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Hydrometallurgy 82 (2006) 54–62
hydrometallurgy
www.elsevier.com/locate/hydromet

# Hydrometallurgical treatment of tailings with high zinc content

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Received 24 September 2005; received in revised form 15 January 2006; accepted 23 January 2006
Available online 20 March 2006

**Abstract**

Zinc exists as smithsonite and hemimorphite in the lead flotation tailings from the Dandi mineral processing plant in north western Iran. In this research, zinc-rich tailings produced in the Dandi plant were characterized mineralogically and a leaching study was carried out to assess the effect of several parameters on the kinetics of zinc dissolution. Parameters studied included: sulfuric acid concentration, reaction time, temperature and slurry density. It was found that leaching is controlled by a single rate-controlling step with an activation energy of 23.5 kJ/mol. To overcome some of the filtration problems associated with polymerization of silicic acid, lime was added as a coagulant. The optimum pH, holding time and temperature required to maximize the filtration rate were determined.


*Keywords:* Lead–zinc oxide ores; Leaching; Kinetics; Silica coagulation

## 1. Introduction

Currently, zinc is produced mostly from zinc sulfide ores because sulfides are easy to separate from gangue and to concentrate by conventional flotation techniques. As new sphalerite mines are becoming more difficult to find, new processes to produce zinc metal from oxidized zinc ores are being developed. Oxidized ores contain zinc in various carbonate and silicates minerals such as smithsonite ($ZnCO_3$), hydrozincite ($2ZnCO_3 \cdot 3Zn(OH)_2$), zincite (ZnO), willemite ($ZnSiO_4$) and hemimorphite ($Zn_2SiO_3 \cdot H_2O$).

Recently, Sole et al. (2005) reviewed the first commercial application of zinc solvent extraction for a primary zinc ore containing ~10.6% Zn in Skorpion, Namibia. In the process an atmospheric leach in sulfuric acid is applied to remove iron, aluminum and silica from solution by precipitation. Zinc is then selectively extracted by solvent extraction.

Extensive work has been carried out on the treatment of zinc oxide ores by hydrometallurgical and pyrometallurgical methods. In particular, there are several processes for the treatment of zinc silicate ores. Leaching is the first step in the hydrometallurgical route and leaching kinetics is important from the economic point of view. Thomas and Fray (1981) studied leaching of oxide zinc materials with chlorine and chlorine hydrate. They found that the rate of leaching of the Adrar Turkish ore could be described using a shrinking core diffusion model, and that the rate of leaching was controlled by surface reaction. In all cases studied, lead was also leached with zinc. However, iron oxides remained virtually undissolved. Abdel-Aal (2000) investigated the kinetics of sulfuric acid leaching of low-grade zinc silicate ore. Abdel-Aal found that leaching of about 94%

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doi:10.1016/j.hydromet.2006.01.005

of zinc was achieved after 180 min of reaction with 10% sulfuric acid at 70 °C. Diffusion through the product layer was found the controlling step during the leaching reaction. In contrast, Zhao and Stanforth (2000) studied the production of zinc powder by alkaline treatment of smithsonite ores. The best leaching results were obtained in presence of 5 M NaOH, at 90–95 °C and a reaction time of 90 min. Frenay (1985) studied leaching of oxidized zinc ores in various solution media and obtained the best leaching results with sulfuric acid and caustic soda. Mineralogical studies showed that smithsonite can be completely leached but hemimorphite is relatively refractory to leaching.

Matthew and Elsner (1977) developed a continuous process in which silica was dissolved first and then coagulated by controlling the pH. The ore was leached with spent electrolyte. The pH of the leach solution was then raised to pH 4 to 5.5 using a neutralizing agent to precipitate and coagulate the colloidal silica. Dufresne (1976) used a quick leach method to treat zinc silicate ores. The method was based on the chemistry of a water-starved system and effectively rejected silica from many silicate materials. Alternatively, Kumar and Biswas (1986) used aluminum sulfate for coagulation of silica gel when recovering zinc from Zawar ancient siliceous slag in sulfuric acid. They found that neutralization, coagulation and precipitation of silicic acid with $Al^{3+}$ ions distinctly improved zinc recovery. Bodas (1996) developed a process for leaching zinc silicate ores from Thailand using sulfuric acid and Magnafloc 156 as coagulant. He found that a maximum of 95% zinc leaching was obtained at a 4.5 M acid concentration after 3 h of leaching at 70 °C and a 1 : 5 solid : liquid weight ratio. Bodas found that 0.5 g Magnafloc 156 was required to coagulate the silicic acid produced in a slurry containing 1 Kg ore.

Willemite and hemimorphite are readily soluble in dilute sulfuric acid. Reactive silica dissolves according to the following reaction (Iler, 1955):

$$SiO_2(s) + 2H_2O = Si(OH)_4(aq) \quad (1)$$

Monosilicic acid ($Si(OH)_4$) polymerizes with time to produce polysilicic acid. Polymerization involves condensation of silanol (SiOH) groups to form siloxane (Si–O–Si) bonds. The overall equation for the polymerization reaction may be written as follows:

$$(SiO_2)_n + 2nH_2O = nSi(OH)_4 \quad (2)$$

With continued polymerization, polymers attain a range of colloidal sizes (0.001 to 0.1 μm) depending on factors such as temperature, pH and impurities. The particles of colloidal silica may or may not be stable. Unstable particles of colloidal silica may aggregate to produce an open network structure (a gel) (Matthew and Elsner, 1977). The challenge is to optimize precipitation of colloidal silica without forming an unfilterable gel and without loosing a large amount of zinc sulfate, which is present in the filtrate. Coagulation of colloidal silica helps to increase the filtration rate.

Monhemius and Terry (1983) investigated the influence of temperature, pH, acid type and surface area on the kinetics of the acid dissolution of natural and synthetic willemites and natural hemimorphite. They found that dissolution of hemimorphite was diffusionally controlled and that dissolution of willemite was chemically controlled.

The objective of this research was to study extraction of zinc from tailings produced in the Dandi plant using sulfuric acid. Mineralogical studies were carried out to identify the main phases present in the mineral and in the gangue and to identify the liberation of these phases. In the leaching experiments, the effect of acid concentration, holding time, agitation rate and solid/liquid ratio on zinc extraction was investigated. The effect of addition of lime on the coagulation of silicic acid was also studied.

## 2. Experimental procedure

### 2.1. Materials/analysis

The sample was provided by the Dandi mineral processing plant in north western Iran. The feed for the Dandi mineral processing plant is currently from the Angouran mine, a large lead–zinc mine in northwestern Iran. In the Dandi plant, low grade ore is divided in two size fractions 0–2 and 2–15 mm. In the 2–15 mm size fraction, gangue is separated using heavy media separation techniques. After grinding, the 0–2 mm size fraction enters the lead flotation circuit, which produces a lead concentrate and zinc-rich oxide-silicate tailings. The sample used in this study was taken directly from the 0–2 mm tailings containing ca. 22% zinc. These tailings are currently stockpiled. The sample was sieved and about 80% of the tailings were smaller than 300 μm (50 mesh).

Mineralogical analysis of the sample was performed by X-ray diffraction (XRD), X-ray Fluorescence (XRF), polished sections and thin sections microscopy. The XRD analysis suggests that the major mineral phases in the tailing are smithsonite ($ZnCO_3$), quartz ($SiO_2$), followed by hemimorphite [$Zn_4Si_2O_7(OH)_2 \cdot H_2O$],