

Research to Determine the Appropriate Flotation Reagents for Zinc Oxide Ore Beneficiation: Case Study at Cho-Dien Mine, Vietnam

LUAN Van Pham¹, THANH-Hai Pham^{1,*}, NHU Quynh Thi Do^{2,3}, HA Viet Le¹

¹ Hanoi University of Mining and Geology, Hanoi, Vietnam

² Metallurgical - Mining Equipment and Consulting Technology Joint Stock Company, Hanoi, Vietnam

³ PhD student at Mining Faculty, Hanoi University of Mining and Geology, Hanoi, Vietnam

* Corresponding author: phamthanhhai@humg.edu.vn

Abstract: Cho-Dien zinc oxide ore is characterized by strong weathering. The ore has a content of 6 - 10% zinc content. Zinc occurs mainly in hemimorphite (calamine), smithsonite and chalcophanite. The rocks are mainly goethite, clay and quartz. However, no feasibility study has been conducted to treat this ore in practical production. This paper presents the effects of different types of flotation reagents (collectors, depressants, dispersers, etc.) on the beneficiation process of zinc oxide ore. From there, the suitable flotation reagents dosages and regimes were given. The research result shows the concentrate has a content of 20 - 25 % Zn at a recovery ratio of 55 - 60%. These preliminary results suggest that developing a technically and economically feasible beneficiation technology for Cho-Dien zinc oxide ore is possible.

Keywords: Zinc oxide ore; flotation; reagents; opened circuit flotation; closed circuit flotation

1. Introduction

Zinc is one of the most commonly used metals with high economic value (after iron, aluminum and copper) and is used in many industries. Metallic zinc is mainly used to produce alloys, galvanizing and batteries. It is an important additive in the rubber and paint industries. In particular, the demand for metallic zinc for solar and renewable energy technologies will increase sharply in the following years (International Lead and Zinc study group (ILZSG), 2020). Also, according to ILZSG, global refined zinc demand is forecast to decrease to 13.79 million tonnes in 2022 but will increase to 13.99 million tonnes in 2023. The shortage of zinc metal (in 2022 and 2023) is 297,000 tonnes and 150,000 tonnes, respectively.

In Vietnam, the demand for metallic zinc in the period 2020 - 2025 is about 160,000 to 200,000 tonnes/year. However, domestic zinc smelting plants can only meet about 12,000 tonnes/year. The output of zinc ingots (99.95% Zn) of the Thainguynen zinc electrolysis plant has only reached less than 12,000 tonnes/year, lower than the design of 15,000 tonnes/year. The plant does not have enough raw materials for production, because the raw sulfide ore is getting poorer and the exploitation has reached the final stage. The rich primary zinc oxide ore with a content of over 15% Zn has also been almost used up by factories. If there are no measures to use poor zinc oxide ore, the domestic raw material supply to the Thainguynen zinc electrolysis plant in Vietnam will be seriously lacking in the coming years. Meanwhile, zinc metal reserves in oxide ore in Vietnam are about 226,618 tonnes (Vietnamese Government, 1997). According to geological data, this ore is mainly concentrated in the Cho-Dien mine, Backan, Vietnam. The reserve of oxide ore with 5 - 10% Zn content of the Cho-Dien mine is about 873,220 tonnes (Tran, 2007). Therefore, Vietnam urgently requires an economically and technically feasible technological plan to recover this type of ore to provide fine ore for zinc oxide powder and electrolysis processing plants.

Flotation is the most common method for the beneficiation of zinc oxide ore. The selection of the type of flotation reagents and their regimen in the zinc oxide ore flotation process depends on the main zinc oxide mineral to be recovered and the accompanying rock minerals. Currently, many studies are using some of the options for the flotation of zinc oxide ore for efficiency. They are: (1) sulfidation with Na₂S followed by flotation with cation collector (such as amines) (Gharabaghi & Irannajad, 2014; Khaleghi et al., 2016; Mehdilo et al., 2012), (2) sulfidation with Na₂S and active with metal ions (such as Cu²⁺) followed by flotation with xanthate collector (Gharabaghi & Irannajad, 2014; Rao et al., 2003), (3) flotation with fatty acid collectors (Gharabaghi & Irannajad, 2014; Hosseini & Forssberg, 2006), (4) flotation with anion/cation collector mixtures such as xanthates with amines (Gharabaghi & Irannajad, 2014; Khaleghi et al., 2016;

Hosseini et al., 2007), (5) flotation with mercaptans or chelates collector (Gharabaghi & Irannajad, 2014; Hosseini & Forssberg, 2006; Hosseini & Forssberg, 2008; Marabini et al., 2007).

This article presents the result of the flotation of zinc oxide ore at Cho-Dien mine using fatty acid collector and kerosene; Na_2CO_3 as pH modification; Sep-X and Tan-XS and water glass as dispersants, Dextrin as depressant. The research aims to separate the minerals smithsonite and hemimorphite from the impure minerals goethite, hematite, quartz and illite.

2. Samples and method

2.1. Samples

2.1.1. Particle size distribution

Since the research sample is a strongly weathered ore containing a significant amount of clay, the wet sieve analysis method was used to determine the particle size distribution. The 50 kg sample was put into the sieve machine with aperture sizes 6, 3, 1, 0.2, 0.1, 0.04 and 0.02 mm. Each fraction size was analyzed chemically to define Zn content. The result is shown in Fig. 1.

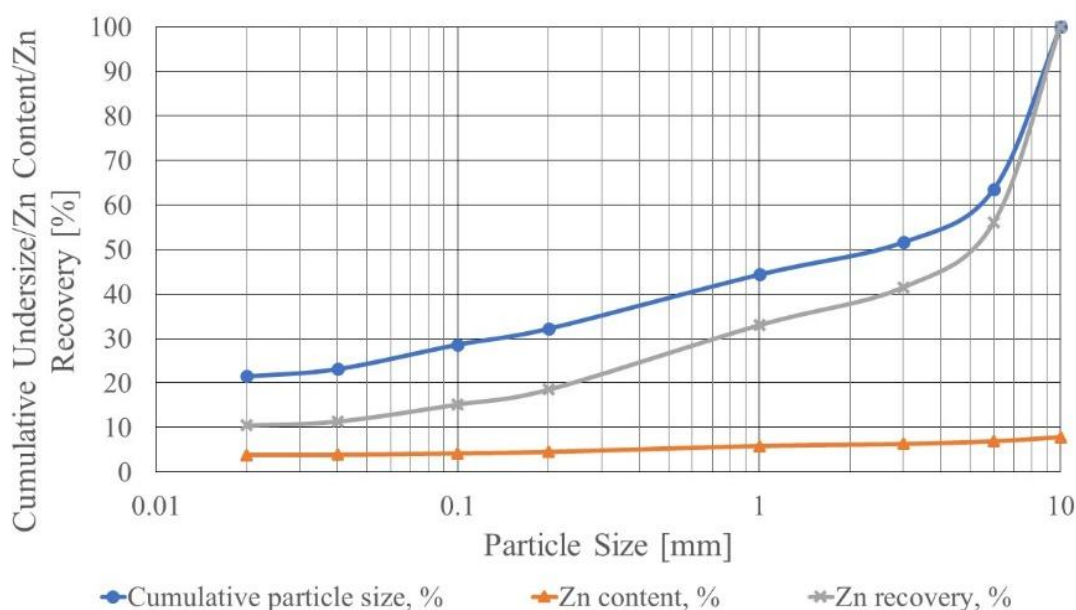


Fig. 1. Cumulative particle size distribution of Zn oxide ore

It can be seen that zinc is mainly concentrated at the size fraction + 0.2 mm with yield, content and recovery up to 67.78%, 9.34% Zn and 81.42%, respectively. The research sample contained 21.51% grain size -0.02 mm with 10.54% Zn recovery and 3.81% Zn content (the lowest among the grain sizes).

2.1.2. Mineralogy composition

The mineralogy composition of the sample was analysed using the X-ray Diffraction (D8 Advance equipment). The results are shown in Fig. 2.

The results indicate that zinc-containing minerals in the research sample include hemimorphite, chalcophanite and smithsonite. Gangues are goethite, magnetite, clay and quartz. Clay minerals are mainly concentrated at the grain sizes of 0.02 - 0.1 and - 0.02 mm. Iron oxide is distributed pretty evenly across grain sizes. The zinc oxide ore of Cho-Dien mine is difficult to process by flotation because of (1) the complex composition, (2) it contains a lot of slime and (3) cannot simultaneously recover hemimorphite (calamine), smithsonite and chalcophanite into concentrate products under the same processing conditions.

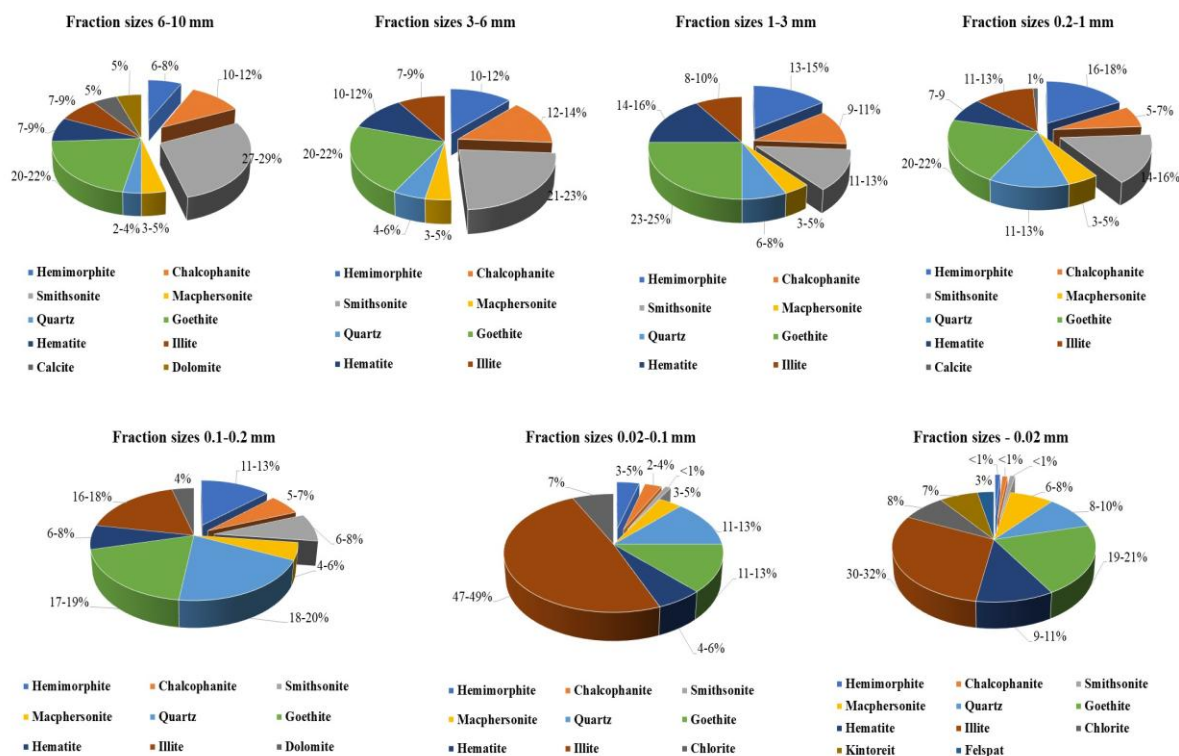


Fig. 2. Mineralogy composition and content of Cho-Dien zinc-oxide ore

2.2. Flotation reagents and laboratory experimental equipment

2.2.1. Flotation reagents

The reagents used in the study are shown in Tab. 1.

Tab. 1. The list of flotation reagents use for research

No	Chemical	Role	No	Chemical	Role
1	Armac C	Collector	7	Na ₂ S	Sulfidizing
2	Armac T	Collector	8	Na ₂ SiO ₃	Depressant
3	PAX	Collector	9	Dextrin	Depressant
4	Oleic acid	Collector	10	Sep-X	Dispersant
5	Hydroxamic acid	Collector	11	Tan-XS	Depressant
6	Kerosene	Collector	12	Na ₂ CO ₃	pH adjuster

2.2.2. Laboratory experimental equipment

Because the research sample contained a large amount of clay, the ore before upgrading was put through a clay removal system including a trommel screen and a mechanical classifier. Then the ore is crushed to 100% particles size below 0.1 mm to feed the mechanical flotation machine with a capacity of 3 liters and 1 liter. The images of the equipment are shown in Fig. 3.



Trommel screen and mechanical classifier



Flotation lab-exquipment

Fig. 3. Laboratory experimental equipment

2.2.3. Test procedure

The sample preparation diagram for the flotation process is shown in Fig. 4. After removing clay, the ore for the flotation process is obtained as shown in Tab. 2. After desliming, the feeding ore to the flotation process has a yield of 80.58%, a content of 8.86% Zn and a recovery of 91.88%.

Tab. 2. The quality of feeding ore for flotation test

Size fractions, mm	Yield, %	Zn content, %	Recovery, %
+ 0,02	80.58	8.86	91.88
Slime	19.42	3.25	8.12
Sum	100	7.77	100

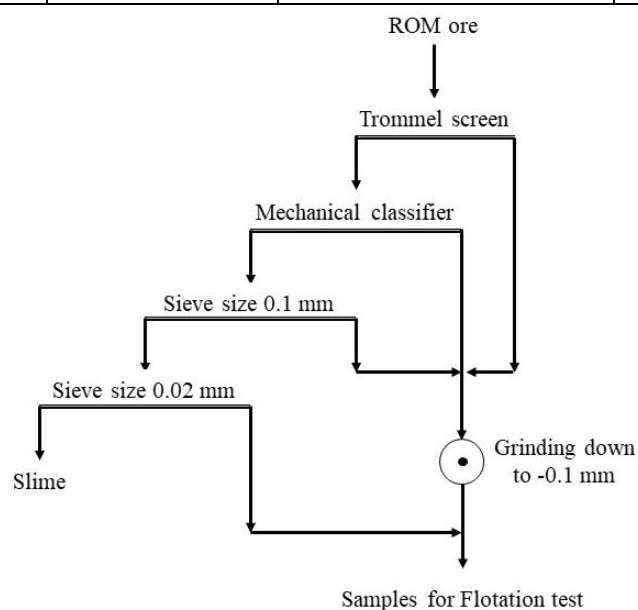


Fig. 4. Sample preparation for flotation test

3. Result and discussion

3.1. Results of condition experiments

Tests were conducted in order to determine the optimal flotation technology regimes such as solid phase concentration, types of reagents, reagent dosage, etc., to serve as a basis for open-circuit and closed-circuit flotation experiments. During the research, Armac C (Cocoamine acetate), Armac T (Tallowalkylamine acetate), PAX (Potassium Amyl Xanthate), oleic acid, hydroxamic acid and kerosene were used as the collectors. However, zinc oxide ore from the Cho-Dien mine does not float well in beneficiation conditions with amine, xanthate, fatty acids and amine - xanthate mixtures as suggested by many studies above. The ore had good flotation results using the collectors, which were a mixture of 80 % oleic acid - 20% hydroxamic acid and kerosene as the secondary collectors. Therefore, in this report, we focus on presenting the results of research on the beneficiation of zinc oxide ore using a mixture of fatty acid concentrates (80% oleic acid and 20% hydroxamic acid) with the addition of kerosene. Condition experiments were conducted once on a 3-liter flotation machine to determine the optimal flotation technology regimes. The results are shown in

In the flotation process, the dispersion of ore slurry plays a critical role in enhancing mineral separation efficiency. Numerous researchers have recommended the use of sodium hexametaphosphate as a dispersant due to its ability to break down particle agglomeration and improve mineral liberation (Gharabaghi & Irannajad, 2014; Navidi Kashani & Rashchi, 2008; Pereira & Peres, 2005; Peres et al., 1994). This chemical has been widely applied in various flotation systems, particularly for ores with complex mineral compositions. However, in the specific case of zinc oxide ore from the Cho-Dien mine, our experimental results indicate that Sep-X—a natural polymer blend containing approximately 50% tannin—is significantly more effective in dispersing the ore slurry. Sep-X not only enhances slurry stability but also improves the interaction between reagents and mineral surfaces, leading to better flotation outcomes. The ore samples from Cho-Dien are characterized by a high content of iron oxides, which tend to interfere with the flotation of zinc-bearing minerals. Traditionally, starch-based reagents have been used to depress iron oxides during flotation. While effective to some extent, starches often require precise dosing and may not perform consistently across different ore types. In contrast, our study found that Tan-XS—a bisulfite-based powder derived from Australian acacia trees, with tannin as its principal active component—offers superior depression of iron oxides. Tan-XS exhibits strong adsorption onto iron oxide surfaces, thereby reducing their floatability and allowing for cleaner separation of zinc minerals. Both Sep-X and Tan-XS were supplied by Bondtite Company, and their combined application in the flotation process has shown promising results in improving zinc recovery and concentrate purity. These findings suggest that natural polymer-based reagents may offer a sustainable and efficient alternative to conventional chemical dispersants and depressants in oxide ore flotation systems.

Tab. 3 and 4.

In the flotation process, the dispersion of ore slurry plays a critical role in enhancing mineral separation efficiency. Numerous researchers have recommended the use of sodium hexametaphosphate as a dispersant due to its ability to break down particle agglomeration and improve mineral liberation (Gharabaghi & Irannajad, 2014; Navidi Kashani & Rashchi, 2008; Pereira & Peres, 2005; Peres et al., 1994). This chemical has been widely applied in various flotation systems, particularly for ores with complex mineral compositions. However, in the specific case of zinc oxide ore from the Cho-Dien mine, our experimental results indicate that Sep-X—a natural polymer blend containing approximately 50% tannin—is significantly more effective in dispersing the ore slurry. Sep-X not only enhances slurry stability but also improves the interaction between reagents and mineral surfaces, leading to better flotation outcomes. The ore samples from Cho-Dien are characterized by a high content of iron oxides, which tend to interfere with the flotation of zinc-bearing minerals. Traditionally, starch-based reagents have been used to depress iron oxides during flotation. While effective to some extent, starches often require precise dosing and may not perform consistently across different ore types. In contrast, our study found that Tan-XS—a bisulfite-based powder derived from Australian acacia trees, with tannin as its principal active component—offers superior depression of iron oxides. Tan-XS exhibits strong adsorption onto iron oxide surfaces, thereby reducing their floatability and allowing for cleaner separation of zinc minerals. Both Sep-X and Tan-XS were supplied by Bondtite Company, and their combined application in the flotation process has shown promising results in improving zinc recovery and concentrate purity. These findings suggest that natural polymer-based reagents may offer a sustainable and efficient alternative to conventional chemical dispersants and depressants in oxide ore flotation systems.

Tab. 3. Optimal flotation technology regimes in condition experiments

Flotation regimes, unit	Value
Solid phase concentration, g/l	250
pH (using soda)	9 – 9.5
Water glass, g/t	500
Sep-X, g/t	1000
Tan-XS, g/t	1000
Collector, g/t	800
Kerosene, g/t	200

Tab. 4. Result of condition experiments at the optimal regimes

Products	Yield, %	Zn content, Zn %	Zn Recovery, %
Concentrate	46.58	16.44	86.43
Tailing	53.42	2.25	13.57
Sum	100	8.86	100

3.2. Open-circuit flotation experiments

The open-circuit flotation was researched to determine the number of cleaners and scavenger stages to obtain the concentrate with the required content and reduce the loss of valuable minerals in the tailings. During the experiment, it was found that the tailing from the rougher stage has lower zinc content than that in the slime, so it is not necessary to use the scavenger stage. However, the 02 stages of cleaner need to be tested to ensure obtaining concentrate with a zinc content of over 23%. At the same time, dextrin and other depressants must be added to the cleaner stages. The diagram and regimes of open-circuit flotation reagents are given in Fig. 5. The results of open-circuit flotation are given in Tab. 5. After 02 stages of cleaner, the concentrate has a content of 26.31% Zn at a recovery ratio of 63.01%.

Tab. 5. Result of open circuit flotation tests

Products	Yield, %	Zn content, %	Zn recovery ratio, %
Concentrate	21.22	26.31	63.01
Middling 1	16.55	7.77	14.51
Middling 2	8.38	11.37	10.75
Tailing	53.85	1.93	11.73
Sum	100	8.86	100

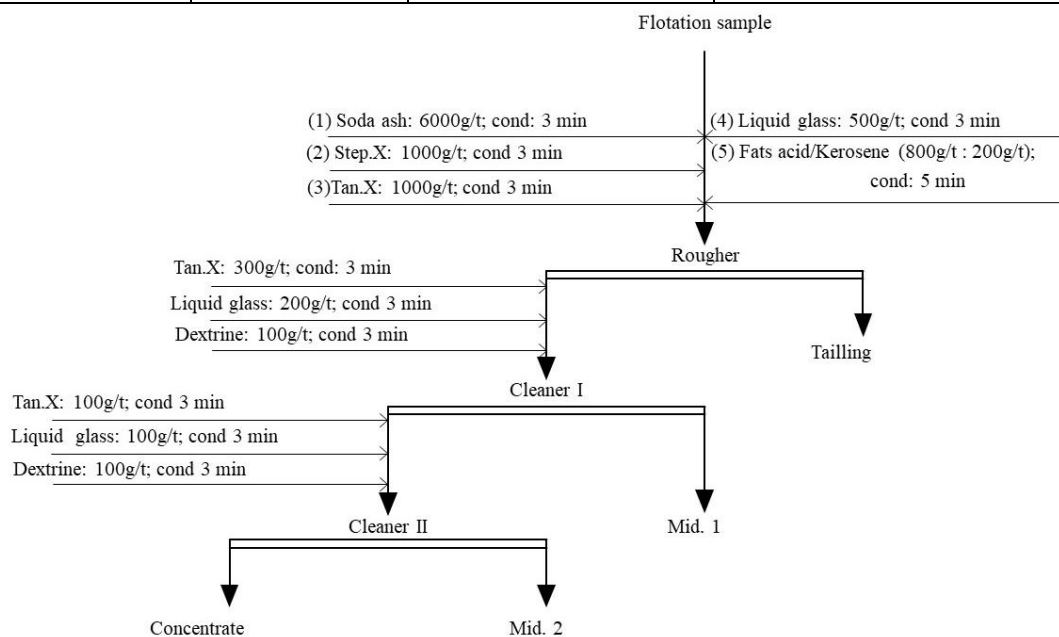


Fig. 5. Opened circuit of flotation test

3.3. Closed-circuit flotation experiments

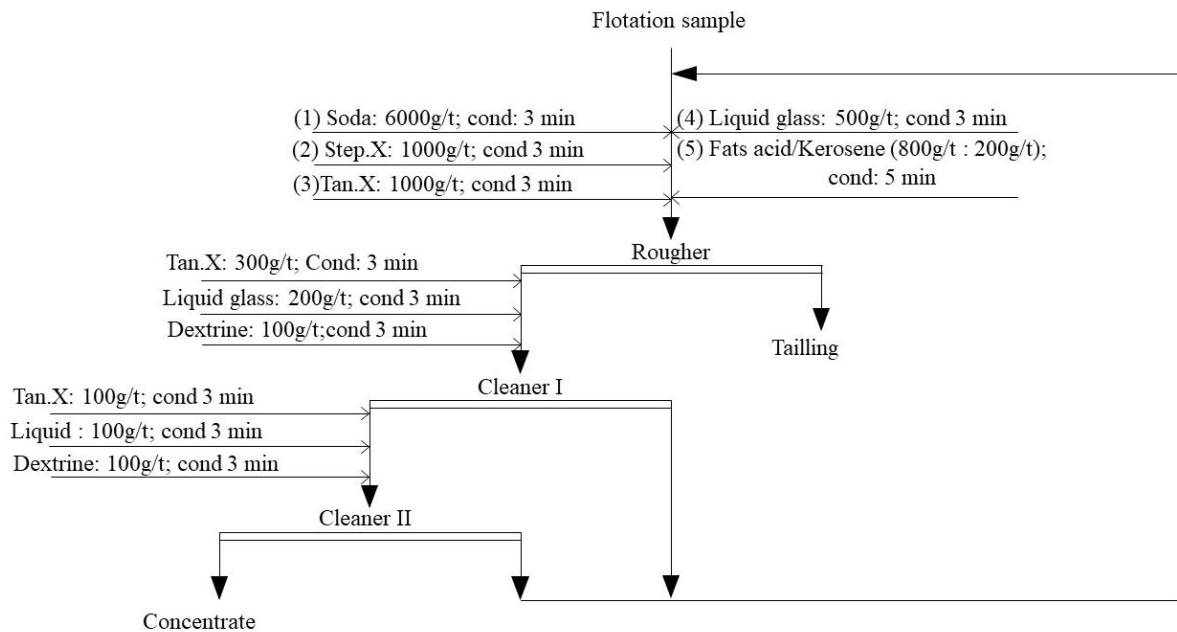


Fig. 6. Closed circuit flotation test

The closed-circuit flotation test was conducted to determine the optimal return point for the middling product within the flotation process. This experiment plays a crucial role in refining the circuit design to enhance recovery efficiency and concentrate quality. During the test, it was observed that the middling products exhibited a zinc content nearly equivalent to that of the run-of-mine (ROM) ore entering the rougher flotation stage. This finding indicated that the middling stream retained significant amounts of recoverable zinc, and therefore, the decision was made to redirect the middling products back to the rougher stage for reprocessing. This approach aimed to maximize zinc recovery while minimizing losses in the tailings. The schematic diagram and operational regime of the closed-circuit flotation process are illustrated in Fig. 6, while the detailed results, including mineralogical compositions of both concentrates and tailings, are presented in Table 6 and Fig. 7.

Following one rougher stage and two cleaner stages, a zinc concentrate was obtained with a Zn content of 24.11%, corresponding to a recovery rate of 58.9% based on the ROM ore. The tailings, however, still contained 4.16% Zn, with a recovery ratio of 32.98%, indicating a relatively high zinc loss. Mineralogical analysis revealed that the residual zinc in the tailings was predominantly in the form of chalcophanite—a mineral that exhibits poor floatability under the flotation conditions optimized for hemimorphite and smithsonite. The applied flotation regime successfully recovered hemimorphite and smithsonite into the concentrate, while gangue minerals were effectively separated into the tailings. Nevertheless, the concentrate also contained substantial amounts of goethite and quartz, and a portion of hemimorphite and smithsonite remained unrecovered. This incomplete recovery is attributed to insufficient liberation of these minerals during the grinding process, as they remained locked in intercrystalline structures. Such mineral associations hinder the flotation response and reduce overall process efficiency, suggesting that further optimization of grinding parameters may be necessary to improve liberation and enhance recovery outcomes..

Tab. 6. The result of closed circuit flotation test at the optimal regime

Products	Zn content, %	In fraction into the flotaion test		In ROM ore	
		Yield, %	Recovery ratio, %	Yield, %	Recovery ratio, %
Concentrate	24.11	23.56	64.11	18.98	58.9
Tailing	4.16	76.44	35.89	61.6	32.98
Sum	8.86	100	100	80.58	91.88

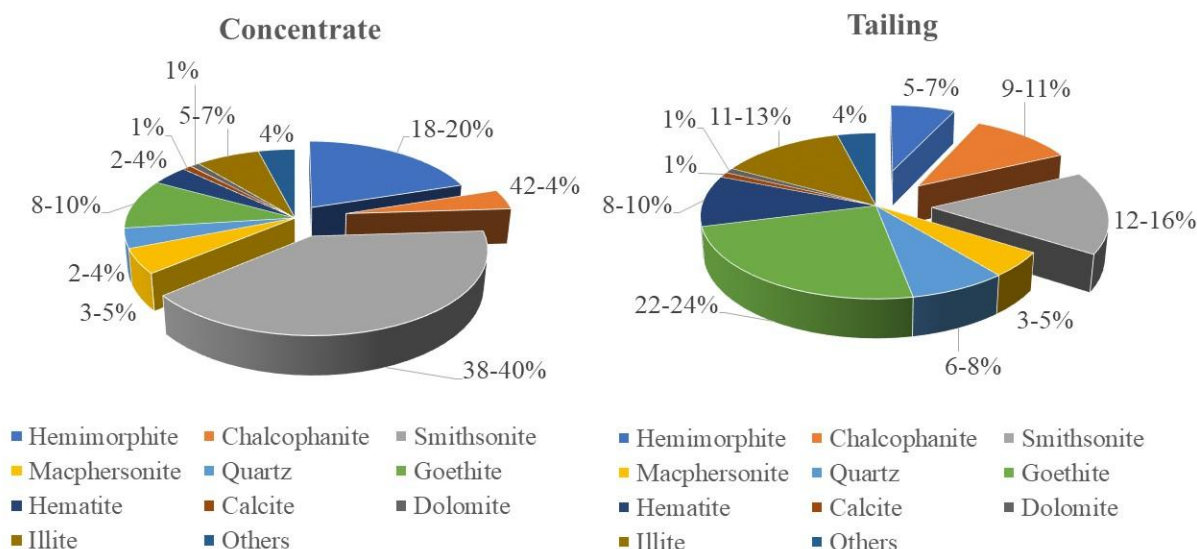


Fig. 7. Mineralogy composition of concentrate and tailing

4. Conclusion and outlook

The ROM ore is difficult to process using flotation due to its complex mineralogy composition, finely disseminated ore and a significant amount of clay. The gangues are goethite and illite, which are difficult to depress and disperse during the flotation. Zinc is concentrated mainly in three minerals: hemimorphite (calamine), smithsonite and chalcophanite. It is difficult to recover all three of these minerals in the same flotation regime. Up to now, there has been no publication on the flotation of chalcophanite minerals.

Using a combination of reagent mixture (80% oleic acid and 20% hydroxamic acid), combined with kerosene, can simultaneously recover both hemimorphite and smithsonite minerals into the concentrate. Tan-XS has demonstrated its depression role in the process, especially with goethite.

The above-studied reagent regimes have demonstrated the separation between zinc-containing minerals (hemimorphite and smithsonite) and gangue minerals (goethite, quartz, illite, etc.). The remaining challenge is to recover chalcophanite minerals into concentrate and completely depress the gangue.

In the above treatment regime, zinc-containing minerals have not been completely recovered into the concentrate. The concentrate is still mixed with many impurities, so the zinc content and recovery ratio only reach 24.11 %Zn and 58.9 %, respectively. The reason is that the valuable and gangue minerals have not been liberated completely after the grinding.

Although the preliminary research results are limited by low technological criteria, high reagent dosages, and the use of multiple reagents, the study provides valuable insights. This study is directional, evaluating the possibility of flotation of poor zinc oxide ore. Considering this aspect, the research has opened up the possibility of applying the flotation method to the beneficiation of zinc oxide ore.

In order to be able to put zinc-oxide ore from the Cho-Dien mine into actual production, additional research is needed, such as (1) reducing grinding fineness, (2) reducing dosages and types of reagents and (3) using flotation machines capable of treating fine and ultra-fine particles, etc., to increase flotation efficiency and reduce production costs.

Acknowledgement

The authors are thankful to the Cho-Dien mine (Backan province, Vietnam) for the sample supply as well as for the field trip procedure support.

References

- (ILZSG), I.L. (2020). The World Zinc Factbook 2020. Lisbon, Portugal: (ILZSG), International Lead and Zinc study group.
- Gharabaghi, M.; Irannajad, M. (2014). A review of zinc oxide mineral beneficiation using flotation method, . *Advances in Colloid and Interface Science*, 206, 68-78.
- Khaleghi, B.; Noaparast, M.; Shafaei, S.Z.; Bayat, S. (2016). Flotation Study of Oxide Zinc Ore using Cationic-Anionic Mixed Collectors. *Russian Journal of Non-Ferrous Metals*, 57(7), 647-658.

- Marabini, A.; Ciriachi, M.; Plescia, P.; Barbaro, M. (2007). Chelating reagents for flotation. *Minerals Engineering*, 20(10), 1014-1025.
- Mehdilo, A.; H., Z.; Irannajad, M.; Arjmandfar, H. (2012). Flotation of zinc oxide ores by cationic and mixed collectors. *Minerals Engineering*, 36(38), 331-334.
- Navidi Kashani, A.; Rashchi, F. (2008). Separation of oxidized zinc minerals from tailings: Influence of flotation reagents. *Minerals Engineering*, 21(12-14), 967-972.
- Pereira, C.; Peres, A. (2005). Reagents in calamine zinc ores flotation. *Minerals Engineering*, 18(2), 275-277.
- Peres, A.; Borges, A.; Galery, R. (1994). The effect of the dispersion degree on the floatability of an oxidized zinc ore. *Minerals Engineering*, 7(11), 1435-1439.
- Rao, S.; J.A.; F. (2003). Base metal oxide flotation using long chain xanthates. *International Journal of Mineral Processing*, 69(1-4), 251-258.
- S.H.; H.; E., F. (2006). Smithsonite flotation using potassium amyl xanthate and hexylmercaptan. *Mineral Processing and Extractive Metallurgy Transactions of the Institutions of Mining and Metallurgy: Section C*, 115(2).
- S.H., H., & E., F. (2008). Selective flotation of angorean oxidized zinc ore using mercaptans. 11th International Mineral Processing Symposia.
- S.H., H., & E., F. (2007). Physicochemical studies of smithsonite flotation using mixed anionic/cationic collector. *Minerals Engineering*, 20(6), 621-624.
- Tran, T.H. (2007). Research on zinc oxide ore processing technology (for under 10 percent of grade content) of Cho-Dien mine to serve the demand of zinc powder production (in Vietnamese). Hanoi: Vietnam Ministry of Industry and Trade project.
- Vietnamese Government. (1997). Decision No. 1997/QĐ-TTg of the Prime Minister: Approving the Planning for exploration, exploitation, processing and use of lead and zinc ores until 2020, with a vision to 2030 (in Vietnamese). Hanoi: Vietnamese Government.

