Optimization of Zinc Leaching Parameters and Arsenic Removal from Lead Smelting Residues in an Acidic Environment Using Ferrous Ion and Potassium Permanganate

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ABSTRACT

This research investigates and optimizes the zinc recovery process from the pyrometallurgical residue of a Kaldo lead smelting furnace in Zanjan province. Chemical analysis revealed that the waste contains 14.7% zinc and 4% arsenic. The primary objectives of this study are to recover zinc as a valuable metal and remove arsenic as a hazardous contaminant. To achieve these goals, first, an acidic leaching method was examined. Under optimal conditions (0.75 M concentration, 75°C temperature, 60 min duration, and a 6:1 liquid-to-solid ratio), acidic leaching with sulfuric acid resulted in zinc and arsenic recovery of 99% and 50%, respectively. These results demonstrate the high efficiency of the acidic leaching in extracting zinc from the waste. For arsenic removal from the leaching solution, a precipitation method using ferrous sulfate and various oxidants was studied. Among the oxidants examined, potassium permanganate showed the best performance with a 99.94% removal recovery under optimal conditions (5:1 ferrous sulfate to potassium permanganate ratio, 60 min duration, ambient temperature, and pH 4.5). The combination of acidic leaching and arsenic precipitation processes provides an effective approach for selective zinc extraction and arsenic removal. This combined method not only enables high-purity zinc recovery but also contributes to reducing environmental pollution caused by arsenic. This study marks a significant step in developing efficient and sustainable methods for metal recovery from industrial waste and can serve as a model for similar projects in the metallurgical industry.

Keywords

Lead residue, Leaching, Zinc recycling, Arsenic precipitation, Kaldo

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1- Introduction

The increasing global demand for metals has led to a growing emphasis on recycling and recovering metals from industrial wastes [1]. The Kaldo furnace, used in lead production, generates significant waste containing valuable zinc and hazardous arsenic [2]. While numerous studies have addressed zinc recovery and arsenic removal from various metallurgical wastes [3], limited research investigates simultaneously recovering zinc and removing arsenic from wastes. This study aims to optimize zinc recovery and arsenic removal from Kaldo furnace waste through a two-stage approach: acidic leaching followed by arsenic precipitation. The study shows that an optimal combination of these methods can maximize zinc recovery while minimizing arsenic content in the final waste. By examining the effects of parameters such as pH, temperature, reaction time, and solid-to-liquid ratio, this research seeks to develop an efficient and sustainable process for managing Kaldo furnace waste, contributing to more environmentally friendly practices in the metallurgy industry.

2- Methodology

The study used waste samples from a lead Kaldo furnace in Zanjan, Iran. Laboratory-scale acidic leaching and arsenic precipitation experiments were conducted using sulfuric acid, iron sulfate, and potassium permanganate. Leaching experiments were performed in 1-liter beakers with a liquid-to-solid ratio of 6. The study examined various parameters, including acid concentration, temperature, and reaction time, varying one parameter at a time to assess individual effects.

3- Results and Discussion

XRD analysis revealed the presence of zinc hydroxide nitrate ammonia and lead hydroxide arsenate in the waste, indicating significant amounts of zinc, lead, and arsenic. Sulfuric acid concentration significantly affected leaching efficiency. Acid concentration varied between 0.1 and 1 M. From Figure 1, it can be noticed that an increase of the acid concentration from 0.5 to 0.75 M increased the zinc recovery from 51.69% to 98.04%, along with the arsenic recovery increase from 13.72% to 50%. The difference in the recovery of zinc and arsenic may be explained by the zinc phase in the sample, which is in hydroxide form and generally has a higher solubility under acidic conditions compared to arsenic [4].

The effect of temperature (25–85°C) was studied at 0.75 M acid concentration for 60 min. At 25°C, 90% of zinc leached while arsenic recovery was 41.67%. According to the Arrhenius equation, lower zinc activation energy leads to higher dissolution [5, 6]. The optimal temperature was selected at 60°C, where zinc recovery reached 97%. After examining the effects of acid concentration and temperature, the effect of leaching time (5–90 min) was explored. In the first 15 min, zinc recovery increased rapidly due to the high solubility of zinc hydroxide in acidic conditions [7]. A 60-min leaching time was optimal, achieving 97.12% zinc and 46.31% arsenic recovery. In addition, the effect of L/S ratios of 3, 4, 6, 8, and 10 were investigated. Results showed that as the ratio increased from 3 to 6, zinc recovery enhanced from 53% to 97%, attributed to the increased volume of the leaching solution relative to the solid waste. This increase enhances the contact surface between the solution and the solid particles, leading to greater dissolution of both zinc and arsenic compounds [8].

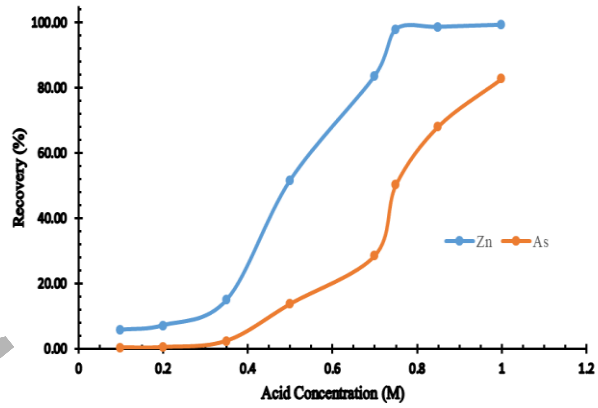

Figure 1. The effect of acid concentration on the recovery of zinc and arsenic at a temperature of 75°C, a reaction time of 90 min, and a liquid-to-solid ratio of 6

Under optimal conditions of 0.75 M acid concentration, 60°C, a leaching time of 60 min, and an L/S ratio of 6, the concentrations of zinc and arsenic were 10.89 g/L and 1.81 g/L, respectively. Due to this significant arsenic concentration, ferrous ions and various oxidants were used for arsenic precipitation. Among the manganese dioxide, hydrogen peroxide, and potassium permanganate, potassium permanganate showed the best performance with a 99.94% arsenic recovery [9, 10]. The optimal condition of ferrous ions and potassium permanganate addition was achieved at a molar ratio of 5 (as shown in Figure 2), while higher ratios (10 and 25) led to a slight decrease in recovery.

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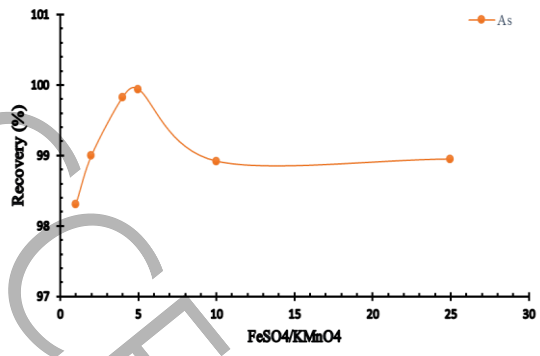

Figure 2. The effect of the iron sulfate to potassium permanganate ratio on arsenic removal at a temperature of 60°C, a reaction time of 60 min, and a pH = 4.5.

Additionally, the effect of reaction time on the arsenic removal was examined over a range of 5 to 90 min. In the first 5 min, 91% of arsenic was removed, indicating a rapid initial reaction due to the strong oxidizing capability of potassium permanganate, which can quickly convert arsenite (As(III)) to arsenate (As(V)) [11]. Therefore, a reaction time of 30 min (with a recovery of 99.88%) is optimal, balancing high removal efficiency and process productivity. Finally, the effect of pH was studied within the range of 2 to 5.5. As shown in Figure 3, increasing pH from 2 to 5.5 significantly improved arsenic removal, reaching a maximum of 99.97% at pH 4.5. At this pH, the colloidal particles formed (likely iron oxides and hydroxides) exhibit suitable stability for effective arsenic adsorption [12].

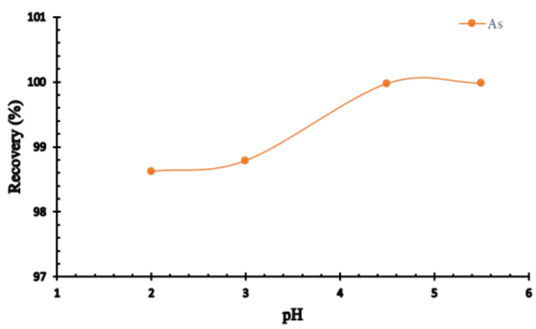

Figure 3. The effect of pH on arsenic removal at a ratio of iron sulfate to potassium permanganate of 5, a reaction time of 60 min, and a temperature of 25°C

4- Conclusions

This study examined zinc recovery from Kaldo furnace lead residue. Acid leaching with sulfuric acid achieved 99% zinc recovery under optimal conditions (0.75 M acid, 60°C, 60 min, 6:1 liquid-solid ratio). For arsenic removal, a precipitation method using iron(II) sulfate and potassium permanganate resulted in 99.94% removal under optimal conditions (5:1 iron sulfate to potassium permanganate ratio, 60 min, room temperature, a pH of 4.5). This combined approach offers effective zinc extraction and arsenic removal from the lead waste.

5-References

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