

Influence of Dissolved Ion Concentration on the Wettability and Flotation Behavior of Galena

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Çözünmüş İyon Konsantrasyonunun Galenin Islanabilirliği ve Flotasyon Davranışı Üzerindeki Etkisi

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Abstract

Dissolved species in process water can influence mineral flotation behavior by affecting mineral wettability and bubble-particle interactions. This study investigated the collective effect of dissolved ions in artificial process waters on the hydrophobicity and flotation response of galena from a complex sulphide ore. Artificial waters containing Na^+ , Ca^{2+} , Mg^{2+} , Pb^{2+} , Zn^{2+} , Cu^{2+} , Fe^{3+} , Cl^- , NO_3^- , CO_3^{2-} , and SO_4^{2-} were prepared at four concentration levels (APW1, APW3, APW5, and APW10), with the ion concentrations in APW1 increased three-, five-, and ten-fold to obtain the higher-concentration waters. Ore characterization, pH profile tests, dynamic contact-angle measurements, and batch flotation experiments were performed to evaluate the flotation behavior of galena to increasing ionic concentration. The galena ore exhibited a buffer pH of approximately 8. The initial contact angle increased from 39° in pure water to 54° in APW1 and reached 60° with 50 g/t potassium ethyl xanthate (KEX). However, further increases in ionic concentration progressively reduced galena hydrophobicity, both in the absence and presence of KEX. In flotation experiments, the galena recovery increased slightly from 79.1% in pure water to 82.0% in APW1, whereas further increases in APW concentration produced no substantial improvement in recovery or concentrate Pb grade. These results demonstrate that a moderate concentration of dissolved ions can enhance galena wettability and flotation behavior, whereas increasing the overall ionic concentration beyond this level does not provide an additional flotation benefit. The findings highlight the importance of controlling the overall ionic environment of flotation water when recycled or ion-rich waters are used in complex sulphide ore processing.

Öz

Minerallerin flotasyon davranışı, flotasyon suyunda bulunan çözünmüş iyonların mineral ıslanabilirliği ve kabarcık-tane etkileşimleri üzerindeki etkileri nedeniyle değişebilmektedir. Bu çalışmada, yapay flotasyon sularında bulunan çözünmüş iyonların karmaşık bir sülfürlü cevherdeki galenin hidrofobluğu ve flotasyon davranışı üzerindeki birleşik etkisi araştırılmıştır. Na^+ , Ca^{2+} , Mg^{2+} , Pb^{2+} , Zn^{2+} , Cu^{2+} , Fe^{3+} , Cl^- , NO_3^- , CO_3^{2-} ve SO_4^{2-} iyonlarını içeren yapay sular dört farklı konsantrasyon seviyesinde (APW1, APW3, APW5 ve APW10) hazırlanmıştır; daha yüksek konsantrasyonlu suların elde edilmesi için APW1'deki iyon konsantrasyonları sırasıyla üç, beş ve on kat artırılmıştır. Artan iyon konsantrasyonunun galenin davranışı üzerindeki etkisini değerlendirmek amacıyla cevher karakterizasyonu, pH profili deneyleri, dinamik temas açısı ölçümleri ve kesikli flotasyon deneyleri gerçekleştirilmiştir. Galen cevherinin yaklaşık 8 tampon pH değerine sahip olduğu belirlenmiştir. Saf suda 39° olan başlangıç temas açısı APW1 varlığında 54° 'ye yükselmiş ve 50 g/t potasyum etil ksantat (KEX) varlığında 60° 'ye ulaşmıştır. Bununla birlikte, iyon konsantrasyonunun daha fazla artırılması hem KEX yokluğunda hem de varlığında galenin hidrofobluğunu kademeli olarak azaltmıştır. Flotasyon deneylerinde galen kazanma verimi saf suda %79,1 iken APW1 varlığında hafif bir artışla %82,0'ye yükselmiş, ancak APW konsantrasyonunun daha fazla artırılması kazanma veriminde veya konsantre Pb tenöründe belirgin bir iyileşme sağlamamıştır. Bu sonuçlar, çözünmüş iyonların orta düzeydeki konsantrasyonlarının galenin ıslanabilirliğini ve flotasyon davranışını iyileştirebildiğini, ancak toplam iyon konsantrasyonunun belirli bir seviyenin üzerine çıkarılmasının flotasyon açısından ilave bir fayda sağlamadığını göstermektedir. Bulgular, karmaşık sülfürlü cevherlerin zenginleştirilmesinde geri dönüştürülmüş veya iyon bakımından zengin sular kullanıldığında, flotasyon suyunun genel iyonik ortamının kontrol edilmesinin önemini ortaya koymaktadır.

Keywords: Contact angle; Dissolved ions; Flotation; Galena; Flotation Water.

Anahtar Kelimeler: Temas açısı; Çözünmüş iyonlar; Flotasyon; Galen; Flotasyon suyu.

1. Introduction

Flotation is a widely used mineral beneficiation method for fine particle sizes (15-150 μm) that separates valuable minerals from non-valuable (gangue) minerals based on

differences in wettability (Farrokhpay *et al.*, 2021). The flotation conditions and surface properties of solids in flotation are controlled through flotation reagents. Chemicals called collectors make particles sufficiently

hydrophobic for flotation. Contact angle, the angle between solid-liquid and air-liquid interfaces, is the main indicator of mineral hydrophobicity (Gungoren *et al.*, 2024). In complex ores, depressants can inhibit the flotation of specific gangue minerals. Subsequently, air bubbles are introduced to the flotation pulp to collect the hydrophobic particles. These bubbles then form a froth zone loaded with hydrophobic minerals, which is obtained as a concentrate; meanwhile, hydrophilic particles remain in the flotation pulp. The need to process low-grade ores underscores the importance of optimizing flotation conditions in the mineral processing industry (Fuerstenau and Somasundaran, 2003; Rankin *et al.*, 2025; Wills, 2016).

The galena mineral (PbS) is the most common industrial source of lead and an important raw material for various industries, including electrical energy storage, construction, and petrochemistry (Collin *et al.*, 2022). In complex Pb-Zn sulphide ores, selective separation of galena from sulfide ores represents one of the key challenges in flotation. Because galena is naturally partly hydrophobic, it is usually floated using xanthates as a collector, while sphalerite particles are depressed. Zinc sulfate (ZnSO_4) is one of the most common depressants used for this purpose (Nowosielska *et al.*, 2023). Introducing Zn^{2+} ions results in the formation of soluble Zn-xanthate complexes in the flotation medium. Therefore, dissolved metal ions such as Pb^{2+} do not activate the sphalerite surface (Nowosielska *et al.*, 2024).

As a complex physicochemical process, flotation relies on a separation mechanism involving three distinct phases: water, minerals, and air. Due to this multi-phase nature, water, constituting roughly 80–85% of the total volume of the flotation pulp, plays a dominant role (Levay *et al.*, 2001). In mineral processing facilities, water required for flotation often cannot be supplied from freshwater sources because of climate and geographical conditions, water access costs, and environmental concerns. Therefore, studies are being carried out to reduce freshwater consumption by using alternative water sources such as bore water or recycled process water (Di Feo *et al.*, 2021; Luukkanen *et al.*, 2022; Nowosielska *et al.*, 2023).

However, these alternative water sources contain a variety of ions originating from the water source and dissolved from the ore being processed (Liu *et al.*, 2013). Since bubble-particle interactions in flotation occur in an aqueous medium, the ions in the composition of the process water can affect the flotation behavior of minerals depending on their type and concentration

through their influence on particles, bubbles, and their bilateral interactions. Particle hydrophobicity (Jung *et al.*, 2022), pulp stability (coagulation/dispersion of particles) (October *et al.*, 2021), zeta potential of bubbles and particles (Nowosielska *et al.*, 2023), bubble coalescence and bubble size (Dzingai *et al.*, 2020; Gungoren *et al.*, 2018; Manono *et al.*, 2013), froth height and stability (Manono *et al.*, 2013), bubble-particle attachment probability (October *et al.*, 2021), flotation rate (Dzingai *et al.*, 2020), hence, water and solids recovery (Corin *et al.*, 2011) are among the flotation parameters that are affected by the concentration and type of ions in the flotation water. However, the exact causes of these effects remain unclear (Muzenda, 2010). While the literature widely acknowledges the impact of single ions on flotation recovery, it is important to determine the combined effects and critical concentrations of common ions in the flotation process water (Bicak *et al.*, 2018; Mohamed Muse, 2024).

For the flotation of galena, the influence of the dissolved ions on the air/water interface and the surface chemistry of galena was previously explained by Gungoren *et al.* (2023) and Gungoren *et al.* (2025), respectively. Therefore, this study aimed to evaluate how increasing the overall ionic concentration of multi-ion artificial process waters affects the wettability and flotation behavior of galena from a complex sulphide ore. In this context, ore characterization studies, contact angle measurements, and batch flotation experiments were carried out using artificial process waters (APWs).

2. Materials and Methods

2.1 Materials

The chunk (~10 cm) and run-of-mine (crushed below 8 mm, $d_{50}=2.1$ mm, $d_{80}=5.7$ mm) galena samples obtained from a Pb-Zn mine in Balıkesir (Türkiye) were used for the contact angle and flotation experiments, respectively. According to the chemical analysis results of the sample (Table 1), the galena sample contained 4.65% PbO. Furthermore, the XRD spectrum of the sample (Figure 1) shows that, in addition to the main mineral of galena, the sample contains the minerals chalcopyrite, dolomite, quartz, and sphalerite.

To obtain galena samples for contact angle measurements, galena chunks were cut (Vommak, Türkiye) and mechanically polished using silicon carbide powders (DAP-3, Struers, Denmark)

The run-of-mine galena samples (-8 mm) were crushed below 2 mm using jaw (Denver, UK) and roller (Unal, Türkiye) crushers, then ground (Denver, UK) with steel

rods to obtain samples for the flotation experiments. To prevent oxidation, the samples were stored in airtight bags.

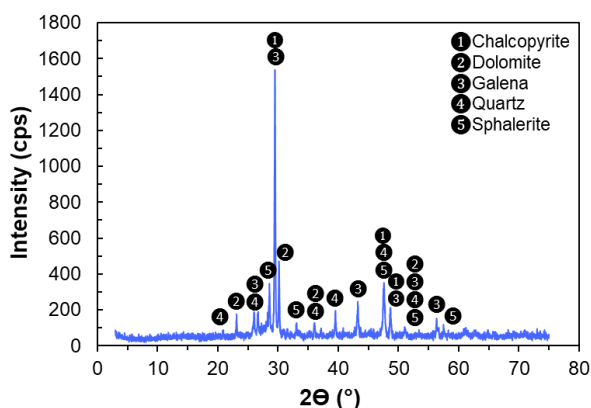


Figure 1. XRD spectrum of the galena sample.

Flotation experiments were carried out with the flotation reagents that are also used in the industrial flotation of galena from which the samples were taken. Potassium ethyl xanthate (KEX) (99.9% $\text{CH}_3\text{CH}_2\text{OCS}_2\text{K}$, Tekkim, Türkiye) and butyl glycol (BG) (96.0% $\text{C}_4\text{H}_9\text{OCH}_2\text{CH}_2\text{OH}$, Sigma-Aldrich, USA) were used as a collector and a

frother, respectively. Meanwhile, technical-grade zinc sulfate (ZnSO_4) and iron sulfate (FeSO_4) were directly supplied from the relevant mineral processing plant to depress sphalerite. The medium pH level was adjusted with HCl (37% purity, Merck, USA) and NaOH ($\geq 97\%$ purity, Merck, USA) when necessary.

In the preparation of artificial process waters (APWs), metal cations present in industrial waters and complex lead-zinc ores were considered, and different salts of these metals were used to provide anion diversity. APWs were prepared using pure water (0–3 ppm total dissolved solids) and high-purity ($\geq 98\%$) salts of NaCl, CaCO_3 , MgSO_4 , PbNO_3 , ZnCl_2 , CuCl_2 , and $\text{Fe}(\text{NO}_3)_3$ (Tekkim, Türkiye). The concentrations of Na^+ , Ca^{2+} , and Mg^{2+} cations in APW1, which has the minimum ion concentration, were determined as 153, 80, and 70 ppm, respectively, in line with the relevant literature (October *et al.*, 2021). Meanwhile, the concentrations of Pb^{2+} , Zn^{2+} , Cu^{2+} , and Fe^{3+} cations were set at 1 ppm. The ion concentrations in APW1 were increased by 3, 5, and 10 times, respectively, to form APW3, APW5, and APW10.

Table 1. Chemical analysis of the galena sample.

PbO (%)	ZnO (%)	CaO (%)	SiO ₂ (%)	Fe ₂ O ₃ (%)	Al ₂ O ₃ (%)	MgO (%)	CuO (%)	K ₂ O (%)	S (%)	LOI* (%)
4.65	8.73	44.00	9.00	8.10	2.30	1.20	0.42	0.80	9.87	10.00

*LOI: Loss-on-ignition

2.2 pH profile experiments

To characterize the sample, the pH profile of the sample was determined in pure water and APWs separately. 0.1 mol/dm³ HCl and NaOH solutions were used to adjust the pH level; then the galena sample (particle size $\sim 38 \mu\text{m}$) was added to the solution to obtain a suspension with a 1% (w/w) solids ratio. Finally, the suspension was stirred at ~ 500 rpm using a magnetic stirrer (IKA, Topolino, Germany), and the pH level was measured (Orion 3 Star, Thermo Scientific, USA) for 60 min.

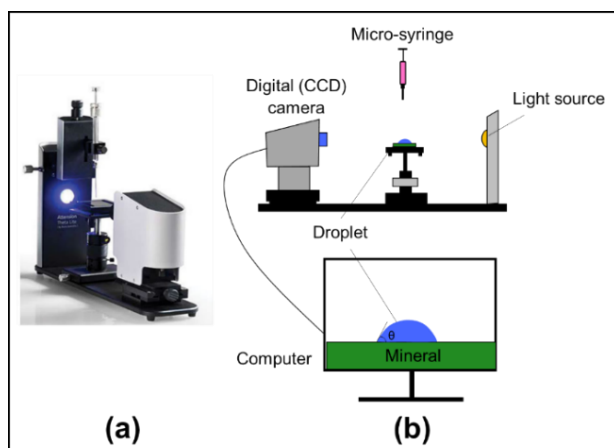


Figure 2. (a) Optical goniometer and (b) experimental setup.

2.3 Contact angle measurements

The contact angle was measured using an optical goniometer (Biolin Scientific, Attension Theta Lite, Sweden). For each measurement, a solution drop was formed on the polished galena surface using a glass micro-syringe. The drop image was recorded via the device's digital (CCD) camera (Figure 2). The device software then automatically defines the contact angle by fitting the Young-Laplace equation around the droplet.

2.4 Flotation experiments

Flotation experiments were carried out with galena particles below $75 \mu\text{m}$ using a mechanical laboratory flotation machine with a 1 dm³ volume (D-12, Denver, UK) at a 10 dm³/min air flow rate (Figure 3). In the experiments, the depressant concentrations at the facility where the sample was taken were used (6 ppm BG, 1500 g/t ZnSO_4 , and 600 g/t FeSO_4).

The effects of solids ratio, collector, and APW concentration were investigated in the experiments. After the flotation process, the flotation products were dried and weighed. Representative samples were taken from each product and ground to $<38 \mu\text{m}$ using an

automated agate mortar (RM 200, Retsch, Germany) for inductively coupled plasma optical emission spectroscopy (ICP-OES) analysis.

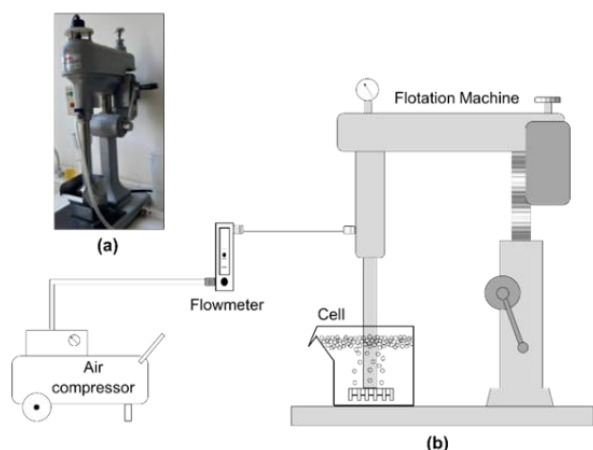


Figure 3. (a) Mechanical flotation device and (b) experimental setup.

The pH of the flotation pulp was adjusted between 10 and 11 to depress sphalerite in the study. FeSO_4 and ZnSO_4 hinder sphalerite flotation by substituting the activating metal ions, which reduces their mechanical entrainment (Cao and Liu, 2006; El-Shall *et al.*, 2000). ZnSO_4 also hydrolyzes in alkaline conditions to form Zn(OH)_2 and $[\text{Zn(OH)}]^+$. Zn^{2+} and $[\text{Zn(OH)}]^+$ adsorb more readily onto the sphalerite surface than onto galena. Zn(OH)_2 reacts with OH^- at high pH levels to form hydrophilic compounds such as HZnO_2^- and ZnO_2^{2-} . These colloidal hydrophilic compounds precipitate on the sphalerite surface and significantly reduce its floatability (Zhang *et al.*, 2023). Therefore, selective Pb flotation is usually carried out under highly alkaline conditions (pH 8.5–11) to depress the sphalerite (Nayak *et al.*, 2021).

Slime-sized particles are generally removed before flotation to increase separation recovery and concentrate grade. These particles coat the surfaces of target particles, preventing collector adsorption, increasing collector consumption due to their high surface area, and being easily entrained (Yu *et al.*, 2017). However, because the complex Pb-Zn ores, such as the ore used in this study, are liberated at fine sizes, the slime was not removed before flotation in this study to avoid recovery loss (Nowosielska *et al.*, 2024; Wei *et al.*, 2021).

3. Results and Discussions

3.1 Flotation experiments

Figures 4a and 4b show the pH profile of the galena ore sample, respectively, in the absence and presence of APW.

As shown in Figure 4a, the natural pH of the galena ore suspension was found to be 7.88. In measurements

starting from acidic pH values, the galena ore suspension pH tended to reach a buffer pH of ~ 8 . This is because the sample has a basic structure due to its high carbonate content (44% CaO) and the low solubility of the calcite mineral ($4.8 \times 10^{-9} \text{ mol/dm}^3$ at 25°C), which limits the amount of cations dissolved from the solid particles (Frear and Johnston, 1929). Meanwhile, Figure 4b shows that the pH value of the galena suspension decreased slightly below the natural pH value (7.88) in the presence of APW. pH levels did not change significantly with time. This is because the chemicals used to prepare APW solutions, which release various acidic and basic dissolution products, largely neutralize each other.

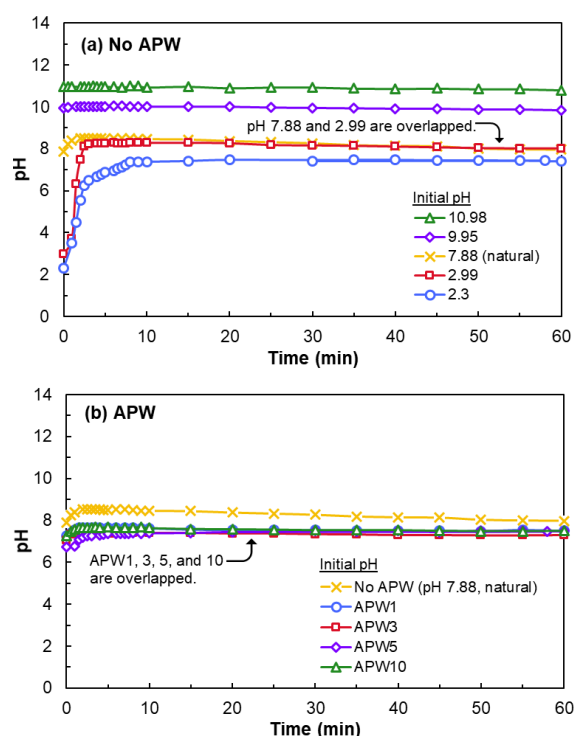


Figure 4. pH profile of the galena ore sample in the (a) absence and (b) presence of APW.

3.2 Contact angle measurements

Figure 5 shows the dynamic contact angle measurement results of galena mineral at various KEX concentrations (0–100 g/t).

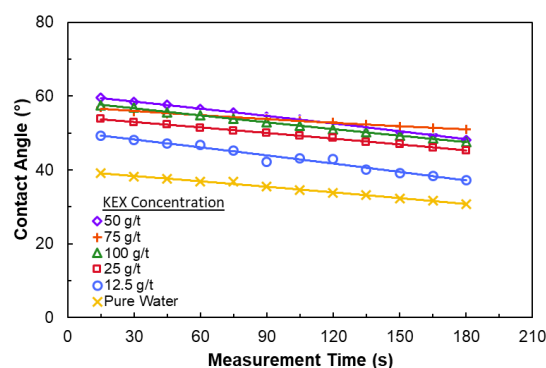


Figure 5. Dynamic contact angle of galena at various KEX concentrations.

Figure 5 indicates that the contact angle of galena decreased linearly with the measurement time due to the evaporation of the formed drop. At the 180th second, the decrease in the contact angle was between 8 and 12°. Furthermore, the initial contact angle of galena, which was 39°, increased with KEX concentration up to 50 g/t KEX concentration in parallel with the increase in hydrophobicity, and the maximum contact angle of 60° was obtained at this KEX concentration. However, further increases in KEX concentration resulted in a slight decrease in contact angle because KEX molecules adsorbed in double layers on the galena surface. Furthermore, the contact angle measurement results are consistent with the literature (Gungoren *et al.*, 2020; Janczuk *et al.*, 1997).

The dynamic contact angle of galena at various APW concentrations (APW1-APW10) is shown in Figure 6.

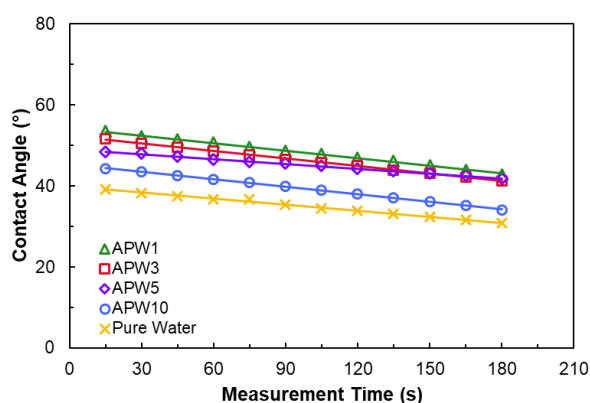


Figure 6. Dynamic contact angle of galena at various APW concentrations.

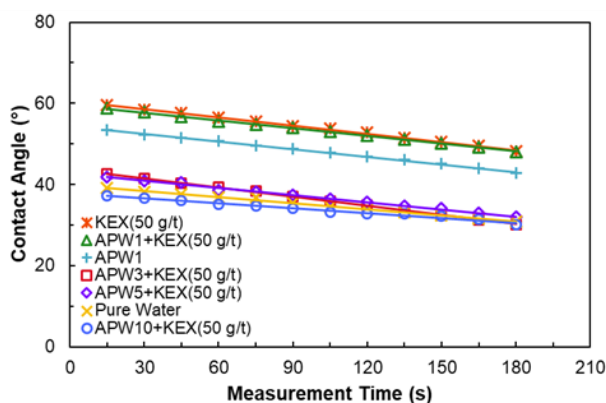


Figure 7. Dynamic contact angle of galena at various APW concentrations in the presence of KEX (50 g/t).

Figure 6 shows that the initial contact angle of galena increased from 39° to 54° in the presence of APW1. Therefore, it can be concluded that the hydrophobicity of galena in the absence of a collector can be moderately increased based on the ion concentration and type. However, excessive ion use caused a decrease in the contact angle of galena, and an initial contact angle of 44°

was obtained in the presence of APW10. Even in this case, the contact angles were higher than in pure water.

In Figure 7, the dynamic contact angle of galena at various APW concentrations in the presence of KEX (50 g/t) is given. The contact angle of galena, which was 54° at APW1 in the absence of KEX, increased to 60° with the addition of 50 g/t KEX. This contact angle value was also obtained at 50 g/t KEX, which indicates that ions have no significant effect on the galena's contact angle at APW1 and 50 g/t KEX. However, even in the presence of KEX, galena's contact angle decreased to the values obtained in the presence of pure water (~40°) with increasing APW concentration.

3.3 Flotation experiments

Figure 8 shows galena flotation results as a function of KEX concentration. Figure 8 shows that flotation recovery increased with increasing KEX concentration due to the increased hydrophobicity of galena. The recovery, which was 2.3% at 10 g/t KEX, reached 66.0% at 100 g/t KEX. Although the increase in KEX concentration increased the flotation recovery, the concentrate Pb grade was negatively affected due to the flotation of gangue minerals at high collector concentrations. Therefore, further experiments were carried out at 100 g/t KEX.

As shown in Figure 9, the flotation recovery increased with the solids ratio. However, due to the decrease in the concentrate Pb grade at a 35% solids ratio, the subsequent experiments were carried out at a 25% solids ratio, where 79.7% flotation recovery and 22.9% Pb grade were obtained.

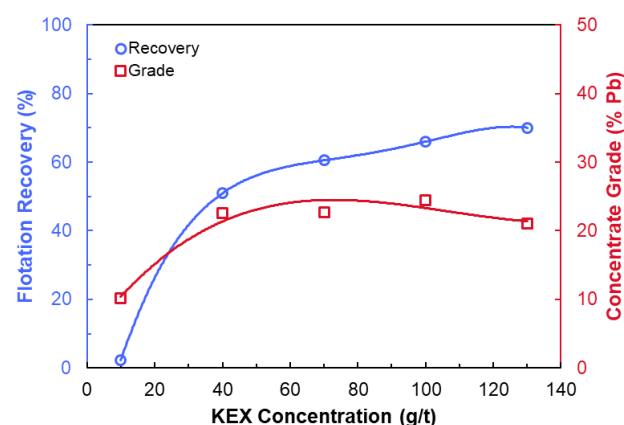


Figure 8. Galena flotation recovery and concentrate grade with respect to KEX concentration at 25% solids ratio.

Based on the data obtained, flotation tests were performed using APWs. The effect of APW concentration on galena flotation is shown in Figure 10. As shown in Figure 10, the flotation recovery, which was 79.1% in the presence of pure water, reached a plateau, increasing to 82.0% in the presence of APW1. Meanwhile, APW

concentration did not significantly affect concentrate grade.

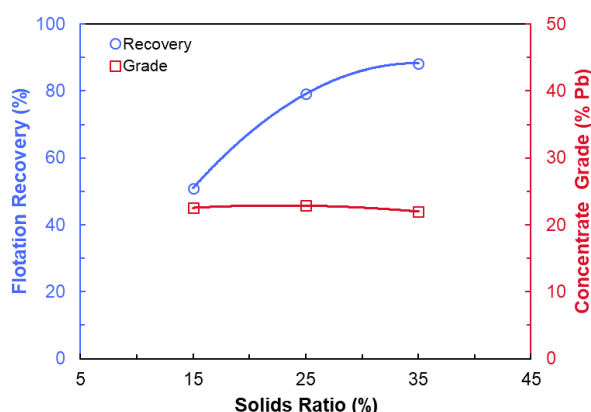


Figure 9. Flotation results of galena as a function of solids ratio.

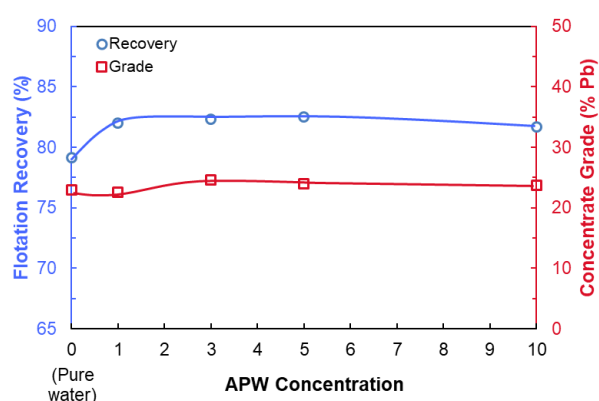


Figure 10. Flotation results with respect to APW concentration.

According to the literature, the positive flotation results in the presence of ions can be attributed to the effects of ions such as disrupting the hydration layer around the particles, delaying bubble coalescence, increasing the flotation rate, reducing the time required for bubble-particle attachment, and affecting the zeta potential of the particle and bubble (Nowosielska *et al.*, 2023). Meanwhile, Bicak *et al.* (2018) attributed the increase in flotation recovery to a more stable froth in the presence of ions. October *et al.* (2021) reported that bubble-particle attachment can increase with increasing ion concentration, which may result from compression of the electrical double layer and particle aggregation. Nowosielska *et al.* (2024) found that increasing NaCl concentration in the solution positively affected Pb and Zn recoveries.

However, as noted by Dzingai *et al.* (2020), there may be a threshold value regarding the effect of ion concentration on flotation. In other words, while flotation efficiency is positively affected by the presence of ions up to a certain concentration, increasing ion concentration can negatively affect flotation. The results of Nowosielska *et al.* (2023) showed that higher galena and sphalerite

recoveries were achieved in the presence of salt (NaCl) solutions. However, the presence of dissolved ions (Ca^{2+} and Mg^{2+}) significantly reduced the recovery of galena and sphalerite. The presence of ions may negatively affect collector adsorption (Jung *et al.*, 2022). Dzingai *et al.* (2020) indicated that ions may negatively affect flotation recoveries by shifting surface charge.

The present experimental design evaluates the collective effect of increasing ionic concentration rather than the contribution of individual ions. Since the concentrations of all ions were simultaneously increased from APW1 to APW10, the observed changes in galena hydrophobicity and flotation response cannot be attributed to a specific cation or anion. Accordingly, mechanisms such as electrical double-layer compression, modification of surface hydration, changes in bubble coalescence, and interference with collector adsorption should be regarded as possible explanations supported by previous studies rather than mechanisms directly demonstrated by the present experiments. Therefore, future studies involving single-ion tests and systematically designed multi-ion experiments are needed to distinguish the individual and synergistic or antagonistic contributions of dissolved species to galena flotation.

4. Conclusions

This study investigated the influence of ions commonly present in the flotation of lead-zinc complex ores using contact angle measurements and batch flotation experiments on galena.

The key findings from this study are listed below:

- (1) The buffer pH of galena ore was approximately pH 8, except for high alkaline initial pH values (>10).
- (2) Galena's contact angle, which was 39° in the absence of any chemical, increased to 54° and 60° with APW1 and 50 g/t KEX, respectively.
- (3) Ions can moderately increase the hydrophobicity of galena in the absence of a collector.
- (4) In the presence of both KEX and APW, the dominant chemical was KEX.
- (5) The excessive use of KEX or ions significantly reduced the hydrophobicity of galena in both single and dual KEX/APW systems.
- (6) The presence of the lowest-concentration artificial process water (APW1) slightly increased galena recovery from 79.1% to 82.0%; however, further increases in the overall ionic concentration provided no substantial

improvement in either flotation recovery or concentrate Pb grade.

Declaration of Ethical Standards

This study is derived from doctorate thesis (thesis number: 858625) under the supervision of Prof. Dr. Ilgin KURSUN and co-supervision of Prof. Dr. Orhan OZDEMIR by Saleban MOHAMED MUSE on date of February 22, 2024 titled "Investigation of the Effects of Water Quality in Flotation on Froth Stability and Bubble-Particle Interaction"

The authors declare that they comply with all ethical standards.

Credit Authorship Contribution Statement

Author-1: Investigation, Writing-original draft, Visualization

Author-2: Writing-original draft, Writing-review & editing, Visualization

Author-3: Investigation, Writing-review & editing

Author-4: Investigation

Author-5: Conceptualization, Methodology, Supervision

Author-6: Conceptualization, Methodology, Supervision, Project administration, Funding acquisition

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The authors declare that the main data supporting the findings of this work are available within the article.

Datasets are available on request. The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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5. References

- Bicak, O., Ozturk, Y., Ozdemir, E. and Ekmekci, Z., 2018. Modelling effects of dissolved ions in process water on flotation performance. *Minerals Engineering* 128, 84-91.
<https://doi.org/10.1016/j.mineng.2018.08.031>
- Cao, M. and Liu, Q., 2006. Reexamining the functions of zinc sulfate as a selective depressant in differential sulfide flotation—the role of coagulation. *Journal of Colloid and Interface Science* 301(2), 523-531.
<https://doi.org/10.1016/j.jcis.2006.05.036>
- Collin, S., Baskar, A., Geevarghese, D.M., Ali, M.N.V.S., Bahubali, P., Choudhary, R., Lvov, V., Tovar, G.I., Senatov, F., Koppala, S. and Swamiappan, S., 2022. Bioaccumulation of lead (Pb) and its effects in plants: a review. *Journal of Hazardous Materials Letters* 3, 100064.
<https://doi.org/10.1016/j.hazl.2022.100064>
- Corin, K.C., Reddy, A., Miya, L., Wiese, J.G. and Harris, P.J., 2011. The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the Merensky reef. *Minerals Engineering* 24(2), 131-137.
<https://doi.org/10.1016/j.mineng.2010.10.015>
- Di Feo, A., Hill-Svehla, C.M., Hart, B.R., Volchek, K., Morin, L. and Demers, A., 2021. The effects of water recycling on flotation at a North American concentrator. *Minerals Engineering* 170, 107037.
<https://doi.org/10.1016/j.mineng.2021.107037>
- Dzingai, M., Manono, M. and Corin, K., 2020. Simulating the effect of water recirculation on flotation through ion-spiking: effect of Ca²⁺ and Mg²⁺. *Minerals* 10(11), 1033.
<https://doi.org/10.3390/min10111033>
- El-Shall, H.E., Elgillani, D.A. and Abdel-Khalek, N.A., 2000. Role of zinc sulfate in depression of lead-activated sphalerite. *International Journal of Mineral Processing* 58, 67-75.
[https://doi.org/10.1016/S0301-7516\(99\)00055-1](https://doi.org/10.1016/S0301-7516(99)00055-1)
- Farrokhpay, S., Filippov, L. and Fornasiero, D., 2021. Flotation of fine particles: a review. *Mineral Processing and Extractive Metallurgy Review* 42(7), 473-483.
<https://doi.org/10.1080/08827508.2020.1793140>
- Frear, G.L. and Johnston, J., 1929. The solubility of calcium carbonate (calcite) in certain aqueous solutions at 25°. *Journal of the American Chemical Society* 51(7), 2082-2093.
<https://doi.org/10.1021/ja01382a014>
- Fuerstenau, M.C. and Somasundaran, P., 2003. Flotation. Principles of Mineral Processing. Fuerstenau, M.C. and Han, K.N., Littleton, CO,
- Gungoren, C., Baktarhan, Y., Demir, I. and Ozkan, S.G., 2020. Enhancement of galena-potassium ethyl xanthate flotation system by low power ultrasound. *Transactions of Nonferrous Metals Society of China* 30(4), 1102-1110.
[https://doi.org/10.1016/s1003-6326\(20\)65281-5](https://doi.org/10.1016/s1003-6326(20)65281-5)
- Gungoren, C., Islek, E., Kursun Unver, I. and Ozdemir, O., 2018. A novel technique to investigate the bubble coalescence in the presence of surfactant (MIBC) and electrolytes (NaCl and CaCl₂). *Physicochemical Problems of Mineral Processing* 54(4), 1215-1222.
<https://doi.org/10.5277/ppmp18158>
- Gungoren, C., Kursun Unver, I. and Ozdemir, O., 2024. Introduction to mineral research. Advances in Minerals Research. Ikhmayies, S.J., Switzerland, 1-23.
- Gungoren, C., Muse, S.M., Terzi, M., Eskibalci, M.F., Kursun, I. and Ozdemir, O., 2025. Understanding the collective effect of dissolved ions on the surface chemistry of galena flotation. *Journal of the Minerals, Metals and Materials Society* 77(10), 7713-7723.
<https://doi.org/10.1007/s11837-025-07579-6>
- Gungoren, C., Muse, S.M., Terzi, M., Eskibalci, M.F., Kursun Unver, I. and Ozdemir, O., 2023. Synergistic effect of frequently found ions in the flotation of Pb-

- Zn sulfide ores on air/water interface. *Minerals* 13(10), 1236.
<https://doi.org/10.3390/min13101236>
- Janczuk, B., Zdziennicka, A. and Wojcik, W., 1997. Influence of ethyl xanthate on the wettability and surface free energy of galena. *Applied Surface Science* 120(1-2), 35-42.
[https://doi.org/10.1016/S0169-4332\(97\)00220-1](https://doi.org/10.1016/S0169-4332(97)00220-1)
- Jung, M., Tadesse, B., Dick, C., Logan, A., Dyer, L. and Albijanic, B., 2022. Influence of monovalent and divalent cations on monazite flotation. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 653, 129975.
<https://doi.org/10.1016/j.colsurfa.2022.129975>
- Levay, G., Smart, R.S.C. and Skinner, W.M., 2001. The impact of water quality on flotation performance. *The Journal of The South African Institute of Mining and Metallurgy* 101(2), 69-75.
- Liu, W., Moran, C.J. and Vink, S., 2013. A review of the effect of water quality on flotation. *Minerals Engineering* 53, 91-100.
<https://doi.org/10.1016/j.mineng.2013.07.011>
- Luukkanen, S., Tanhua, A., Zhang, Z., Mollehuara Canales, R. and Auranen, I., 2022. Towards waterless operations from mine to mill. *Minerals Engineering* 187, 107793.
<https://doi.org/10.1016/j.mineng.2022.107793>
- Manono, M.S., Corin, K.C. and Wiese, J.G., 2013. The effect of ionic strength of plant water on foam stability: a 2-phase flotation study. *Minerals Engineering* 40, 42-47.
<https://doi.org/10.1016/j.mineng.2012.09.009>
- Mohamed Muse, S., 2024. Investigation of the effects of water quality in flotation on froth stability and bubble-particle interaction (in Turkish: Flotasyonda su kalitesinin köpük stabilitesi ve kabarcık-tane etkileşimi üzerindeki etkilerinin incelenmesi), Ph.D. Thesis, Istanbul University-Cerrahpasa Graduate Studies Institute, Istanbul, 78.
- Muzenda, E., 2010. An investigation into the effect of water quality on flotation performance. *World Academy of Science, Engineering and Technology* 69, 237-241.
- Nayak, A., Jena, M.S. and Mandre, N.R., 2021. Beneficiation of lead-zinc ores – a review. *Mineral Processing and Extractive Metallurgy Review* 43(5), 564-583.
<https://doi.org/10.1080/08827508.2021.1903459>
- Nowosielska, A.M., Nikoloski, A.N. and Parsons, D.F., 2023. The effects of saline water on the recovery of lead and zinc sulfide during froth flotation. *Minerals Engineering* 202, 108236.
<https://doi.org/10.1016/j.mineng.2023.108236>
- Nowosielska, A.N., Nikoloski, A.N. and Parsons, D.F., 2024. Selective flotation of galena and sphalerite from a Pb/Zn complex sulfide ore using saline water: the effects of xanthate and pine oil addition. *Mineral Processing and Extractive Metallurgy Review* 47(1), 1-22.
<https://doi.org/10.1080/08827508.2024.2432669>
- October, L.L., Manono, M.S., Wiese, J.G., Schreithofer, N. and Corin, K.C., 2021. Fundamental and flotation techniques assessing the effect of water quality on bubble-particle attachment of chalcopyrite and galena. *Minerals Engineering* 167, 106880.
<https://doi.org/10.1016/j.mineng.2021.106880>
- October, L.L., Manono, M.S., Wiese, J.G., Schreithofer, N. and Corin, K.C., 2021. Fundamental and flotation techniques assessing the effect of water quality on bubble-particle attachment of chalcopyrite and galena. *Minerals Engineering*, 167, 106880.
<https://doi.org/10.1016/j.mineng.2021.106880>
- Rankin, P., Di Feo, A. and Kelebek, S., 2025. Ionic strength of flotation medium and consequential effects. *Minerals Engineering* 220, 109048.
<https://doi.org/10.1016/j.mineng.2024.109048>
- Wei, Q., Dong, L., Qin, W., Jiao, F., Qi, Z., Feng, C., Sun, D., Wang, L. and Xiao, S., 2021. Efficient flotation recovery of lead and zinc from refractory lead-zinc ores under low alkaline conditions. *Geochemistry* 81(4), 125769.
<https://doi.org/10.1016/j.chemer.2021.125769>
- Wills, B.A., 2016. Wills' mineral processing technology, an Introduction to the practical aspects of ore treatment and mineral recovery. Amsterdam,
- Yu, Y., Ma, L., Cao, M. and Liu, Q., 2017. Slime coatings in froth flotation: A review. *Minerals Engineering* 114, 26-36.
<https://doi.org/10.1016/j.mineng.2017.09.002>
- Zhang, F., Sun, W., Zhang, H., Chen, D., Li, S., Chen, J. and Zhang, C., 2023. Selective adsorption mechanism of zinc ions on the surfaces of galena and sphalerite in the flotation separation of Pb-Zn. *The Journal of The Minerals, Metals & Materials Society (TMS)* 75(11), 4808-4818.
<https://doi.org/10.1007/s11837-023-06098-6>