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Cost-Effective Extraction of Zinc, Aluminium, and Lead from their Lamprophyre Dyke's Mineralization, South-West Mersa Alam, Egypt Somia T. Mohamed¹, Abeer A. Emam¹, Wael M. Fathy², Amr B. ElDeeb^{*2}

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The Lamprophyric Dykes cut cataclastic rocks in NNW-SSE trends via share zones. The recorded minerals are mostly Zn-Mn oxide, an extract of the element Franklinite ZnFe₂O₄. Zinc and manganese oxide minerals are represented essentially by franklinite and woodruffite. The current study aims at the extraction of valuable metals including Al, Zn and Pb from lamprophyric Dykes using cost-effective technology. The parameters affecting the extraction of Al, Zn and Pb from the used sample include the concentration of reagent, leaching time and temperature, and solid/ liquid ratio have been investigated. The kinetics and the mechanism of the leaching process was also studied. It has been noted that under the optimum leaching conditions, the leaching efficiencies for Al, Pb and Zn were 98.67%, 98.98% and 99.98%, respectively. Thermodynamic analysis has also been studied and the activation energies for leaching the different metal ions were 16.189, 19.66 and 15.867 kJ/mol for Pb, Al and Zn, respectively.

Keywords: Alkaline leaching, Hydrometallurgy, Zinc, Aluminium, Lead, Leaching Kinetics.

1. Introduction

Zinc sulphide ores, which account for the vast majority of zinc metal production. Hemimorphite $(Zn_4(Si_2O_7)(OH).H_2O)$, Willemite (Zn_2SiO_4) , and smithsonite $(ZnCO_3)$ is considered as promising zinc sources due to the rapid depletion of zinc sulphide ores. The concentration of zinc oxide ores is always accomplished using flotation or gravity, resulting in low metal recovery but significant operational expenses. Zinc oxide ores can be processed easily using acidic leaching. The acidic leaching leads to the dissolution of Zinc in addition to many iron, calcium, magnesium, and silicate minerals. With these conditions, the use of acid produced necessitates the employment of time-consuming and complex separation processes [1-8]. Due to the high concentration of silica in the slurry, the slurry may gel and interfere with the separation of zinc sulphate during the separation process. It is also noted that it is not viable to treat low-grade zinc oxide ores (25-30% Zn) with acidic leaching processes. The pyrometallurgical technique is also used as a method of treating zinc oxide but it is not preferred due to environmental pollution. Recently, The Organic acids have also been used as effective leach reagents, which is a first component for the industry. The treatment of low-grade zinc oxide ores with alkaline solutions has been investigated [9-14].

It has been demonstrated that Zn and Pb are reduced in oxidized zinc ore. An alkaline treatment for oxidized zinc ores has been the subject of only a few previous investigations [15, 16]. The leaching of zinc oxide ore using alkaline leaching has been the subject of few scientific studies. Alkaline media are preferable to acidic media. The maximum percent recovery of zinc oxide ore under ideal alkaline leaching conditions was obtained at 5% NaOH, 90-95°C, 90 min. [17]. The zinc oxide ore containing 5.2% ZnO was leached with ammonium sulfate, and 92.2% of the zinc was recovered. It has been noted that more than 73 % ZnO can be recovered from zinc oxide ore having 65–76 μ m particle size at 120 minutes at 85°C, using 5 mol/L NaOH solution and at 1: 10 (S: L) solid: liquid ratio [18]. The main advantage of alkaline leaching is that it prevents iron dissolution or the formation of silica gel. Although this method can dissolve the hemimorphite mineral, it is not capable of precipitating it. Due to the formation of zine ions because of the following reaction, hot concentrated caustic soda dissolves in the presence of zinc oxide or hydroxide [19-21].

Hydrometallurgical procedures provide more selectivity, as well as cheaper reagent and reagent costs, hence these technologies have been proposed as alternative technologies instead of high temperature processes in leaching of lead. To obtain high lead solubilities, powerful acids and/or chloride ions at near boiling temperatures are used this process namely formalized [21, 22]. PbS may be recovered from lead sulphide ores by melting it with caustic soda at a weight-ratio range from 0.18–1.8. NaOH and PbS were blended. An aqueous solution of NaOH was prepared and the PbS powder was added to it (7–10 % of the total weight of the mixture). After heating the paste between 20 and 200°C, the paste was allowed to cool completely before being used (20 min.). For determining the melting temperature of this product, it was heated to approximately 500° C for 40 minutes and then cooled to room temperature. After allowing the paste to cool down to room

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temperature, it leached in hot water [22]. A single oxidation state of Al exists in solution, and that is in the state I. It begins to precipitate when the pH is approximately equal to 4. pH greater than 9 and this causes the formation of the soluble tetrahydro aluminate anion with fluoride, oxalate, tartrate, and EDTA, aluminium forms stable compounds. However, it has a weaker precipitate with acetate. Al can be precipitated from metals containing hydroxides by adding ammonia or an acetate buffer to bring the pH of the solution to 4.5–5.0 and aluminum is then extracted from the extruder matrix.

The caustic solution loses its active component as the concentration of tetrahydroxo aluminate increases. The amount of this leftover substance that is produced in Europe each year is estimated to be about 14,000 cubic metres [23, 24]. To make the anodizing mud, a little amount of the alkaline waste stream from the anodizing stage is combined with the acid waste stream from the anodizing phase. A large amount of solid aluminium hydroxide anodizing residues is produced by this method, which results in continual loss of aluminium and sodium hydroxide. Removing aluminium from the environment and repurposing it to be environmentally and economically sustainable are both imperative. When it comes to the wastewater treatment of the anodizing industries, aluminum recovery and caustic soda reuse are commonplace. After a short period of time, Al(OH)₃ precipitates, causing the concentration of sodium hydroxide in the solution to increase. After reacting with Na(aq), the tetra alkyl ammonium salt is formed as Al(OH)₄. An aqueous solution of Na⁺_(aq) combined with Al₂O_{3(s)} yields an aqueous solution of OH_(aq). Using the caustic regeneration approach, aluminum could be recovered from wastewater etching effluent that did not contain any aluminum complexing chemicals [25-32].

The lamprophyre dykes are discontinuous and act as chemical and physical traps for polymineralization. SW of Mersa Alam port mineralization is mainly associated with basic lamprophyre dykes intruded in some shear zones that are cutting through cataclastic quartzo-feldspathic rocks (gneisses and granites). Several alterations and mineralization processes have occurred in this area. While the altered and mineralized lamprophyre dykes give the highest aeroradiometric anomalies in the Eastern Desert, they are associated with several metal values in a manner that they appear to have acted as chemical traps for polymineralization. Besides silicification, argillization, carbonatization and several reduction and oxidation processes, the Na-K metasomatism was found to be quite important. The latter is primarily accompanied by Zn, REEs, U, and Sn in shear zones, and Nb, Ta, Th, Ga, Zn, and U in cataclastic rocks. The Zn and Mn minerals are also accompanied by ferrugination minerals. REEs, Zn, and V, U, and Cu may be found as adsorbed on iron oxide and clay minerals in the wall zones of some Dykes [33-38]. Several minerals have been identified besides cassiterite, zircon and allanite, namely, uranium minerals niobium and tantalum minerals represented by columbite, betafite and fergusonite. The heavy rare earths xenotime mineral. Zinc and manganese oxide minerals are represented essentially by franklinite and woodruffite [35]. Uranium as well as other useful elements such as zinc, lead, and aluminium have been successfully recovered from a sample of 50 kg of this lamprophyre dyke. In this study, the best results were obtained with a sulfuric acid concentration of 100 g/L, 1: 5 S: L, and 15 days of soaking at 25°C. The leaching efficiency for recovery of uranium and other elements such as aluminum, zinc, and lead were 40%, 33.6%, 98.8%, and 78%, respectively.

The aim of the current study is to determine how valuable metals such as zinc, lead, and alumina are extracted from the SW of Mersa Alam port lamprophyre dykes, which are in Egypt's southeastern region via alkaline leaching that does not result in iron dissolution or the formation of silica gel. Another goal of this research is to determine the most effective factors influencing metal extraction and enrichment in general and study the reaction controlling rates.

2. Materials and Methods

2.1. Materials characterization

A representative sample from the technological sample that had been collected adequately prepared for a comprehensive chemical analysis in addition to the tenor of the economic metal values that had been collected. The major oxides content was determined using the quick silicate analytical approach developed by [38]. The elements Zn and pb were investigated using the atomic absorption technique, which was carried out on a Unicam instrument model 969 auto gas box.

2.2. Procedures for the Leaching Process

The leaching efficiency of Zn, Al and Pb was investigated using alkaline agitation leaching technique under a variety of various settings. In each experiment, the crushed ore sample fraction was mixed with the alkaline solution of the known concentration at specific (S: L) ratio. The pulp was agitated for a predetermined period at a predetermined temperature before discharging and filtration. Each leaching experiment produced a slurry that was then filtered and washed. The filtrate and washings were then combined to make up the total volume of the leaching solution. Correct aliquots of the latter were then examined for Zn, Al and Pb that had been leached to calculate their respective leaching efficiencies. The applicable leaching factors studied include the alkali concentration, leaching time, the pulp temperature, and the solid/liquid ratio. Studying these factors would result in the proper selection of the optimum conditions, i.e., those which compromise between the efficiency of the leaching process and economic considerations.

2.3. Recovery Procedures

To obtain highly pure Zn, Al and Pb concentrates, it was found advantageous of using alkaline compounds in leaching process to avoid iron dissolution or the formation of silica gel. For precipitation procedures have been performed; namely bulk hydroxides precipitation of Zn, Pb and Al at pH 7-8. Then, the mixed precipitate is subjected to relatively severe treatment with sulfuric acid to selectively separate the interested metal value Al. followed by separating Zn and Pb via conventional techniques.

3. Results and Discussion

3.1. Chemical composition

The used sample in the current study was obtained from a mineralized basic Lamprophyre Dyke, South-West Mersa Alam, Egypt. The wall zone of the latter is composed mainly from a quartzo-feldspathic rock. Tables 1 and 2 show the chemical composition of a lamprophyre dyke sample which shows that it contains 19% Al₂O₃, 1.6% Zn, 0.23% Pb and 1.24 % ∑ REE presented in the sample. It is clear that there is a relatively high concentrations of SiO_2 , Al_2O_3 , and Fe_2O_3 that enhances the application of alkaline leaching technology. The investigation of several variables is essential to achieve the best potential recovery of the targeted elements. When evaluating the various variables that could be involved, it is vital to consider the following: the concentration of alkali solution, leaching temperature and time and (S: L) ratio.

Major oxides	Wt. %	Major oxides	Wt. %
SiO ₂	44.91	MgO	0.95
Al ₂ O ₃	19.00	Na ₂ O	1.00
TiO ₂	2.95	K_2O	1.98
MnO	1.48	P_2O_5	0.77
Fe ₂ O ₃	15.4 8	L.O.I.	8.12
CaO	2.03	Total%	98.60

Table 2: (Chemical anal	vsis of the	trace and r	are earth e	elements of l	Lamprop	hvre sam	ples

Trace element	ррт	Trace element	ррт
Ba	315	Cr	80
V	345	Sr	40
Ni	211	Ga	17
Cu	512	Cd	100
Zn	16211	Zr	200
Rb	333	Th	15
Y	1678	U	700
Pb	2300	REEs	12435

3.2. Factors affecting the Leaching of SW of Mersa Alam port Ore Material

3.2.1. Effect of Alkaline concentration

The effect of alkaline solution concentration was studied in the range between 80 and 240 g/L NaOH, while the other factors remain constant at -200 mesh size ore particle size, 3h leaching time, 70°C leaching temperature, and 1:2 S: L ratio. The obtained leaching efficiencies of Zn, Al and Pb are shown in Fig. 1.



Fig. 1. Effect of alkali solution concentration on the leaching efficiency of the studied metal ions.

The obtained results indicate that Zn is relatively more easily leached than both Al and Pb. The leaching efficiency of Zn increases from 20.50% to 54.10% when the concentration of the alkali solution increases from 80 - 240 g/L, respectively, whereas the Al reached only 24.69% and 42.30% at the same concentrations, respectively. The recovery of Pb significantly increased when the NaOH concentration was increased from 80 and 240 g/L, respectively, resulting in 12.95% and 41.20% leaching efficiency. Thus, 240 g/L solution concentration is considered as the optimum leaching concentration and recommended for the subsequent experiments.

Egypt. J. Chem. 68, No. 8 (2025)

S. T. Mohamed et.al.

3.2.2. Effect of leaching time

The influence of leaching time on the leaching efficiency of Zn, Al and Pb was investigated in the time range from 2 to 4 h. All leaching experiment were carried out while the other leaching conditions were constant at 240 g/L NaOH solution concentration, 200 mesh ore size, at 70° C, and a 1: 2 S: L ratio. Extending the leaching duration to 4 h at 240 g/L alkali was able to practically leach nearly the same quantity of lead and aluminum, 68.90% for the Pb and 72.33% for the Al, although the Zn leaching efficiency was extended to 91.56%, according to the leaching efficiencies as shown in Fig. 2. It is clear that the leaching efficiencies of all the targeted elements are increased continuously with increasing the leaching time from 2 up to 4 h and the maximum leaching efficiencies of all elements were obtained at 4 h. Hence, the leaching time of 4hr has been selected as the optimum leaching time and recommended for the subsequential leaching experiments.



Fig. 2. Effect of leaching time on the leaching efficiency of the studied metal ions.

3.2.3. Effect of leaching temperature

The effect of the leaching temperature up on the leaching efficiencies of Zn, Al and Pb has been investigated over a wide range of temperature ranging from room temperature (25° C) to 90°C. Additionally, all the other leaching conditions were constant for all experiments to be material with a mesh size of -200, 240 g/L NaOH solution concentration, 4 hr. leaching time, and 1/2 S: L ratio. Fig. 3 shows that the leaching temperature has a significant effect on the alkaline leaching efficiencies of the targeted Zn, Al and Pb elements. It is clear that the temperature is required to produce satisfactory leaching efficiencies of the interesting elements. At 25°C, the results show that only 29.61% Al, 39.46% Pb and 63.15% were successfully leached. When the leaching temperature increases to 50°C, the leaching efficiencies enhances by a percentage of 52.78% for Pb, 31.77% for Al, and 74.27% for Zn. It is clear that the effectiveness of leaching the interesting elements like Pb is improved by increasing the leaching temperature to 70°C and 90°C, in which the leaching efficiency increases from 68.90% to 86.18%, respectively. On the other hand, the leaching efficiency of Al increases from 72.33% and 79.73% respectively. On other hand, Zn leaching efficiencies increases to 91.56% and 99.98%, respectively. It can be concluded that the leaching time is important and critical for Zn leaching and on the other hand, the leaching temperature is more critical for leaching the other elements.



Fig. 3. Effect of leaching temperature on the leaching efficiency of the studied metal ions.

3.2.4. Effect of S/l ratio

The preliminary study showed that the solid: liquid ratio between 1/2 and 1/5 has a significant effect on the leaching efficiency of Zn, Al and Pb. The effect of solid: liquid has been investigated at constant conditions of -200 mesh size of raw material, 240 g/L NaOH solution concentration, for 4 hr. and at 90°C. Figure 4 shows that with increasing the S: L, the percent recovery for all the targeted elements is increases gradually up to 1/4 S: L ratio and after this it nearly the same.



Fig. 4. Effect of S : L ratio on the leaching efficiency of the studied metal ions.

It is shown that Zn has only achieved complete leaching at S: L ratios of 1/2. The leaching efficiency of both Pb and Al also reached complete leaching at S: L of 1/4. Hence, for the effective leaching of all the targeted elements the 1/4 S: L ratio has been selected for achieving the maximum recovery. For the maximum recovery of all the targeted Zn, Al and Pb elements, the following conditions are recommended 240 g/L NaOH solution concentration, at 90°C, 1/4 S: L ratio, and for 4 h.

3.4. Dissolution thermodynamic analysis

Diffusion through film of fluid, diffusion through solid or produced solid layer on the particle surface, or chemical reaction at the particle outer surface, commonly regulate the reaction rate and mechanism in a fluid-solid reaction system. Diffusion through the product layer, chemical reaction at the particle surface, and combination of the two mechanisms are the three main models for determining reaction rate. The slowest of these successive phases controls the process carrying out [39, 40]. As the reaction progresses, a layer of inert solid formed around the unreacted shrinking core. The shrinking core model (SCM) is the most important model for expressing the fluid-solid reaction [41 - 46]. Considering that, a solid particle (M) is immersed and reacts with a fluid (N) as shown in Equation 1.

$$N_{(fluid)} + bM_{(solid)} \rightarrow products$$
 Equation

If the reaction rate of particle leaching is controlled by diffusion of the fluid N through the solid layer, the time t required for a spherical solid to react with solution can be calculated using Equation 2.

$$1 - 3(1 - x)^{2/3} + 2(1 - x) = \frac{6bDC_o}{C_B r_o^2} t = K_1 t \text{ Equation } 2$$

Where X is the dissolved metal fraction, t is the leaching time (min.), D is the diffusivity of targeted metal ions through the product solid layer (m^2/s), C₂ is the concentration of the fluid outside the particle (mol/L), CB is the apparent concentration of the solid reactant (mol/L), r^o is the initial outside radius of the particle (m), and K₁ and K₂ are the apparent rate constants.

If the reaction rate is chemically controlled, the integrated rate equation is expressed using Equation 3.

$$1 - (1 - x)^{1/3} = \frac{bK_d C_0}{C_B r_0} t = K_2 t \quad Equation 3$$

where K_d is the chemical reaction rate constants. To explain the influence of temperature on the reaction kinetics of metal ions, a plot of 1- $(1-x)^{1/3}$, 1-3 $(1-x)^{2/3}$ + 2(1-x) against leaching time is presented in Figures 5 - 11.

Only Equation 4, of the two shrinking core models, provides a solid straight line with a strong correlation coefficient among the data. Thus, the shrinking core model with the chemical reaction model as the rate controlling step was found to suit all the results.



Fig. 5. Plot of $1 - (1-x)^{1/3}$ against dissolution time for Pb.









Fig. 8. Plot of $1-3(1-x)^{2/3}+2(1-x)$ against dissolution time for Al.



Fig. 9. Plot of 1- $(1-x)^{1/3}$ against dissolution time for Zn.

Egypt. J. Chem. 68, No.8 (2025)



Fig. 10. Plot of $1-3(1-x)^{2/3}+2(1-x)$ against dissolution time for Zn.



Fig. 11. Arrhenius plot of Pb, Al and Zn thermodynamic analysis.

As shown in the graphs in Figures 5, 7, 9 the apparent rate constants K_2 for Pb, Al, and Zn for the two shrinking core models were calculated from the slopes of the straight lines. Tables 3-5 summarize the K_2 values and the accompanying correlation coefficient.

Table 3: Rate constant K ₁ and K ₂ and its correlation coefficient for Pb leachin	ng
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Temperature, K	Apparent ra	Apparent rate constant		oefficients (R ²)
	K_1 (min. ⁻¹)	K_2 (min. ⁻¹)	\mathbb{R}^{2}_{1}	R ² ₂
298	0.0005	0.0011	0.9564	0.9982
323	0.001	0.0014	0.9425	0.9923
343	0.002	0.0023	0.9333	0.9897
363	0.0036	0.0035	0.9089	0.9702

Table 4: Rate constant K1 and K2 and its correlation coefficient for Al leaching

Temperature, °K	Apparent rate constant		Correlation c	Correlation coefficients (R ²)	
	K_1 (min. ⁻¹)	K ₂ (min. ¹)	\mathbb{R}^{2}_{1}	R ² 2	
298	0.0003	0.0008	0.9564	0.999	
323	0.0003	0.0010	0.9425	0.9956	
343	0.0022	0.0025	0.9333	0.9802	
363	0.0029	0.0029	0.9089	0.9789	

Temperature, °K	Apparent rate constant		Correlation coefficients (R ²)	
	K_1 (min. ⁻¹)	K_2 (min. ⁻¹)	\mathbb{R}^{2}_{1}	R ² ₂
298	0.0016	0.0020	0.9564	0.9914
323	0.0024	0.0026	0.9425	0.9778
343	0.0045	0.0039	0.9333	0.9376
363	0.0074	0.0064	0.9089	0.8575

Table 5: Rate constant K1 and K2 and its correlation coefficient for Zn leaching

The apparent rate constant values of K_2 were used to evaluate the activation energy of the leaching reaction (E_a) from the Arrhenius equation (Equation 4).

$$\ln K = \frac{-E_a}{R} \left(\frac{1}{T}\right) + \ln A \qquad Equation 4$$

where K is the apparent rate constant, Ea is the activation energy in kJ/mol, A is the Arrhenius constant and R is the molar gas constant in J/mol K. and, Pb, Al, and Zn have activation energies of 16.189, 19.66, and 15.867 kJ/mol, respectively, based on the plot of ln K against 1/T in Figure 11. There is a strong correlation between all these results and the shrinking core model with chemical reaction which is considered as the rate controlling step [47-50]. Many ores have been dissolving in a shrinking core model (SCM) using a mixture of diffusion and chemical control methods [51, 52].

3.5. Al, Zn and Pb recovery from alkaline leach solution

The 500 g of working sample has been leached using alkaline leaching process under the abovementioned optimum leaching conditions (240 g/L NaOH, 90°C, 1/4 solid: liquid ratio, and for 4hr) to recover the interesting metals Al, Zn and Pb from the alkaline solution. The obtained leaching solution (2000 ml) has been analyzed for Pb, Al and Zn, and the obtained concentration were 0.28, 23.4, and 2.02 g/L respectively, with leaching efficiency of 98.98%, 98.67% and 99.98%, respectively. The Zn was separated from Al and Pb by various phases; first, the shape of hydroxide of the three metal values is exposed to bulk hydroxide by controlling pH at 7. Then, it is dissolved into three metals acetate by heating in sulfuric acid. Firstly, the removal of pure aluminum was carried out via adjusting the pH at 5.5 leaving pb and Zn and the obtained alumina was characterized physically using EDX-analysis as presented in Fig. 12A.



Egypt. J. Chem. 68, No.8 (2025)



Fig. 12. EDX spectrum of the obtained A) Al₂O₃, B) PbO and C) ZnO from the lamprophyre dyke.

Then, the solution containing Pb and Zn metals was re-precipitated at pH 7. Also, excess amount of ammonia solution was added to dissolve the Zn more than ammonia white precipitate $Pb(OH)_2$ which was characterized physically using EDX-analysis as presented in Figure 12B. Then, the obtained precipitate is insoluble in excess of aqueous ammonia, then the zinc will be precipitated via CO_2 as oxide which was characterized physically using EDX-analysis as presented in Figure 12C. The proposed flowsheet for the effective extraction of Zn, Al, and Pb from the used raw material is presented in Fig. 13.



Fig. 13. The proposed flowsheet for the effective extraction Al₂O₃, PbO and ZnO from the Lamprophyre Dyke.

Egypt. J. Chem. 68, No. 8 (2025)

4. Conclusions

Al, Zn, and Pb polymineralized lamprophyres are reported in the SW of Mersa Alam port area, South-eastern Desert of Egypt. The current study aims at the extraction of Al, Zn, and Pb from lamprophyre dykes using cost-effective alkaline leaching process. The factors influencing the alkaline leaching process such as the solution concentration, leaching temperature, time and solid: liquid ratio have been studied. The kinetics and the mechanism of leaching process have also been studied to describe and analysis thermodynamic and the activation energy of the leaching process. The obtained results indicated that the maximum recovery of the three metal ions can be obtained at 240 g/L NaOH concentration, 1: 4 solid: liquid ratio, at 90°C and for 4 h. The maximum recovery of Al, Pb and Zn, at the optimum leaching conditions are 98.67%, 98.98%, and 99.98%, respectively. The activation energies of Pb, Al and Zn are 16.189 kJ/mol, 19.66 kJ/mol, and 15.867 kJ/mol, respectively.

5. Conflicts of interest

There are no conflicts to declare.

6. Formatting of funding sources

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7. References

- [1] Ayinla K. I., Baba A. A., Girigisu S., Bamigboye O.S., Tripathy B.C., Ibrahim A. S., Azeez S. O., Acidic leaching of iron from Kaoje goethite ore by hydrochloric acid: kinetics modelling, Nigerian Journal of Technology. 2020, 39(3):800 - 806. <u>http://dx.doi.org/10.4314/njt.v39i3.20</u>
- [2] Ejtemaei M., Gharabaghi M., Irannajad M., A review of zinc oxide mineral beneficiation using flotation method. Advances in Colloid and Interface Science, Adv. Colloid Interface Sci. 2014, 206: 68-78. <u>https://doi:10.1016/j.cis.2013.02.003</u>
- [3] Ahmed I. M., Nayl A. A., Daoud J. A., Leaching and recovery of zinc and copper from brass slag by sulfuric acid, Journal of Saudi Chemical Society. 2016, 20: S280–S285. <u>https://doi.org/10.1016/j.jscs.2012.11.003</u>
- [4] Qin W., Lan Z., Li W., Recovery of zinc from low-grade zinc oxide ores by solvent extraction. Journal of Central South University of Technology. 2003, 10(2): 98–102. <u>https://doi.org/10.1007/s11771-003-0047-1</u>
- [5] Hursit M., Lacin O., Sarac H., Dissolution kinetics of smithsonite ore as an alternative zinc source with an organic leach reagent. Journal of the Taiwan Institute of Chemical Engineers .2009, 40(1): 6–12. <u>https://doi:10.1016/j.jtice.2008.07.003</u>
- [6] Larba R., Boukerche I., Alane N., Habbache N., Djerad S., Tifouti L., Citric acid as an alternative lixiviant for zinc oxide dissolution. Hydrometallurgy .2013, 134-135: 117–123. <u>https://doi:10.1016/j.hydromet.2013.02.002</u>
- [7] Irannajad M., Meshkini M., Azadmehr A., leaching of zinc from low grade oxide ore using organic acid, Physicochem Probl Miner Process. 2013, 49(2): 547-555. <u>https://doi.org/10.5277/ppmp130215</u>
- [8] Wu D.D., Wen S.M., Yang J., Deng J.S., Investigation of dissolution kinetics of zinc from smithsonite in 5sulphosalicylic acid solution, Canadian Metallurgical Quarterly. 2014, 54(1): 51–57. https://doi:10.1179/1879139514y.0000000150
- [9] Peng N., Peng B., Chai L., Liu W., Li M., Yuan Y., Hou D. K., Decomposition of Zinc Ferrite in Zinc Leaching Residue by Reduction Roasting, Procedia Environmental Sciences. 2012, 16: 705–714. <u>https://doi:10.1016/j.proenv.2012.10.097</u>
- [10] Li Q., Zhao Y., Jiang J., Zhang C., Optimized Hydrometallurgical Route to Produce Ultrafine Zinc Powder from Industrial Wastes in Alkaline Medium. Procedia Environmental Sciences. 2012, 16: 674–682. https://doi:10.1016/j.proenv.2012.10.093
- [11] Chenglong Z., Youcai Z., Mechanochemical leaching of sphalerite in an alkaline solution containing lead carbonate, Hydrometallurgy. 2009, 100(1-2), 56-59. <u>https://doi.org/10.1016/j.hydromet.2009.10.004</u>
- [12] Chen A., Zhao Z. W., Jia X., Long S., Huo G., Chen X., Alkaline leaching Zn and its concomitant metals from refractory hemimorphite zinc oxide ore, Hydrometallurgy .2009, 97(3-4): 228–232. <u>https://doi:10.1016/j.hydromet.2009.01.005</u>
- [13]Santos F.M.F., Peina P.S., Porcaro A., Oliviera V.A., Silva C.A., Leão V.A., The kinetics of zinc silicate leaching in sodium hydroxide, Hydrometallurgy 2010, 102 (1-4): 43-49. <u>https://doi.org/10.1016/j.hydromet.2010.01.010</u>
- [14] Shen X., Shao H., Ding J., Liu Y., Gu H., Zhai Y., Zinc extraction from zinc oxidized ore using (NH₄)₂SO₄ roastingleaching process. International Journal of Minerals, Metallurgy and Materials. 2020, 27(11): 1471–1481. <u>https//doi:10.1007/s12613-020-2015-2</u>
- [15] Tomas Havlik, Hydrometallurgy: Principles and Applications, Cambridge : Cambridge International Science Publishing Limited in association with Woodhead Publishing Limited .2008, cop.: 17-28.
- [16] Havlik T., Turzakova M., Stopic S., Friedrich B., Atmospheric leaching of EAF dust with diluted sulphuric acid, Hydrometallurgy, 2005, 77(1-2): 41-50. <u>https//doi:10.1016/j.hydromet.2004.10.08</u>
- [17] Deng J., Sun Q., Lin P., Song G., Wen S., Deng J., Wu D., Dissolution Kinetics of Zinc Oxide Ore with an Organic Acid, International Journal of Metallurgical & Materials Engineering . 2015, 1, 109, 1 -7. <u>http://dx.doi.org/10.15344/2455-2372/2015/109</u>
- [18] Chen A., Zhao Z., Jia X., Long S., Huo G., Chen X., Alkaline leaching Zn and its concomitant metals from refractory hemimorphite zinc oxide ore ,Hydrometallurgy. 2009, 97 (3–4), 228–232. <u>http://doi:10.1016/j.hydromet.2009.01.005</u>
- [19] Feng L., Yang X., Shen Q., Xu M., Jin B., Pelletizing and alkaline leaching of powdery low grade zinc oxide ores, Hydrometallurgy . 2007 89(3-4): 305–310. <u>http://doi:10.1016/j.hydromet.2007.08.002</u>
- [20] Li S., Ma A., Yang K., Yin S., Zhang L., Peng J., Weiheng C., Xie, F., Alkaline leaching of zinc from low-grade oxide zinc ore using ammonium citrate as complexing agent. Green Processing and Synthesis. 2015, 4(3): 219–223. <u>http://doi:10.1515/gps-2015-0023</u>

Egypt. J. Chem. 68, No.8 (2025)

- [21] Zárate-Gutiérrez R., Gregorio-Vázquez L., Lapidus G. T., Selective leaching of lead from a lead-silver-zinc concentrate with hydrogen peroxide in citrate solutions, Canadian Metallurgical Quarterly. 2015, 54(3): 305-309. http://doi:10.1179/1879139515y.000000020
- [22] Ibrahim A.H., Lyu X., Sharafeldin H.E., ElDeeb A.B., Eco-Friendly and Complex Processing of Vanadium-BearingWastefor Effective Extraction of Valuable Metals andOtherBy-Products: ACritical Review, Recycling. 2025, 10, 6. https://doi.org/10.3390/recycling10010006
- [23] Saha P. K., Aluminum Extrusion Technology, ASM International, Materials Park . 2000, 87 ISBN: 978-0-87170-644-7.
 [24] La Iglesia A., González M. V., Dufour J., Zeolite synthesis employing alkaline waste effluents from the aluminum industry. Environmental Progress. 2002, 21(2): 105-110. http:// doi:10.1002/ep.670210212
- [25] ElDeeb A.B., Brichkin V.N., Sizyakov V.M., Kurtenkov R.V., 2020. Effect of sintering temperature on the alumina extraction from kaolin. Pp. 136-145 in: Advances in Raw Material Industries for Sustainable Development Goals (E. Litvinenko, editor). CRC Press, Boca Raton, FL, USA.
- [26] ElDeeb A.B., Brichkin V.N., Povarov V.G., Kurtenkov R.V. 2020. The activating effect of carbon during sintering the limestone-kaolin mixture. Tsvetnye Metally 7: 18-25.
- [27] ElDeeb A.B., Brichkin, V.N., Kurtenkov R.V., Bormotov I.S., 2019. Factors affecting on the extraction of alumina from kaolin ore using lime-sinter process. Pp. 502-508 in: Topical Issues of Rational Use of Natural Resources 2 (E. Litvinenko, editor). CRC Press, Boca Raton, FL, USA.
- [28] ElDeeb A.B., Brichkin V.N., Bertau M., Awad M.E., Savinova Y.A., 2022. Enhanced alumina extraction from kaolin by thermochemical activation using charcoal. Clay Minerals 56(4), 269 283. DOI: https://doi.org/10.1180/clm.2022.7
- [29] ElDeeb A.B., Brichkin V.N., Kurtenkov R.V., Bormotov I.S., 2021. Study of the peculiarities of the leaching process for self-crumbling limestone-kaolin cakes. Obogashchenie Rud, 2021, 27-32.
- [30] ElDeeb A.B., Brichkin V.N., Salman S.A., Gouda M.K., Abdelhaffez G.S., Cost-effective and Eco-friendly extraction of alumina based on kaolin ore using thermo chemically activated lime-sinter process, Journal of Al-Azhar University Engineering Sector 18, pp. 736 - 750, 2023. doi10.21608/auej.2023.235500.142.
- [31] Shamroukh A., Salman S. A., ElDeeb A. B., Gouda M. K., Berends W., Abdel-Fadeel W., Abdel-Jaber G.T., Challenges in Energy Savings in Aluminium Reduction Cell by Improving the Anode Design and Inserts, Journal of Al-Azhar University Engineering Sector 19, pp. 1369 - 1381, 2024. Doi: 10.21608/auej.2024.249663.1481
- [32] Verheul H., How social networks influence the dissemination of cleaner technologies to SMEs, J. Cleaner Prod. 1999,7(3): 213-219. https://doi.org/10.1016/S0959-6526(99)00079-7
- [33] El-Hazek N. T., Amer T. E., Badr M. H., Shawky N. M., Zaky D. I., AL-Azhar Bultien of Science. 2007, 1(18), 75-85. https://doi.org/10.21608/ABSB.2007.10870
- [34] Zaki D. I., Studies on the physical and chemical characteristics of some complex rare metal occurance in wadi Abu Rusheid Area Southeastern Desert Egypt.", Msc. Thesis, Faculty of Science for Girl, Al-Azhar University., Egypt, 2007, 85. p.
- [35] Rashed M. A., Geologic Studies on a New Occurrence of Nuclear Materials in Abu Rusheid Area, SE. Desert, Egypt", Ph.D. Thesis, Fac. Sc. Damietta, El Mansoura Univ., Egypt., 2005, 143p.
- [36] Ibrahim M. E., El-Tokhi M., Saleh G. M., Rashed M. A., Lamprophyre Bearing-REEs, South-Eastern Desert, Egypt, and 7th Intern. Conf. on Geochemistry; Alex. Univ. 7-9 Sept., Egypt 2006.
- [37] Zaki D.I., Shawky N., El-Sheikh E. M., Ahmed F. Y., Ibrahim M. E., Recovery of some valuable elements from lamprophyre dykes in the Abu Rusheid area, Southeastern Desert, Egypt: Chinese journal of geochemistry. 2012, 31: 64 - 73. https://doi.org/10.1007/s11631-012-0550-x
- [38] Shapiro I., Brannock W. W., Rapid Analysis of Silicate, Carbonate and Phosphate Rocks, USGS Bull., 1144- Ap 1962.
- [39] Atia B. M., Gado M. A., Cheira M. F., Kinetics of uranium and iron dissolution by sulfuric acid from Abu Zeneima ferruginous siltstone, Southwestern Sinai, Egypt, Euro-Mediterranean Journal for Environmental Integration, 2018, 3(1), 39: 1-12. https://doi.org/10.1007/s41207-018-0080-y
- [40] Ibrahium H. A., Gado M. A., Awwad N. S., Fathy W. M., Selective separation of Yttrium and Uranium from Xenotime Concentrate, Zeitschrift für anorganische und allgemeine Chemie. 2021, 647 (15): 1568-1577. https://doi.org/10.1002/zaac.202100118
- [41] Salem I.A., El Bahariya G.A., El Dosuky B.T., Refaey E.F., Ibrahim A.H., ElDeeb A.B., 2024. Mineralogical studies and extraction of some valuable elements from sulfide deposits of Abu Gurdi area, South-Eastern Desert, Egypt. Analytical Science & Technology 37 (1), 47-62. https://doi.org/10.5806/AST.2024.37.1.47
- [42] Mohamed S.T., Emam A.A., Fathy W.M., Salem A.R., ElDeeb A.B., 2024. Enhanced extraction of copper and nickel based on the Egyptian Abu Swayeil copper ore. Analytical Science & Technology 37 (1), 1-16. https://doi.org/10.5806/AST.2024.37.1.63
- [43] Mahran G.M.A., Gado M.A., Fathy W. M., ElDeeb A.B. 2023. Eco-Friendly Recycling of Lithium Batteries for Extraction of High Purity Metals. Materials 16(13). https://doi.org/10.3390/ma16134662
- [44] Ibrahim, A.H., Lyu X., ElDeeb A.B., 2023. Synthesized Zeolite Based on Egyptian Boiler Ash Residue and Kaolin for the Effective Removal of Heavy Metal Ions from Industrial Wastewater. Nanomaterials 13(6):1091. https://doi.org/10.3390/nano13061091
- [45] Ibrahim, A.H., Lyu X., Atia B.M., Gado M.A., ElDeeb A.B., 2023. Phase transformation mechanism of boiler ash roasted with sodium salt for vanadium extraction. Journal of Material Cycles and Waste Management 25(1) 86-102. https://doi.org/10.1007/s10163-022-01512-8
- [46] Ibrahim, A.H., Lyu X., Atia B.M., Gado M.A., ElDeeb A.B., 2022. Cost-Effective and High Purity Valuable Metals Extraction from Water Leaching Solid Residues Obtained as a By-Product from Processing the Egyptian Boiler Ash. Minerals 12, 1084. https://doi.org/10.3390/min12091084
- [47] Yuan F., Study on kinetics of Fe (II) oxidized by air in FeSO₄–H₂SO₄ solutions, Miner Eng. 2018, 121:164–168.

Egypt. J. Chem. 68, No. 8 (2025)

https://doi.org/10.1016/j.mineng.2018.03.013

- [48] Brichkin V.N., Kurtenkov R.V., ElDeeb A.B., Bormotov I.S., State and development options for the raw material base of aluminum in non-bauxite regions. Obogashchenie Rud 2019, 4, 31-73.
- [49] Azooz E.A., Ramadan H.E., Abd Elaal M.A., El-Amir M.A., EL-Absy M.A., Mahmoud W.H., Kinetic and Thermodynamic Parameters of ⁹⁹Mo Sorption on Zirconia Nanoparticles Prepared By Hydrothermal Method. Egypt. J. Chem. Vol. 66, No. SI: 13, 2023, 187 – 197. <u>https://doi.org/10.21608/ejchem.2022.146915.6376</u>
- [50] Naji A.M., Mohammed I.Y., Al-Bayaty S.A. Mechanical and Thermal Degradation Kinetic Study Of Basalt Filled Polyvinyl Chloride Composite Material. Egypt. J. Chem. Vol. 64, No. 2, 2021, 893 – 901.
- [51] Souza A. D., Pina P. S., Leo V. A., Silva C. A., Siqueira PF The leaching kinetics of zinc sulphide concentrate in acid ferric sulphate., Hydrometallurgy. 2007, 89:72–81. <u>https://doi.org/10.1016/j.hydro.met.2007.05.008</u>
- [52] Silva G. A., Relative importance of diffusion and reaction control during the bacterial and ferric sulphate leaching of zinc sulphide, Hydrometallurgy.2004, 73:313–324. <u>https://doi.org/10.1016/j.hydro.met.2003.12.00</u>