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# DISSOLUTION KINETICS OF LOW-GRADE ZINC SILICATE ORE IN HYDROXIDE SOLUTION

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**ABSTRACT** – A kinetic study of the leaching on a low-grade zinc silicate ore by concentrated sodiun hydroxide (NaOH) solution has been investigated. The effects of reaction time, temperature, NaOH concentration and particle size on the dissolution rate of zinc were examined. It was found that the dissolution rate of zinc is significantly influenced by temperature, particle size and concentration of NaOH solution. When an ore sample of -53+38 µm size was leached for 2 hrs at 85°C in the presence of 5 M sodium hydroxide solution, at liquid:solid ratio of 10:1 and agitation speed of 400 rpm, the zinc recovery was about 78%. The kinetic study indicate that the process is chemically controlled with an activation energy of 52.45 kJ/mol.

**Keywords:** Zinc Silicate Ore, Hemimorphite, Alkaline Leaching, Leaching Kinetics.

## INTRODUCTION

The zinc smelting industry is mainly dependent on zinc sulfide ore [1]. However, the depletion of high-grade deposits has made it increasingly challenging to meet rising zinc demand, highlighting the need to utilize zinc oxide ores [2].

The hydrometallurgical processing of zinc oxide ores involves either acidic or alkaline leaching [3−5]. While acid leaching achieves a high zinc recovery, the presence of alkaline gangue and impurity metals leads to high sulfuric acid consumption and complicates purification [6,7]. Additionally, Si readily forms silica gels in acidic media, hindering solid-liquid separation [8].

The alkaline leaching process, including NaOH and ammonia leaching, offers several advantages such as the insolubility of impurities like $Fe_2O_3$, $SiO_2$, CaO, and MgO due to the high pH (6–7) of the solution. Additionally, solution purification is straightforward, and treating ores with high gangue content in an alkaline solution reduces reagent usage and avoids filtration challenges commonly encountered in acid leaching.

Ammonia leaching has been found to cause significant environmental pollution and ammonia loss due to its inherent volatility. Accordingly, the application of ammonia leaching technology must be improved [9,10].

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Compared to acid leaching of non-sulfide zinc, fewer studies have explored alkaline leaching with sodium hydroxide. This research aims to investigate zinc extraction using an alkaline solution and the kinetics of the leaching process. The study systematically examines the optimal conditions for zinc extraction from zinc silicate ore in a NaOH medium and the dissolution kinetics of the process.

## EXPERIMENTAL

### Materials

Zinc silicate ore from Bagherabad mine (11.65% Zn, 11.14% Fe, 24.7% CaO and 12.58% $SiO_2$) in central Iran, was used in this study. Mineralogical analysis of the sample was performed by X-ray diffraction (Fig 1), polished and thin sections microscopy. XRD analysis of the sample showed the presence of hemimorphite [$Zn_4Si2O_7(OH)_2{\cdot}H_2O$], sphalerite (ZnS), calcite [$CaCO_3$], dolomite [$Ca(Mg,Fe)(CO_3)_2$] and goethite [FeO(OH)] as the major mineral phases followed by smithsonite ($ZnCO_3$), cerussite [$PbCO_3$], kaolinite [$Al_2Si2O_5(OH)_4$], quartz ($SiO_2$) and jarosite [$KFe_3(SO_4)_2(OH)_6$] as minor phases.

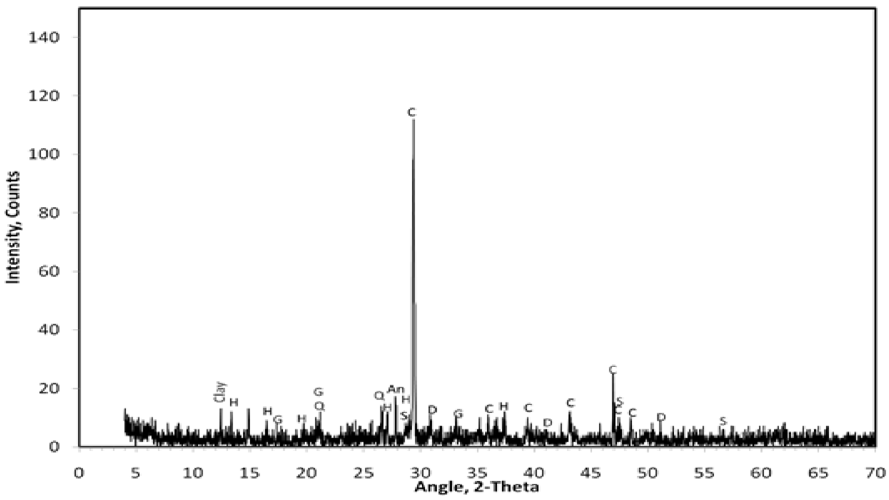


**Figure 1** XRD pattern of the zinc silicate sample (H-Hemimorphite, G-Goethite, Q-Quarz, C-Calcite, S-Sphalerite, D-Dolomite, An-Anorthoclase)

### Methods

Leaching experiments were conducted batch-wise with a total volume of 400 mL. A mechanical stirrer provided adequate dispersion of the mineral particles. Leaching solutions were prepared using NaOH crystals and distilled water. Unless otherwise stated, experiments were performed with 38–53 µm particles in 5 M NaOH at 85°C, stirred at 400 $min^{-1}$, and a solution volume of 200 mL. At selected time intervals, 2 mL of slurry was withdrawn, filtered, and analyzed for zinc content using atomic absorption spectroscopy (AAS).

## RESULTS AND DISCUSSION

### Effect of leaching time

The effect of leaching time on the dissolution of zinc silicate is shown in Fig 2. Zinc recovery increased with leaching time under the following conditions: 85°C, 5 mol/L NaOH concentration, 400 rpm agitation, liquid/solid mass ratio of 1:10, and particle size of -53+38 µm. After 60 minutes, 50% zinc recovery was achieved, rising to 78% after 120 minutes. A leaching time of 120 minutes was found to be optimal and was used for all subsequent experiments.

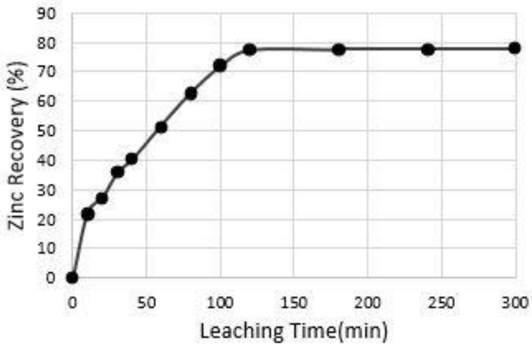


**Figure 2** Effect of leaching time on zinc extraction.

### Effect of sodium hydroxide concentration

The effect of NaOH concentration on zinc extraction is depicted in Fig 3. Other parameters were kept constant. Zinc extraction increased with NaOH concentration up to 6 M, with leached zinc rising from 41% to 80% after 120 minutes as the concentration increased from 3 M to 6 M. At concentrations of 7 and 8 M, the leaching rate decreased due to increased solution viscosity, which hindered the diffusion of reactants. A concentration of 5M is considered optimal, as increasing it to 6M resulted in only a 3% improvement in recovery.

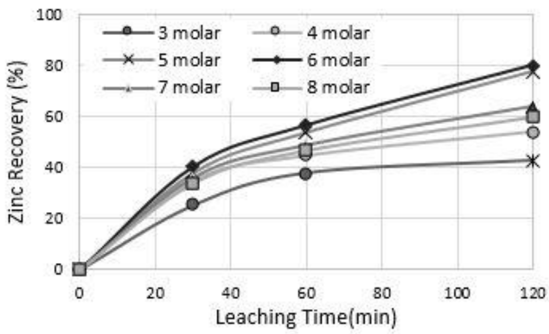


**Figure 3** Effect of NaOH concentration on zinc extraction.

**Effect of particle size**

Fig 4 shows the effect of particle size on zinc extraction. The results indicate that reducing the particle size from -150+106 µm to -53+38 µm improved zinc extraction from 48% to 78%. This enhancement is due to the increased surface area of smaller particles, which provides more contact with the solution.

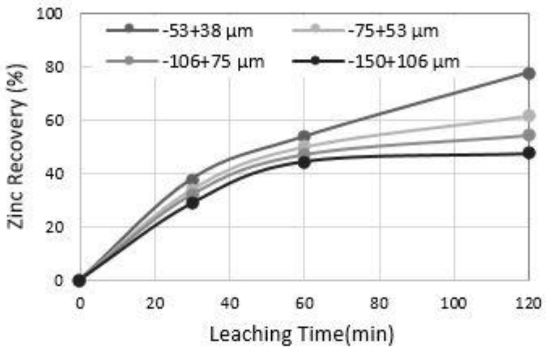


**Figure 4** Effect of particle size on zinc extraction.

**Effect of temperature**

As seen from Fig 5, the temperature has strong influence on the zinc extraction. The zinc recovery increased as the temperature was increased. After 120 min, zinc extraction increased from 44% to 78% as temperature increased from 65 to 85 °C. It suggests that the process is chemically controlled, which has been confirmed in further kinetic analysis.

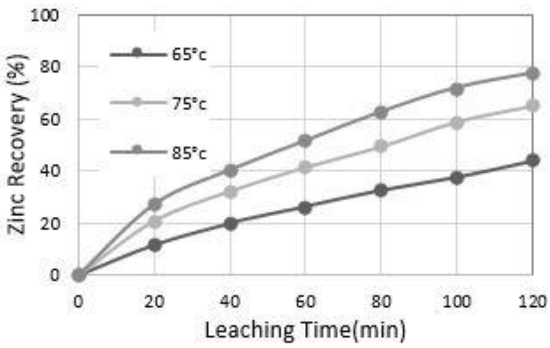


**Figure 5** Effect of temperature on zinc extraction.

**Leaching kinetics**

Microscopic analysis of the residues revealed a progressive reduction in particle size during leaching, supporting the shrinking particle model. Data analysis showed that the

SPM model with chemical control good correlated with the results at all three temperatures (Fig 6). The $R^2$ values were acceptable, confirming that the process follows a chemical reaction model.

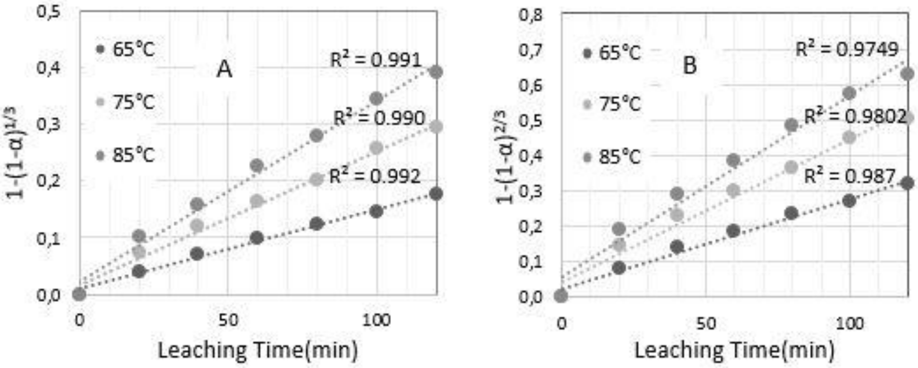


**Figure 6** Plots of shrinking core model for chemical reaction control (A), and diffusion control (B), in various temperatures.

A chemically controlled process is highly temperature-dependent. Fig 7 presents the Arrhenius plot (ln k vs. 1/T), showing an activation energy of 52.45 kJ/mol. This high value confirms that zinc silicate leaching in NaOH is controlled by surface chemical reactions.

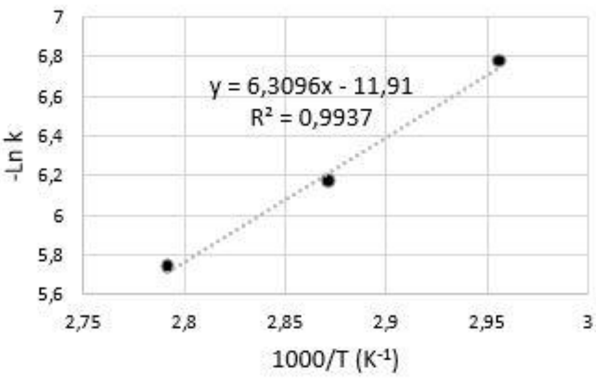


**Figure 7** Arrhenius plot for leaching of zinc silicate ore

**CONCLUSION**

1) The dissolution kinetics of a low-grade zinc silicate ore in NaOH medium was studied. Mineralogical analysis of the sample showed the presence of hemimorphite [$Zn_4Si_2O_7(OH)_2 \cdot H_2O$] as major zinc phase.
2) When the ores of -53+38 µm size were leached for 2 h at 85°C in the presence of 5 M sodium hydroxide, liquid:solid ratio of 10:1 and agitation speed of 400 rpm, the leaching rate of zinc recovery was about 78%.

3) The dissolution kinetics of zinc silicate ore increases with increasing sodium hydroxide, temperature and with decreasing particle size.
4) The activation energy was found to be 52.45 kJ/mol which indicated a chemically controlled process is the controlling step.

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