

Bacterial Leaching of Pyrite

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ABSTRACT: The ability of bacteria to catalyse the oxidation of sulphide minerals is well known. Pyrite is the most common of the naturally occurring sulphide minerals and is present as an accessory mineral in practically all commercial sulphide ore deposits. This paper presents the results of the bacterial leaching of pyrite with different particle size and pulp density. Pyrite leaching was performed in flask and the laboratory scale stirred reactor using a 1.7 litre capacity for different size fractions. The pyrite leaching was found to have increased as particle size decreased. Fe oxidation rate also found to be depending on the pulp density for the coarser particle size. At 1 % pulp density 45 % Fe oxidation was obtained in 48 hours whereas with 0.5 % pulp density 35 % Fe oxidation was obtained for -63+56 micron size fractions for the same time interval. The experiments revealed that the rate of bacterial oxidation of pyrite was depend on particle size and slightly rapid oxidation obtained in flask comparing the reactor.

1 INTRODUCTION

The ability of certain microorganisms to catalyse the oxidation of sulphide minerals has attracted much attention in recent years in minerals engineering. Bacterial oxidation of sulphide minerals is an attractive method for the production of metals from ores or concentrates as it is flexible, does not require high operating temperatures or pressures, it is self-generating in terms of solvent in the form of acid ferric sulphate solution. It involves reactants which cannot be produced by simple chemical means alone, being a less energy intensive and an environmentally attractive process (Pooley, 1987).

Pyrite can be considered to be the most important sulphide mineral substrate as far as leaching with bacteria is concerned, and it is also the most common contaminant of complex sulphide ores and the tailings produced from their beneficiation. Materials containing pyrite in excess are therefore ideal substrates and feedstock for conventional bacterial leaching treatment as it contains equal quantities of ferrous iron and sulphur required for energy sources (Pooley, 1998). The iron oxidising bacterium *Thiobacillus ferrooxidans* was isolated from an acid mine waters in 1947. They were soon associated with the dissolution of metals from ores. Since then, extensive efforts have been concentrated in this direction in an attempt to gain better understanding of pyrite bioleaching. The removal of pyritic sulphur from coal has also been investigated

and the commercial feasibility of removing sulphur from coal has been realised using bacteria.

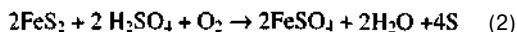
Bacterial leaching also has been shown to offer alternative routes to the production of many metals such as copper, zinc and nickel containing sulphides (Pooley 1987, Göktepe et al. 1998, Smith et al. 1993, Brierly, 1978). It offers process options for low grade, especially extraction of copper and uranium metals from low grade ore or mine waste, small deposits and problematic ores that would be uneconomic to treat using conventional process technology. One of the most rapidly developing areas in hydrometallurgy is the application of bacterial leaching as a pre-treatment step for the extraction of gold from refractory ores and concentrates, offering potentially significant advantages over the conventional oxidative pre-treatment alternatives (Komnitsas and Pooley, 1989). Bacterial leaching has been shown in numerous dump and heap leaching situations to be an economic process for the treatment of various commercial sulphide ores.

The aim of this paper is to provide an overview of the pyrite bioleaching considering particle size related to the research carried out for pyrite removal from coal by bacterial leaching.

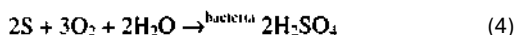
2 THE MECHANISM OF SULPHIDE MINERAL OXIDATION BY BACTERIA

Thiohaecillns jerrooxidans and *Thiohaecillus thiooxklans* are live in inorganic matter (autotrophic) and utilise oxygen for growth (aerobic) bacteria and require an acid environment between pH 1.5-5. These organisms exhibit different temperature optima for different strains and substrates but optimum is often considered 30-35° C. The organisms are slow-growing and division time is variable with conditions (Poolcy, 1998).

The exact role of bacteria in bacterial oxidation of sulphide minerals is complex. The bioleaching is due to a catalytic effect of the organisms. Two main mechanisms for bacterially assisted oxidation of insoluble sulphide minerals have been proposed, which often referred to as the direct and indirect mechanisms. Both direct leaching (bacteria attached to the sulphide minerals) and indirect leaching (Fe⁺² oxidised to Fe⁺³ by the bacteria followed by metal leaching by the Fe⁺³) take place. In the presence of water, oxygen and sulphuric acid pyrite slowly autooxidises, due to the formation of reaction product layers such as sulphur on the surface of pyrite particles that resulting in diffusion controlled reactions, according to equations 1 and 2 :



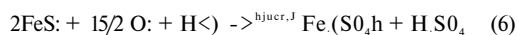
The fundamental reaction for indirect leaching then involves the microbial oxidation of ferrous iron to ferric sulphate and elemental sulphur to sulphuric acid as shown in equations 3 and 4 respectively. *Thiohaecillus ferrooxidans* are able to oxidise ferrous iron at a rate 500,000 times as fast as would occur in their absence (Brierly, 1978).



The ferric sulphate formed during the indirect mechanism reacts with pyrite according to equation 5



The ferrous sulphate and sulphur which are formed in equation 5 are again oxidised by bacteria to ferric sulphate and sulphuric acid as shown in equation 3 and 4. The overall reaction equation for direct oxidation of the ferrous sulphate ions of pyrite is represented by equation 6



The direct attack on the sulphide mineral with ferrous iron as the oxidant as shown in equation 6 proceeds rapidly and is chemically controlled. The reaction products such as elemental sulphur do not form on the pyrite surface since they are oxidised by the bacteria (Pooley, 1998).

3 MATERIALS AND METHODS

3.1 Materials

Pure pyrite sample was used in the bacterial leaching experiments and was crushed and ground to below 63 micron in the tema mill. Then sample was separated to size fractions by using the Cyclosizer and after 15-20 minutes processing, sample from each cyclone were collected into separate beakers, filtered, dried and weighed. Bacterial leaching was applied for each cyclone fractions.

3.2 Microorganisms

A culture of iron oxidising *Thiohaecillus Ferrooxidans* which have been grown on a variety of sulphide concentrates over years in the Cardiff University, Division of Materials and Minerals Engineering Department were used throughout the study.

3.3 Methods

The bacterial leaching experiments performed in this study employed by shake flasks and pachuca air-stirred reactors techniques.

Shake flask tests consists of culturing the bacteria with the pyrite samples in 250 ml Erlenmeyer flasks containing 100 ml of suspension in an thermostated gyratory shaker at 220 rpm maintained at 35 °C. Nutrient chemicals, "9 K" salts medium, to promote bacterial growth (0.01 gr/l Calcium Nitrate, 0.1 gr/l Potassium Chloride, 3gr/l Ammonium Sulphate, 0.5g/l Magnesium Sulphate) was used throughout the tests. The desired quantity of the mineral size fraction followed by addition an innoculum of bacteria harvested from a stock reactor where they had been grown on pyrite to provide an initial concentration of approximately 1x10⁸ cells/ml. 100 ml of bacterial ferric sulphate stock solution and 9K medium was dispensed into an Erlenmeyer flask and flasks were stoppered and incubated in the gyratory shakers at the required temperatures. Correction for evaporation was made prior to sampling by the addition of acidified water (pH 1.8).

Pachuca air stirred reactors of 1.7 litre capacity, which was sparged with air, was also used to compare their efficiency with the results of shake flask leach tests under similar conditions. The reaction vessel was maintained at a temperature of 30-33°C by means of warm water socket. The

leaching tests were initiated by charging the 1.7 litre reactor by an inoculum bacterial stock leach solution and sample plus "9K" nutrient chemicals to promote bacterial growth. Water lost due to evaporation was replaced by the addition of acidified water (pH 1.8) to the predetermined mark before sampling.

Throughout the experimental programme bacterial oxidation of the pyrite with respect to time was monitored by measuring the iron concentrations and Eh/pH values of the leach solutions at specific time intervals. The Eh/pH of the medium was measured using a Corning Eh/pH meter. Periodically representative 1 ml sample of leach suspensions were removed from the shake flasks and pachuca reactors. To determine iron oxidation sample was diluted which necessary for metal analysis on the A.A.S (Perkin Elmer Atomic Adsorption Spectrometer).

4 RESULTS AND DISCUSSIONS

Bacterial leaching processes are affected by numerous variables. Variations in the mineralogical structure of the mineral may significantly alter the oxidation response of sulphide minerals. Also there are a number of critical variables which effect the reactions, these include particle size, pulp density, iron content of ferric liquer solutions, bacteria amount and time of process,

Ferric iron plays an important role in bacterial leaching and its content in leaching liquer has effect on oxidation rate. The influence of initial ferric iron on bacterial oxidation of sulphides is complex. In the literature it has been reported that Fe^{+7}/Fe^{+2} couple is the major intermediate electron acceptor/donor system for pyrite oxidation in the bacterial leaching (Başaran et. al. 1987).

Also surface area is important in bacterial attachment, since increased surface exposure provides greater area for attachment (Brierly, 1978). The rate of bacterial and chemical oxidation of sulphides can be enhanced by increasing the total surface area exposed to leach solutions. This can be achieved by decreasing the size of particle which increases the specific surface area and increasing the pulp density which places more particle mass of fixed specific surface area into a unit volume. It appears that a low specific surface area metal extraction is limited by the availability of solid surface for bacterial activity.

The significance of particle size and distribution has been investigated using sized fractions of pyrite and a series of tests were conducted. Figures 1 and 2 illustrate graphically rate at which pyrite can be leached for 0.5% and 1% pulp density for different particle sizes. At the beginning the Eh/pH of the solutions were 686 mV/ pH 1.28 and 716 mV /pH 1.26 respectively. Eh/pH was varied between 650-

720 mV/1.20-0.96 through all experimental study. Fe content of the stock bacterial ferric liquer solution was about 12g/l. Leaching rates have been found to be proportional to the pyrite particle size. As shown in Figure 1 leaching rate almost doubled especially with the fine particle fractions and as particle get coarser slower leaching was occurred. More rapid metal dissolution occurred -20+10 micron and -10 micron size fractions due to the higher available mineral surface area. Reducing the particle size from 63 micron to less than 32 micron almost doubled the rate of bacterial leaching. Figure 2 shows the 1% pyrite leaching with the same particles fractions with the similar experimental conditions. With particle size below 10 micron in 50 hours 90% Fe oxidation occurred while for -63+56 micron size fraction about 42% Fe oxidation occurred for the same time interval. As expected leaching is very depend on particle size, metal extraction decreased with increasing particle size. When the results were compared between Figures 1 and 2, it is shown that for -20+10 and -10 micron size fractions leach rate was two times faster in 0.5% pulp density while the other fractions revealed not very much differences probably very small increase in pulp density. It has been shown that the highest rate of oxidation occurs at a particle size below 20 micron.

As Figure 3 shows, leaching in the reactor with 1% pulp density slower leach rate was observed comparing the shake flask with the similar experimental conditions. Within 60 hours about 40% Fe oxidised for -56+45 micron fraction while 65% oxidation was obtained in shake flasks for the same

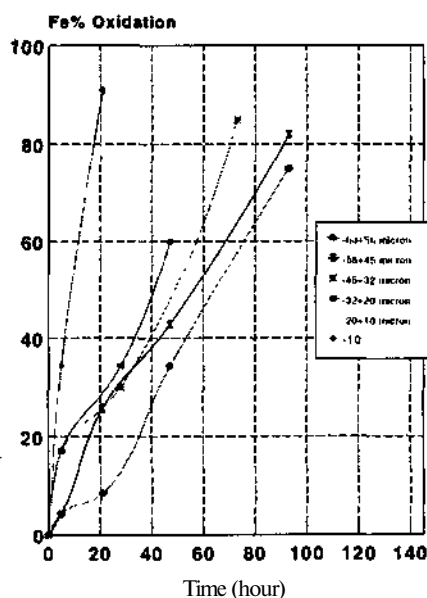


Figure 1. 0.5 % pyrite bacterial leaching in the flask

traction These figures show that within 2 days 80% and 55% pyrite can be leached respectively in flask and leactor

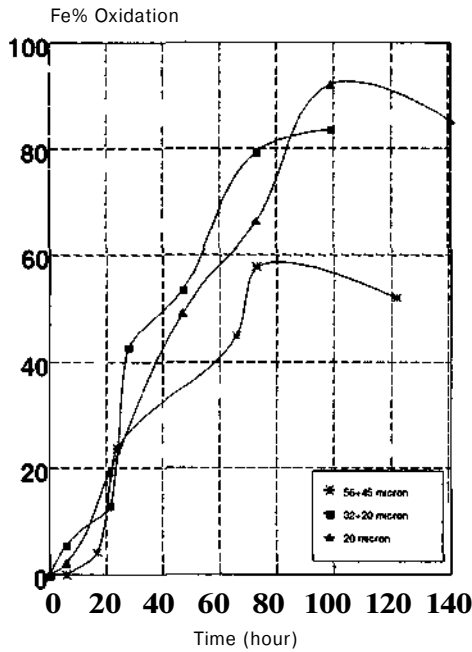


Figure 1 1% pyrite bacterial leaching in the leactor

It has been shown a relationship between the leach rate and surface area where high surface area was maintained decreasing the particle size. Investigation have revealed that pyrite leaching was very depend on particle size even very narrow particle fractions. Expected effect of pulp density was not observed for the fine particle fractions in the used low pulp density. Bacterial leaching of pyrite in the leactor showed slightly slower leaching rate. It is proven that oxidation of pyrite by the presence of *Thiobacillus ferrooxidans* is greatly accelerated by the surface area.

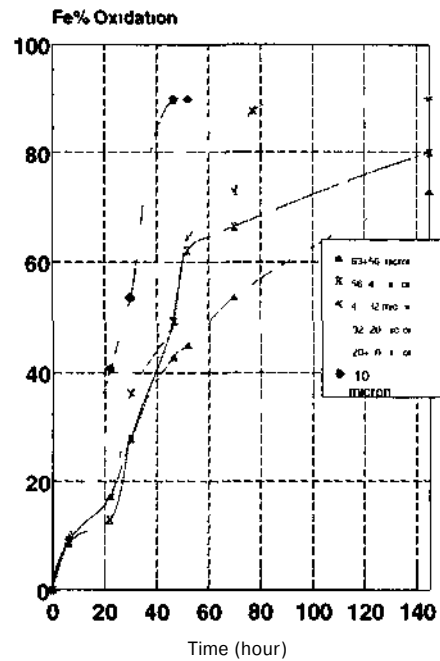


Figure 2 1% pyrite bacterial leaching in the flask

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