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# Implementation of Sodium Hydrosulfate (NaHS) Flotation with F83 and F515 on Mass Recovery of Gold Ore

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***Abstract***

*There exist more and more gold mines in Indonesia, especially those that have just been started. It is indispensable to do test work to decide the process flow that will be utilized. Reagent usage tests on the flotation of gold ore were carried out to determine the mass recovery obtained by using a specific reagent and to determine which reagent is more optimal and profitable for further test work. Flotation is carried out using mechanical flotation with F83 and F515 as collector and frother respectively along with the addition of NaHS as modifier or sulfidization reagent.. Based on the flotation that has been conducted, it is known that the use of NaHS enhances the mass recovery obtained. Moreover, compared to the usage of other reagents, flotation with NaHS gives a slightly larger mass recovery with an increase around 2-3%. This indicates that the gold ore used is ores that have been oxidized More in-depth test work is required to get the optimal dose to obtain considerable mass recovery.*

***Keywords:*** *Gold ore; Flotation; Mass recovery; Mineral Processing; Sodium hydrosulfide*

## Introduction

Gold is one of the vital metals in Indonesia since it can be utilized by the state and its citizens to develop the nation's economy. The existence of gold in Indonesia spread from Sabang to Merauke. This makes Indonesia the 12th gold-producing country in the world according to the USGS (United State Geological Survey) with a production of 70 metric tons. The first place is China with a production of 330 metric tons, followed by Australia, Russia, and Canada. This is followed by more and more gold mining in Indonesia, both large and pioneering. For newly established mines, it is indispensable to carry out plant designing, especially in determining the processing flow that will be used. In determining this, various test works will be carried out to determine a simple, cheap, and profitable process flow.

Flotation is a concentration method that utilizes the surface properties of minerals so that particles can attach to air bubbles in the stirred pulp (Wills & Finch, 2016) by adjusting the pulp conditions using various reagents, it is possible to make valuable minerals became air-loving (aerophilic) and gangue minerals water-averse (aerophobic). This results in separation through the transfer of valuable minerals to air bubbles that form froth floating on the surface of the pulp.

Reagents are the most important part of the flotation process. In the early stages of the flotation process development, great progress was made in improving the quality of flotation reagents. In developing these methods, significant time and energy have been invested in the selection of reagents to achieve the most effective separation and enrichment results. In industry, control of reagent addition is the most important part of a flotation strategy (Bulatovic, 2007). Generally, based on their function reagents are divided into collectors, frothers, regulators, and depressants.

The association of gold and copper in merchantable ores is common. At one end of the spectrum is copper ore which contains mostly gold mineralization. This would be uneconomical to mine due to the gold content, yet the gold provides significant opportunity value. The use of flotation methods in the gold mining industry began in the early 1930s after the introduction of water-soluble flotation collectors (xanthate and dithiophosphate) that enabled the flotation of sulfide minerals (Dunne, 2016). Gold is recovered to varying degrees along with copper during the flotation process and ultimately recovered from copper smelting residue (Sceresini & Breuer, 2016).

Chalcopyrite is a type of copper ore that is commonly associated with gold. The presence of pyrite indicates that the ore is a sulfide mineral. These minerals are essentially easier to flotation when compared to oxide minerals because they are more hydrophobic and insoluble (Jia et al., 2023). In addition, sulfide minerals are also more easily wetted by the collector. Only sulfide minerals are more easily oxidized because of the pyrite and sulfur contained in them (Palit, Hartami, & Saifullah E, 2019; Virginia, Nursanto, & Wardana, 2019).

Sulfide minerals that have undergone oxidation require different treatment than before because the surface of the mineral has changed to hydrophilic and soluble (Cai et al., 2021; Chen, 2021; Li, Zhou, & Lin, 2020; Shen et al., 2020). Therefore, it is common to add sulfiding agents (sodium sulfide and sodium hydrosulfide) to the pulp to sulfide the minerals before flotation (Dunne, 2016). Compared to the mechanochemical, hydrothermal, and roasting methods, the method of adding a sulfiding agent directly to the pulp (surface sulfidation) is considered to be cheaper, easier to operate, and less likely to corrode equipment (Liu et al., 2020).

Sodium hydrosulfide, NaHS, is a flotation reagent for some copper minerals. NaHS is commonly used as a chalcopyrite depressant in Cu-Mo flotation processes (Ansari & Pawlik, 2007; Bulatovic, 2007; Wills & Finch, 2016). In addition, NaHS is also used as an activator of copper oxide minerals such as malachite ($Cu_2(CO_3)(OH)_2$) to sulfidize its surface (Zhou & Chander, 1993). There are only a few examples of activation applications involving copper sulfide minerals (Matsuoka et al., 2020), and the reaction between NaHS and copper-gold minerals is rarely analyzed.

Therefore, the use of F83, F515, and NaHS reagents in the copper-gold ore flotation process was tested to determine the mass recovery obtained and determine which reagent is more optimal and profitable for further test work.

## Materials and Methods

This research was conducted by experimentally testing the use of reagents in the flotation process of copper-gold ore samples from PT Saka Indonesia.

In this research, the reagents used are NaHS (Sodium hydrosulfide), F83 (collector), and F515 (frother) with additional lime as a pH Regulator. In conducting flotation, there is a procedure that can be seen in Figure 1.

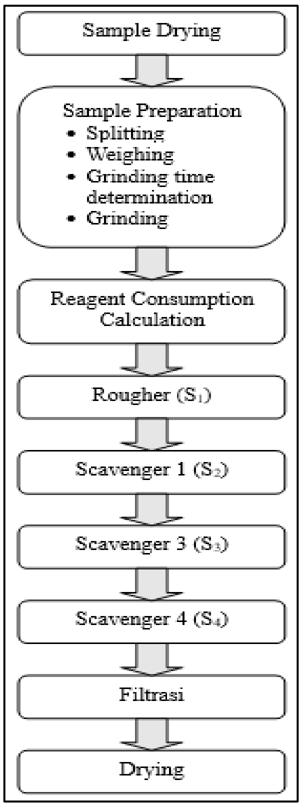


Figure 1 Flotation Procedure in PT. Florrea Indonesia
*Source: obtained from primary data* (2022)

The stage begins with sample drying, followed by sample preparation (including sample splitting, determination of grinding time, and grinding), calculation of reagent consumption, flotation, filtration, and drying. The flotation concentrate obtained will be analyzed for mass recovery to determine the effectiveness of the reagents used when compared to other reagents.

In addition, some parameters need to be considered in conducting this flotation test, as listed in Table 1.

Table 1 Flotation Test Parameter

| No | Parameter | Keterangan |
|---|---|---|
| 1 | *Sample Weight* | 630 gr |
| 2 | *% Solid* | 21 % |
| 3 | *Cell Capacities* | 3000 cc |
| 4 | *Impeller Rate* | 1002 rpm |
| 5 | *Air Injection Rate* | 5 L/h |
| 6 | *Scrapping Rate* | 20 rpm |
| 7 | *Grinding Time* | 28 min |

*Source: obtained from primary data* (2022)

### 1. Drying and Sample Preparation

Samples that are still wet need to be pre-dried using an oven to reduce the moisture contained in them, so that an accurate weight is obtained for the flotation process. The dried samples will be homogenized using a riffle splitter. The samples were then weighed until 630 grams × 6 sample containers were obtained. This sample weight is obtained from the percent solid used, which is 21% with a volume of water of 3 litres, then Equation 1 is used to calculate the required sample weight.

$$\% \, solid = \frac{berat \; sampel \; (gr)}{berat \; sampel \; (gr) + berat \; larutan \; (gr)} \times 100 \qquad (1)$$

In this process, wet grinding was carried out 6 times with details of 2 for determining grinding time and 4 for the flotation process itself. The determination of grinding time is done to know the time to reach P80 at -200 mesh size by ignoring the loss due to human error. In its determination, a linear regression calculation obtained from experiments with 2 different times (10 and 25 minutes) was used to obtain an estimate of this time, resulting in a grinding time of 28 minutes, as can be seen in Figure 2.

The sample used to determine the grinding time could not be used in the flotation process because this sample had gone through the sieving process. In the sieving process, there is a lot of fine material that is wasted to get the weight of the material that is still stuck on the sieve. Therefore, a different sample with a predetermined weight was used for flotation.

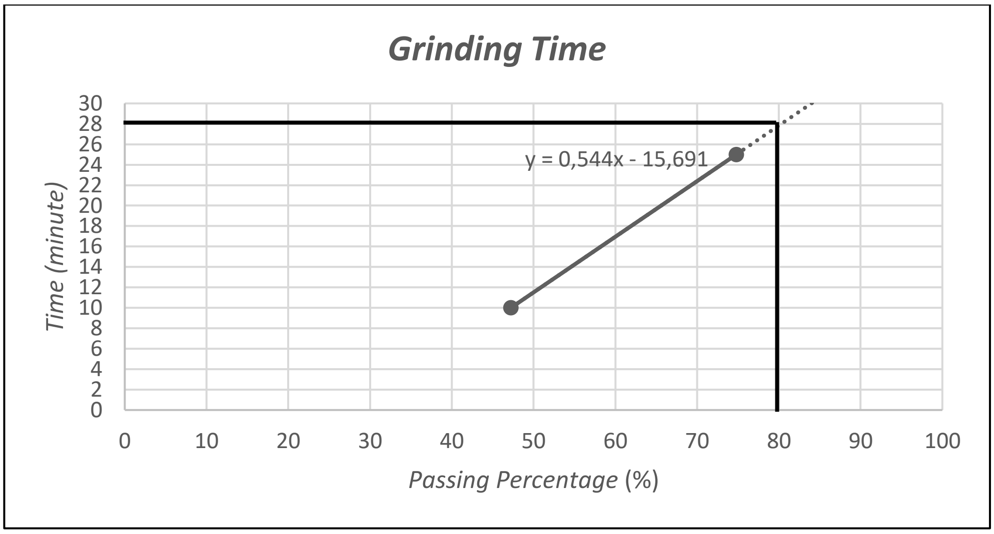


Figure 2 Linear Regression of Grinding Time Determination
*Source: obtained from primary data* (2022)

**2. Calculation of Reagent Consumption**

Calculation of reagent consumption is conducted to find out the amount of reagent required in a particular dose. In this gold ore flotation, several reagents are used, namely base-collector (PAX) and F83 as a comparison. Then for frother, MIBC is used as a base frother which will be compared with F515. Also used are dispersant D120, NaHS as a sulfidation reagent, and hydrated lime ($Ca(OH)_2$) as a pH modifier. Of the many reagents that were utilized, some of them are products of PT Florrea Indonesia.

The consumption of a reagent can be calculated from the dose

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added using the formula that can be seen in Equation 2 for reagents that have a solid form and Equation 3 for reagents that have a liquid form.

Especially for NaHS, the volume added to the flotation process depends on the eH value obtained, which is ≤-100 mV. If in the flotation process the eH observed was > -100 mV, then the addition of NaHS will be carried out until the minimum eH of NaHS can work optimally is obtained.

$$\mu L = \frac{Dosage \times Feed\ (ton)}{Strenght\ Reagent\ ({}^{gr}/_{\mu L})} \qquad (2)$$

$$\mu L = \frac{Dosage \times Feed\ (ton)}{Specific\ Gravity\ Reagent\ ({}^{gr}/_{\mu L})} \qquad (3)$$

## 3. Flotation and Dewatering

The flotation is conducted using a mechanical flotation machine equipped with oxygen injection, this process is conducted in 4 stages with details of stage 1 as a rougher followed by a scavenger of 3 stages, as shown in Figure 2. Cleaner is not carried out in this flotation because this process was more focused on mass recovery than metal recovery. Mass recovery can be used as a base or illustration of metal recovery, although a large mass recovery does not guarantee a high metal recovery.

The results of the grinding process will be flotated with the addition of water until a solid percent of 21% is obtained. In this process, the agitation speed utilized during flotation is 1002 rpm, because at this speed, there is no turbulence on the flotation surface, so the agitation is sufficient to circulate the particles in the cell without breaking the bubbles that have formed. If the agitation speed is too fast, it can result in a reduction in the percent recovery that will be obtained.

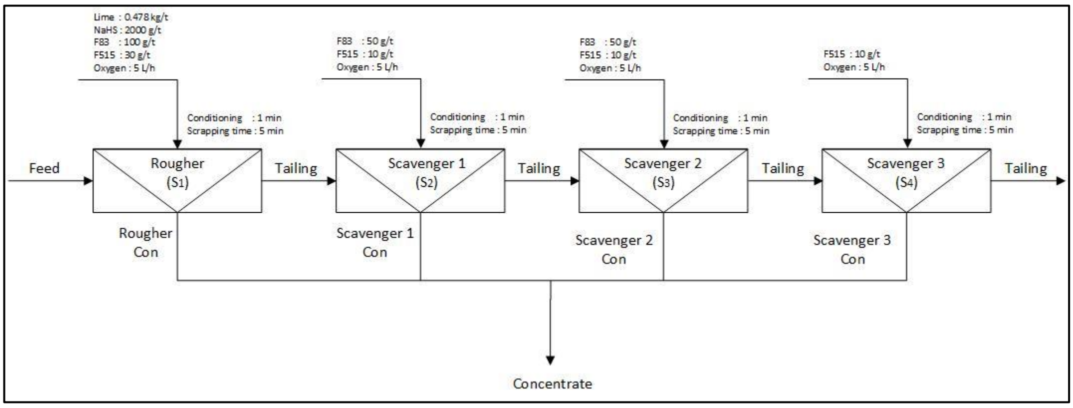


Figure 3 Flotation Test Flowchart
*Source: obtained from primary data* (2022)

In stage 1, the addition of lime for the pH regulator in the flotation process is carried out at the beginning of the stage until a pH ≥ 8 is obtained because flotation will run more optimally at an alkaline pH, which is around 8.5 - 9.5 for the rougher and scavenger which focuses on the amount of recovery obtained. Meanwhile, for the cleaner which focuses more on the high grade obtained, a pH of 10.5 - 12 is required. If there is a decrease in pH when flotation is in the next stage, then the addition of lime is necessary.

Then the addition of reagents is carried out in stages in the order of activator/modifier, collector, frother, with conditioning time for 1 minute at each addition. In this flotation, the reagents used are NaHS 2000 g/t as a sulfidation activator, F83 100 g/t as a collector, and F515 30 g/t as a frother, as can be seen in Figure 2. Oxygen is added to the flotation cell after frother conditioning. After the last conditioning, scrapping was carried out at a speed of 20 rpm for 5 minutes. Each addition of reagents is checked for pH, Eh, and temperature to determine the changes that occur in the flotation cell. The parameters of this flotation process can be seen in Table 1.

In stages 2 and 3, the reagents added are only collector and frother with doses of 50 g/t and 10 g/t respectively. In these three stages, it is necessary to ensure that the pH is maintained at ≥ 8, as well as the eH which needs to be maintained at less than -100 mV so that the flotation process can run optimally.

After obtaining the flotation concentrate at each stage, filtration is carried out with a vacuum filter. Filtration is done to separate the solid and solution in the flotation results so that the drying of the concentrate can take place quickly. Filter paper is placed on top of the vacuum device, then the filtration process is carried out. The results of this process are solid concentrate and tailings which will be put into the oven to go through the drying process. The results of this drying will be used to calculate the mass recovery from the flotation process.

## Results and Discussion

From the flotation test that has been carried out, the dry concentrate will be calculated so that the mass recovery is obtained at each stage. Based on Figure 4, it can be seen that the tendency of the material is taken at stage 1 (rougher) where there is an addition of NaHS at this stage, which is 4.22%. This gain is more when compared to the next stage with a difference of close to 4%. This shows that the addition of NaHS can increase the amount of mass recovery obtained.

Also can be seen in Figure 5, a comparison of reagent types for copper-gold ore flotation with the same dosage was conducted, where:

A: PAX (collector) + MIBC (frother)
B: F83 + F515
C: D120 (depressant)+ F83 + F515
D: NaHS + F83 + F515

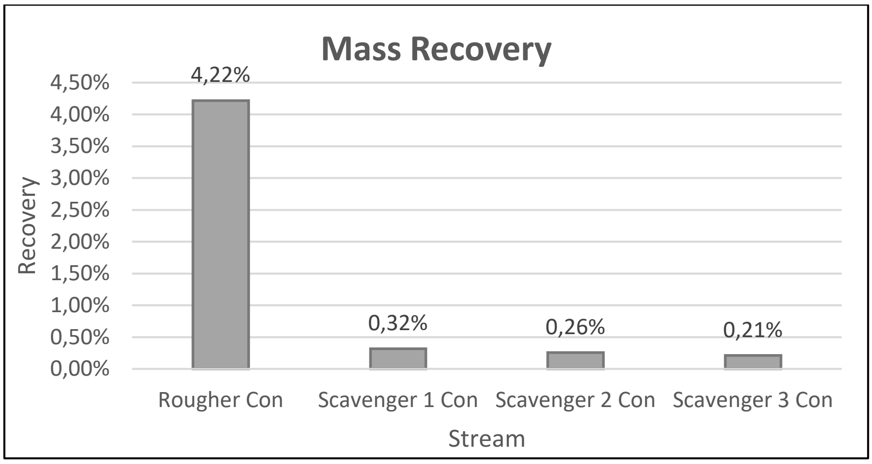


Figure 4 Mass Recovery of Gold Ore Flotation in Each Stream with Addition of NaHS
*Source: obtained from primary data* (2022)

It was shown in Figure 5, the highest cumulative recovery was obtained with the addition of NaHS. This shows that the addition of NaHS can increase the amount of mass recovery obtained. This is in accordance with research conducted (Aksoy & Yarar, 1989) that sulfate ions act as activators at low concentrations (<$10^{-5}$ mol/L), while at high concentrations (>$10^{5}$ mol/L), sulfate ions act as strong depressants.

In addition, other studies have shown that flotation gold concentrates contain higher concentrations of silver and sulfur than those remaining in the tailings. This indicates that these two elements can aid gold flotation. Laboratory flotation experiments on flotation tailings samples using NaHS and silver ions recovered 30 - 45% of the unflotated gold and NaHS gave the best results. This was applied at Los Pelambres Mine, Chile resulting in a 7% increase in gold recovery (Chryssoulis, 2001).

Instead of $Na_2S$-$9H_2O$, sodium hydrosulfide can be used to sulfide mineral oxides. Sodium hydrosulfide in solution is much less alkaline than $Na_2S$. Although the performance of NaHS does not match that of $Na_2S$, this reagent is used due to its low cost (Bulatovic, 2007). Another reason can be seen in the visual samples, both before and after flotation, which has a reddish colour when dried. However, the oxidation level of the samples is unknown due to the unavailability of tools to check this.

Based on the things that have been mentioned, it can be concluded that NaHS, F83, and F515 reagents are the right reagents to do the next test work. It only needs to be adjusted again (screening test) for dosage and conditioning time at each stage to get more optimal results, then an optimization test can be carried out to determine the optimum solid percent in this gold ore flotation test.

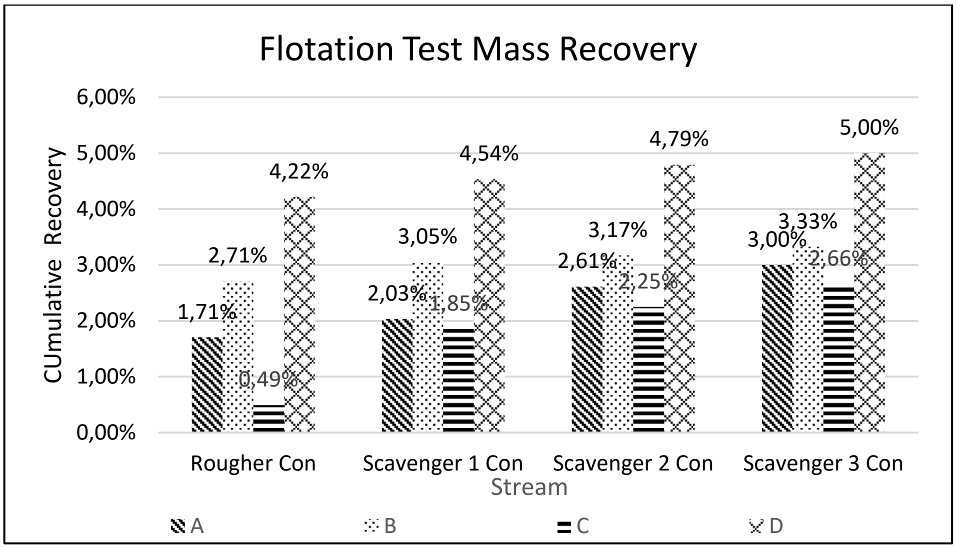


Figure 5 Flotation Test Mass Recovery
*Source: obtained from primary data* (2022)

## Conclusions

The conclusions obtained from the analysis that has been carried out are as follows.

1. Mass recovery obtained from the flotation process using reagents at each stage is 4.22%; 0.32%; 0.26%; and 0.21%, respectively, with a cumulative recovery of 5%.
2. In gold ore flotation with different reagents and the same parameters, the recovery obtained using Reagent D (NaHS + F83 + F515) reached 5%, higher when compared to other reagents which only reached 3% for reagent A, 3.33% for reagent B, and 2.66% for reagent C. This indicate that the gold ore used is oxidized ore because it can produce a large enough mass recovery when NaHS is added to the flotation process.

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