother changes is shown in figure 9. The increasing of dose frother shows a tendency for increasing recovery values. This result is consistent with the research conducted by Klimpel and Isherwood which states that increasing the dose frother is directly proportional to the increase in recovery value. This is due to the reduction in bubble size (figure 10) therefore the bubble surface area in the same volume will increase. The resulting effect causes an increased likelihood of contact between mineral particles and bubbles due to the wider surface of the bubble therefore the recovery from the flotation process will increase [9].

4. Summary

Based on this research, it can be concluded that air flow rate affects the recovery of sphalerite flotation. Initially ZnS recovery will increase to a certain maximum point by increasing the water flow rate, then will decrease even though the water flow rate is increase. The highest recovery (90.29%) was achieved at a water flow rate of 3 L / min and the lowest (57.64%) at 4 L / min. The increase in percent solid value or dilution of pulp is not always followed by an increase in recovery. It can be seen that the highest recovery is obtained at 7.5 percent solid which is equal to 71.26%, then the recovery value increases with increasing percent of solid value. Variations in particle size affect the physical appearance of the pulp. The smaller particle size will produce the more concentrated froth and many sphalerites will float on the pulp. The highest recovery (85.55%) was produced in the size of -100 + 140 # with an air flow rate of 2 L / min. 

![Figure 8. Effect of Particle Size on Flotation Recovery.](image1)

![Figure 9. Effect of Frother Dose on Flotation Recovery.](image2)

![Figure 10. Effect of Frother Dose on Bubble Size at 2L/min air flow rate.](image3)
rate of 3.5 L / min. Recovery increases with increasing doses of frother. The highest recovery (86.04%) was achieved at 40 ppm dose frother, and 3.5 L / min water flow rate.

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