Recovery of Base Metals from Mine Tailings Dumps collected in the Vicinity of Potchefstroom: Leaching assisted by Complexing Agent

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Abstract—Toxic mining waste around the country is currently a problem of higher concern both for industries and the government. In the vicinity of Potchefstroom there are a number of mine tailings dumps that have been abandoned and not sufficiently stabilized. Once the tailings containing sulphide minerals and residual metals come in contact with diluents like rain water, it forms acid mine water that can leach metals into groundwater, rivers and streams. An effective way to remediate the mine tailings is to recover the residual metals through leaching. For this study, the leaching of zinc, nickel and iron from gold mine tailings in the presence of sulphuric acid and EDTA was investigated. The aim of the study was to determine the effect of different physicochemical parameters on the leaching process and to examine the effect of a complexing agent on metal dissolution. A sample was collected from a gold mine tailings dump characterised using XRD and XRF analyses. The effects of particle size, temperature, sulphuric acid concentration and EDTA concentration were studied, whilst other parameters were kept constant. The concentration of zinc, nickel and iron leached increased as particle size decreased. The highest recoveries of zinc, nickel and iron were obtained at a leaching time of 240 minutes, particle size of 75μm, sulphuric acid concentration of 1M, temperature of 55°C. The addition of EDTA as complexing agent improved the recovery of Fe, whilst Zn and Ni recoveries were not significantly influenced. Dissolution results also show that the leaching rate of zinc was the fastest, followed by nickel and iron respectively.

Keywords—Leaching kinetics, mine tailings, zinc, nickel, iron, sulphuric acid, EDTA

I. INTRODUCTION

Although the mining industry has played a pivotal part in economic development over the world, it is leaving a somewhat undesirable legacy. Mining activities remain one of the biggest contributors to pollution worldwide, a fact that is causing more and more concerns. The effect this pollution has on the environment is not only short lived but has serious long term implications [1].

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The mining industries together with governments worldwide are placing more emphasis on pollution prevention in the mining sector in an effort to avert any further damage to the environment [2]. Although it might already be too late to reverse the damage done, it is of utmost importance to limit the effect on the environment.

The main contributor to pollution from the mining sector is in the form of mining waste. Mines produce waste consisting of milled and processed waste rock that is dumped in huge quantities in open areas of land [3]. This toxic mine waste can lead to immense environmental damage if not stabilized and sufficiently remediated [1].

Up until 1997, South Africa produced approximately 468 million tons of mineral waste per year [4]. Due to a lack of rehabilitation and precautionary measures, this mining waste produced by South African mines has resulted in lasting environmental damage [5].

This study is specifically focused on mining waste in the form of mine tailings. Tailings are a form of fine-grained mining waste produced when large quantities of rocks are crushed and milled to extract valuable minerals [6]. Tailings contains an estimated 10 to 20 percent of recoverable economic minerals and is usually kept in tailings dams or piles [7]. These mine tailings dams and piles pose a number of environmental threats, e.g. acid mine drainage (AMD), air and water contamination due to wind erosion and the risk of possible dam failures [4].

In South Africa there are approximately 400 tailings dams of which 270 are contained in the Witwatersrand Basin, covering an estimated 400 km² [4,8,9]. When mines terminate production, these tailings dams are frequently left without any stabilization or protection. In the Potchefstroom vicinity there are a number of mine tailings dumps that have been abandoned and not sufficiently stabilized. The abandoned Machavie mine near Potchefstroom have five tailings dams containing approximately 2.5 million tons of material without any stabilization or protection [5].

One of the ways to effectively mobilize specific metals to remove them from tailings dumps, is by making use of a hydrometallurgical process. Hydrometallurgy is a modern day method used to extract metals from ore deposits by using aqueous chemistry [10].

The main hydrometallurgical process that the study will be focused on is leaching. Leaching occurs when an aqueous
solution containing a lixiviant flows through the ore deposits, dissolving solid minerals from their host rocks [11]. The lixiviant can be acidic or basic. Ideal lixiviants should be economical, universally applicable, easy and safe to transport and easily recyclable [12]. Complexing agents are also frequently used during industrial leaching processes. These complexing agents form strong water-soluble metal-chelant coordination compounds by desorbing trace metals from ore deposits [13]. Adding complexing agents during the leaching process can vastly improve the efficiency of metal removal.

In this study the leaching behaviour of Zn, Ni and Fe contained in gold mine tailings will be studied in the presence of a lixiviant (sulphuric acid) as well as a complexing agent (EDTA). Different physicochemical parameters are varied to investigate their influence on the leaching process.

II. METHODOLOGY

A. Materials

The first step in the experimental procedure was the sampling of mine tailings dump in the vicinity of Potchefstroom. The mine tailings dump was situated in Randfontein (S26°7′53″, E27°42′44″) and the location of the dump can be seen in Figure 1.

![Fig 1: Mine tailings dump location](image)

B. Characterization of tailings

X-ray Fluorescence (XRF) as well as X-ray Diffraction (XRD) analyses was used to determine the chemical and mineralogical composition of the two samples.

C. Leaching experiments

Leaching experiments were conducted using 250ml Erlenmeyer flasks that were placed inside a heated shaker. The heated shaker was set at a specified stirring speed and temperature. Analytical grade sulphuric acid (98 vol% H2SO4) was used as lixiviant for leaching experiments, whilst EDTA disodium salt ([CH3N(CH2COOH)CH2COONa]2H2O) was used as complexing agent. Leaching experiments were carried out in 2 stages i.e. sulphuric acid first, followed by EDTA leaching in combination with sulphuric acid.

a) Sulphuric acid leaching:

A 100ml aqueous solution acidified with sulphuric acid (pH = 2) was added to a 250ml Erlenmeyer flask together with 5g of sample (S/L ratio = 0.05g/ml) and placed inside the heated shaker at a stirring speed of 200rpm and temperature of 45°C. After 1 hour, 2ml of pregnant solution was taken from the flask using a syringe and a 0.45μm syringe filter. This was done four times for a total time of 4 hours with an increment of 1 hour. The sample was then analysed through means of ICP-OES analyses. The procedure was repeated for different particle sizes (-75μm, -106+75μm, -180+106μm, -300+180μm) acid concentrations (0.1M, 0.25M, 0.5M, 1M) and temperatures (20°C, 35°C, 45°C, 55°C).

b) EDTA and sulphuric acid leaching

Solutions were made up for 4 different EDTA concentrations (0.05M, 0.1M, 0.2M, 0.3M). These solutions were then brought to a pH of 2 using sulphuric acid. 100ml of the solution was added to a 250ml Erlenmeyer flask together with 5g of sample (S/L ratio – 0.05g/ml) and placed inside the heated shaker at a stirring speed of 200rpm and temperature of 35°C. After 1 hour, 2ml of pregnant solution was taken from the flask using a syringe and a 0.45μm syringe filter. This was done for a total time of 4 hours. The sample was then analysed through means of ICP-OES analyses.

III. RESULTS AND DISCUSSION

A. Mineralogical and elemental composition of tailings

The X-ray diffraction of the tailings illustrated that the sample consisted of Quartz (35.7%), Pyrophyllite (29.6%), Ilmenite (7%), Hematite (27.4%) and Illite (0.3%). The elemental composition was determined through X-ray fluorescence analysis and showed high concentrations of Fe present in the tailings, whilst Ni and Zn was also present but at lower concentrations.

B. Sulphuric acid leaching

a) Effect of particle size:

The results as illustrated in Figure 2 show that the smallest particle size (-75μm) provided the highest recovery for all three metals. This is in accordance with literature, given that smaller particle sizes provide a larger surface area for reactions to take place. Various authors [14,15] found that smaller particle sizes improved metal recovery.

![Fig 2: Effect of particle size on metal recovery at 45°C, pH - 2 and a stirring speed of 200 rpm](image)

b) Effect of sulphuric acid concentration:

The leaching results with the different sulphuric acid concentrations clearly showed that the mass % recovered of each metal increased as concentration increased. At a concentration of 0.1M and time of 4 hours, the mass % Zn, Fe and Ni recovered was 61%, 6.5% and 11% respectively.
recovery of Zn, Fe and Ni increased to 83%, 9.3% and 15% respectively at a concentration of 1M. These results are illustrated in Figures 3-5 for all three metals. Previous studies illustrated the similar trends [16, 17, 18].

**c) Effect of temperature:**

The leaching results for various temperatures are illustrated in Figures 6-8. The results indicate that leaching efficiency increased as temperature increased. The highest recovery for all three metals was achieved at 55°C. All of the Zn in the sample was recovered at this temperature, whilst 9.6% Fe and 19.8% Ni was recovered. This was in accordance with results reported in previous studies [15]. An increase in temperature has the potential to increase the interaction between the elements or/and compounds involved in the reaction, therefore increasing the reaction rate linearly or exponentially.

d) **Effect of EDTA concentration:**

The introduction of EDTA as complexing agent had varied effects on the recovery of each metal. In the presence of EDTA, the recovery of Fe considerably increased. The recovery of Ni was not significantly affected, whilst the recovery of Zn decreased with the addition of EDTA. These results can be seen in Figures 9-11.
The effect of a complexing agent on the leaching kinetics was determined as: particle size of -75µm, 1M H₂SO₄ concentration and temperature. The optimal leaching with a decrease in particle size, an increase in sulphuric acid and 55°C. It was further noted that EDTA had varied effects on the metal recovery. Whilst improving the recovery Fe, no significant effect was observed with Ni whilst Zn recovery decreased with the addition of EDTA. Additional investigation is thus needed to further understand the effect of EDTA as complexing agent with regards to gold mine tailings.

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REFERENCES


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Dr Elvis Fosso-Kankeu has been the recipient of several merit awards.