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HYDROPROCESSING OF SULPHIDES FORUM

BACTERIAL LEACHING AT ELEVATED pH USING BIOHEAP™ TECHNOLOGY

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ABSTRACT

Many low grade nickel sulphide ores are hosted in gangue containing high levels of magnesium silicates, which consequently consume a large amount of sulphuric acid in conventional bacterial leaching scenarios where solution pH's below 2 are required. BioHeap has developed a saline tolerant bacterial culture using patented methods, that is capable of operating at elevated pH's at levels where ferric iron precipitates out of solution. Operating at elevated pH has the dual advantage of significantly reducing the acid consumption and reducing limestone demand for iron disposal.

Further work is planned to critically compare the performance of the high pH culture against cultures operating at conventional pH and to expand the range of cultures that are capable of operating at high pH.

BACKGROUND

Introduction of Western Areas and BioHeap

Western Areas is an Australian-based nickel miner listed on the ASX and TSX. The main asset is the 100% owned Forrestania Nickel Project, located 400km east of Perth. The company's two high grade mines, Flying Fox and Spotted Quoll, are two of the lowest cost nickel mines in the world.

Flying Fox is a high grade nickel deposit that produced 81,143 tonnes of Ore at 5.3% nickel for 4,278 tonnes of contained nickel, in the March 2012 quarter. Spotted Quoll is Western Areas second mine located 6km to the south of Flying Fox and consisting of an open pit and underground mine. The total ore reserves at Spotted Quoll comprise 1.67Mt at an average grade of 4.1% nickel containing approximately 67,870 tonnes of nickel.

Production from the Tim King pit for the March 2012 quarter was 57,207 tonnes of ore at 4.0% nickel for 2,280 tonnes of contained nickel. The Spotted Quoll underground mine production for the same period was 23,651 tonnes of ore at 4.5% nickel for 1,044 tonnes of contained nickel.

Flying Fox and Spotted Quoll are the main feed sources for Western Areas' Cosmic Boy nickel concentrator which produces high grade nickel concentrate for sale in Australia and China. Sales from the Cosmic Boy concentrator during the March quarter totalled 57,363 tonnes of concentrate containing 8154 tonnes of nickel.

Western Areas' other assets include 19.9% of Canadian nickel company, Mustang Minerals Corp, 75 % of Finnish nickel company, Finn Aust Mining Plc and 100% of the BioHeap Sulphide leaching technology.

Western Areas acquired BioHeap in 2009, including the technology, intellectual property and key personnel. The BioHeap technology utilizes microbes for leaching of base metal sulphides, including primary copper, nickel and zinc sulphides as well as refractory gold ores. BioHeap has been successful in developing proprietary bacterial cultures that address the needs of the industry through its extensive research and development program for more than the last decade.

The results of this research program are a wide range of cultures that can leach primary sulphides (including chalcopyrite) over a wide range of temperatures (15°C - 95°C) in fresh, saline and hypersaline water, up to 200 g/L TDS. Arsenic tolerant variants are also available for treating high arsenic ores and work is continuing on cost reduction and broadening the range of conditions over which the technology is suited. The success of the bacterial development work and practical experiences have resulted in a number of patents that have being filed by BioHeap Ltd. These patents cover areas such as bacterial assisted heap leaching of sulphides minerals including chalcopyrite, to adaptation and improvement of bacteria used in the leaching process. This paper aims to demonstrate one of the recent advances in the BioHeap technology.

EXISTING LEACHING CONDITIONS

Bioleaching is a process whereby microorganisms catalyze the dissolution of valuable metals from ores into solution. In general, the dissolution of mineral sulfides in bacterial systems, is the results of ferric iron and proton attack via the polysulfide pathway (Rohwerder et al., 2008). The conditions for such a reaction to occur are generally dictated by the ability of the microorganism to catalyze the leaching process efficiently.

Previous studies have demonstrated that bioleaching of mineral sulfides occurs favorably at pH <3 (Halinen et al., 2009), with majority of heap bioleaching processes of low grade ore are treated with a solution pH between 1.5 to 2.5 (Plumb et al., 2008). At such pH conditions, the bio-oxidation acidophilic microorganisms convert ferrous ion to ferric ion which is needed for the leaching of sulfide minerals.

Bioleaching of materials at a high pH range has been studied in the past (Cameron, et al., 2009a; Cameron, et al., 2009b; Cameron, et al., 2010; Halinen et al., 2009; Plumb et al., 2008) .The majority of results published suggested that beyond a pH of 2 the rate of leaching is significantly decreased and the percentage of metals recovery is reduced (Plumb et al., 2008). Halinen et al., 2009 reported the rate of bioleaching of nickel and zinc at pH 1.5 is 3-4 times faster than the rate of leaching observed at pH 3. It is suggested that the lack of dissolved ferric ion and diffusion barriers created by iron oxide precipitates minimized the rate of leaching at pH 2.5 to 3.

Interestingly, Cameron et al. (2009a; 2009b; 2010) , has successfully demonstrated bioleaching of low-grade ultramafic nickel suphide ore at temperature 30 °C and 45 °C at pH 3 by mixed microbial culture previously adapted to the ore. The success of Cameron's studies may be largely contributed to the adaptating of the microbes to specific conditions and feed materials prior to the bioleaching procedure. The use of adapted microorganisms prior to leaching can enhance the leaching efficiency by 2 to 4 times when compared to unadapted culture (Li and Ke, 2001a; Li and Ke, 2001b).

WHY DO WE WANT TO LEACH AT HIGHER PH?

Bioleaching of metal sulphides at extreme pH (<2) can result in the dissolution of gangue materials. Undesirably cations, such as aluminium, manganese, amorphous silica and specifically, excessive ferric, can further result in releasing toxic trace elements, thickening of leach liquor thus potentially interfering with liquid flow in heap leaching, formation of passivation of sulphide minerals by jarosite formation or can be problematic during recovery of base metals during refining (Dopso et al., 2009, Halinen et al., 2009). Final effluents from bioleaching operation generally have to be neutralized and to remove iron and sulphate as stable end products by the addition of limestone or lime to increase of the pH of effluent to approximately 3. Therefore, bioleaching of metals at high pH may potentially improve the downstream metals recovery processes, as well as reducing the operating costs.

The mineralogy of the specific ore can have a significant impact on the acid consumption properties and solution composition of the bacterial leaching system. Depending on the composition of the feed sample, the dissolution of mineral sulfides can be classified as either acid-producing or acid consuming. The majority of the gangue present in most ore samples, include magnesium silicates, and are acid consuming (Rawlings et al., 2003; Strömberg and Banwart, 1999). Therefore, maintaining of solution pH within a desirable range with the addition of sulfuric acid can be a major cost during a bioleaching operation (Watling, 2006). The application of pre-leaching of ore containing high levels of magnesium gangue prior to the bioleaching phase has been shown to reduce time required to stabilize the pH level between 1.7 – 2.2 (Zhen et al., 2009; Qin et al., 2009) . However, such a method has resulted in higher overall acid consumption at greater than 600 g kg^{-1} ore (Zhen et al., 2009; Qin et al., 2009). Halinen et. al. (2009) has demonstrated that an increase of pH from 1.5 to 2.0 during the column leaching of a particular black schist ore can reduce the acid consumption from 160 g kg^{-1} ore to 38 g kg^{-1} ore.

BIOHEAP DEVELOPMENT PROGRAM

Methodology

Bacterial

For development of cultures capable of operating at high pH's, it was advantageous to select a starting culture that was not dependent on high ferric levels for leaching to progress. Both BioHeap's chalcopyrite and saline tolerant cultures naturally operate in low ferric environments at conventional pH's (below 2), and the saline culture was chosen as the starting point, as it also operates in low total iron environments due to tendency of the iron to precipitate in the highly saline environment. As ferric iron begins to precipitate beyond pH 3 due to exceeding the solubility product, in a similar manner that precipitation is noted in BioHeap's saline culture, this culture was thought to be the best match to the proposed leaching conditions. Using BioHeap's patented procedures, this culture was then adapted to operate at higher pH's.

BioHeap culture, Ni-S-J065B, was used in these studies. The cultures were grown in 3L stirred tank reactors and were maintained on nickel concentrate suspended in water. The desirable pH of the solution was achieved by addition of concentrated sulphuric acid. A customised water bath was used to regulate the temperature in the bioreactor at approximately 55 °C and aeration was provided to the culture by compressed air introduced into the mixing zone of the reactor

Prior to it use, Ni-S-J065B was adapted to saline condition of 100g/L Cl- (115 g/L TDS). , and a sub-culture of Ni-S-J065B was gradually adapted to a solution pH of 3.5. To distinguish the newly developed culture from the original inoculum, it was renamed to Ni-S-J069B.

Sample Preparation of High Magnesia Ore

A high magnesia ore sample, J062A, was split using rotary splitter to provide samples as feed for bacterial development work and metallurgical analysis. A Head sample of the ore was assayed for Ni, Co, Zn, Cu, Fe, Al, Ca, Mg, Mn, S (Total), S (Elemental), S_2- (Sulphide), SO_4^{2-}, C (Total), CO_3^{2-}, and an ICP Scan.

Acid consumption studies were carried out on sample crushed to P100= 9.5mm using a bottle roll technique. Concentrated sulphuric acid was used to maintain the solution at pH 1.8 to simulate conventional bioleaching conditions. Acid addition was recorded and used to calculate the total quantity of acid consumed by the ore.

Results

Head Grade and Mineralogical Characterization

Head grade assay revealed that the ore, J062A contains 0.68% nickel, 11.30% iron and 20.10% magnesium. Mineralogical analysis indicated the main nickel bearing sulphide to be pentlandite at 2.18% of the total sample. Chalcopyrite is the other economic sulphide with a concentration of 0.14%. The main sulphide gangue occurs as pyrrhotite (2.18%). Magnesium is found in the form of forsterite (56.1 %), edenite (18.8%), clinochlore (7.9%) and dolomite (2.9%). There appears to be a low level of liberation of nickel sulphides, however at the 3mm crush size the majority of the grains have some exposure to the surface of the particle, indicating potential for leaching.

Table 1: Head Grade of Ore Sample

Element	Ni	Fe	Mg
Grades (%)	0.68	11.30	20.10

Acid Consumption Test based using Bottle Roll

In order to understand the acid consumption characteristic of the ore under bioleaching solution acid consumption tests using a bottle roll technique at pH 1.8 was carried on ore crushed to 100% passing 9.5 mm. Figure 1 shows that the solution pH took 54 days to reach a value of 1.8 and consumed ~311 kg of 98% H_2SO_4 per tone of ore. The ore sample continued to consume significant quantity of acid when the pH condition was maintained at value of 1.8. Upon termination of the study on day 119 (2856 hrs) the ore sample reported an acid consumption value of 558 kg t-1 ore.

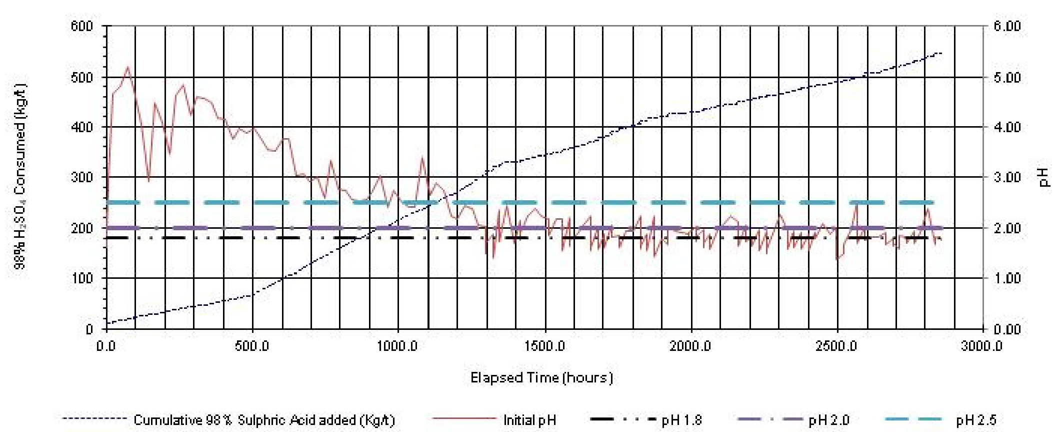


Figure 1: Acid consumption study on ore sample crushed to P_{100} = 9.5 mm and pH value of the solution maintained at bio-leaching condition of 1.8

Bacterial Leaching Study

The bioleaching of J062A ore was carried out at a temperature of 55 °C at various solution pH values. Preliminary results indicated that nickel recoveries between all cultures were similar (Figure

2 A). Cultures leaching at pH of 3.5 were able to obtain a slightly higher nickel recovery in contrast to those operating at solution pH's less than 3.5 and comparable to the result obtained at pH 1.8. At solution pH's of 1.8 and 3.5, the cultures were able to leach more than 75% of the nickel in the ore. Cultures maintained at pH 2.8 and 3 obtained the least nickel recovery at approximately 56.7% and 67.9%, respectively.

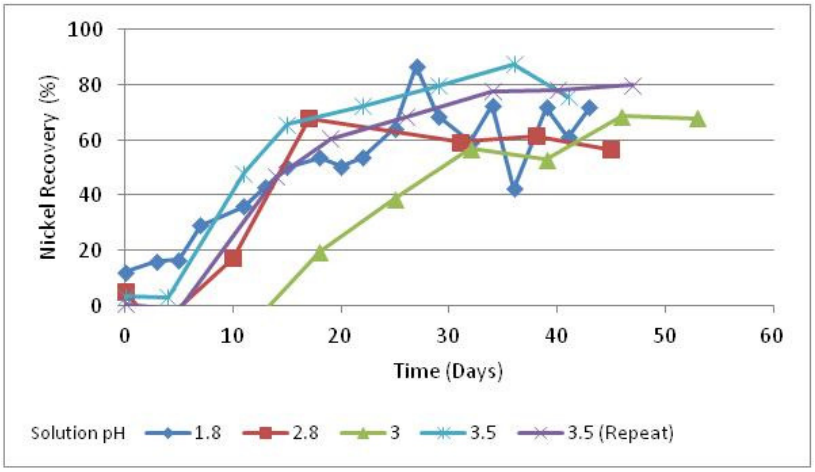


Figure 2: Percentage of nickel recovered from bioleaching of ore sample J062 containing high MgO using standard culture Ni-S-J065 and high pH adapted culture (Ni-S-J069) under saline condition (100 g/L Cl) at solution pH of 1.8, 2.8, 3 and 3.5

Redox potential measurements throughout the study revealed that the readings fluctuated during the first 20 days in all cultures before increasing and stablising at a constant value (Figure 3). At the end of the study, cultures grown at pH 1.8 and 2.8 reported an ORP value of 434 mV and 413 mV v's Ag/AgCl, respectively. For cultures maintained at pH 3 and 3.5 redox potential was found to be in the range of 380 to 395 mV v's Ag/AgCl.

The concentration of total iron in solution monitored during the experiment clearly shows the effects of pH on the iron in solution. At end of the study the total amount of dissolved iron in solution for the culture grown in pH 1.8 solution was 2.10 g L-1. The tests conducted at pH values of 2.8 and 3 showed a significant decrease of dissolved iron, with a final concentration of approximately 117 mg L-1 and 82 mg L-1 of total iron, respectively. Minimal iron was found to remain in solution for the culture grown at pH 3.5 (≤ 4 mg L-1).

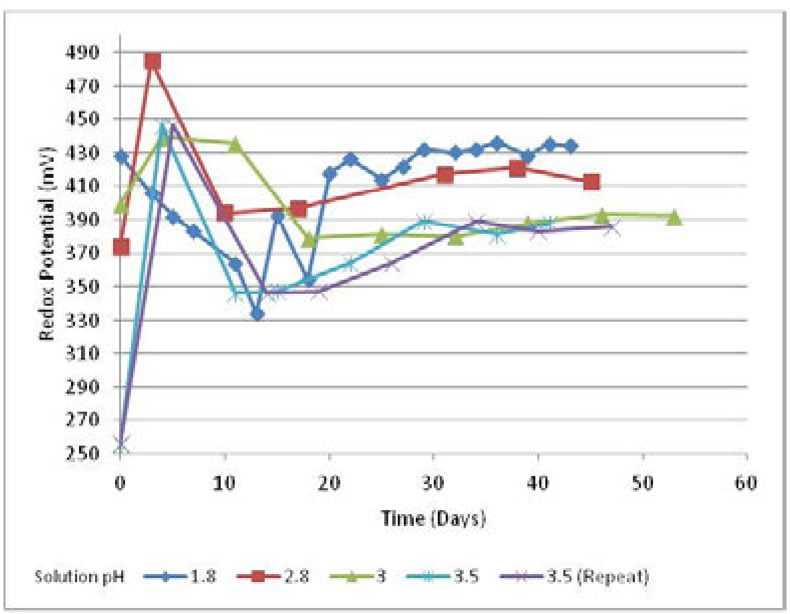
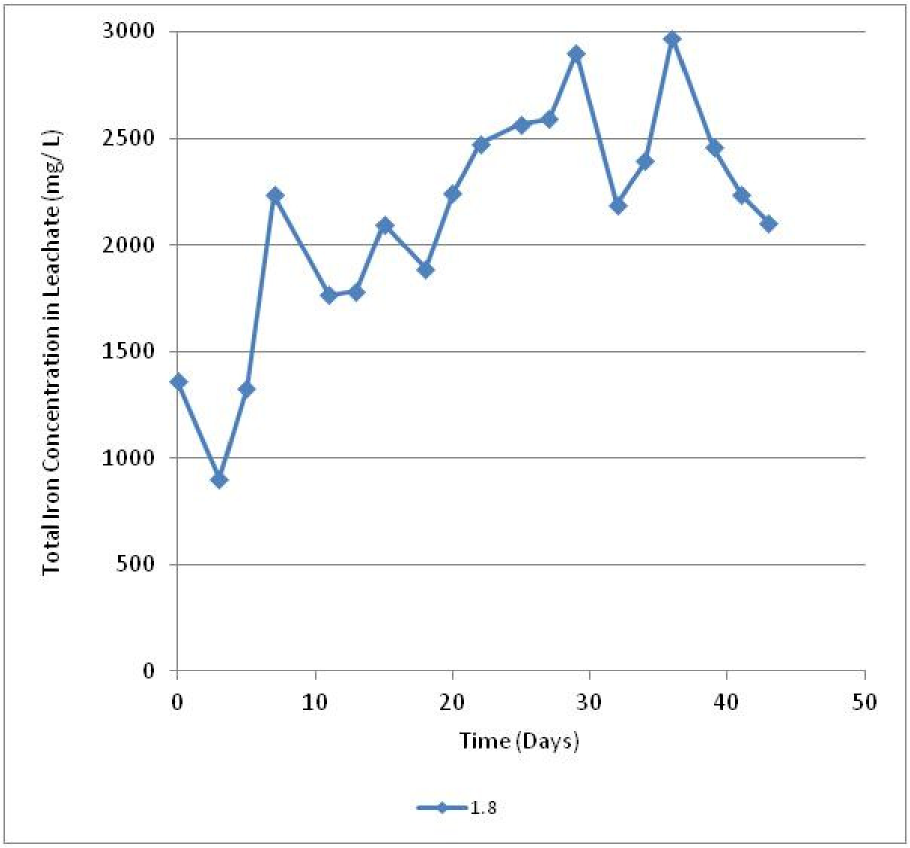


Figure 3: Redox potential (v Ag/AgCl) recorded during leaching of ore sample J062 containing high MgO using culture Ni-S-J065 and high pH adapted culture (Ni-S-J069) under saline condition (100 g/L Cl) at solution pH of 1.8, 2.8, 3 and 3.5

(A)



(B)

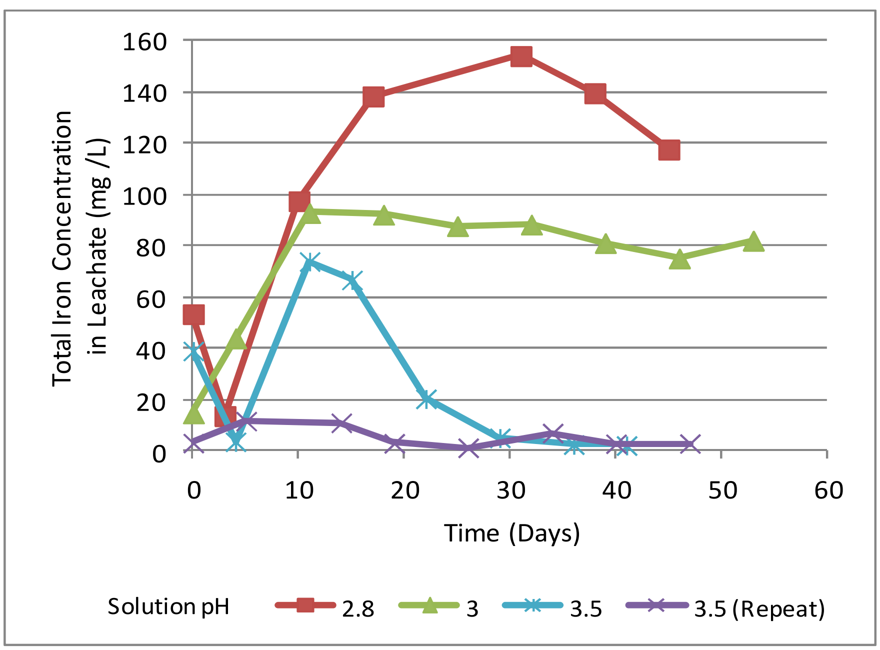


Figure 3: Total iron in solution from bioleaching of ore sample J062 containing high MgO using standard culture Ni-S-J065 and high pH adapted culture (Ni-S-J069) under saline condition (100 g/L Cl) at solution pH of 1.8 (A) and at pH 2.8, 3, 3.5 (B)

Sulphuric acid used to maintain the solution pH for each of the cultures was recorded during the study and used as a method of comparing acid consumptions between the tests. Preliminary analysis revealed that the cumulative quantity of acid needed to maintain the solution pH at low pH, is greater than for those tests at higher pH. The test at pH 1.8 recorded an acid consumption of

736 kg of acid per ton of ore. The quantity of acid required at pH 2.8 and 3 were 163 kg/t and 91 kg/t, respectively. At pH 3.5 acid addition was between 11 and 22 times less than those reported at pH 1.8.

It should be noted that acid consumptions are comparatively higher compared to the bottle roll test above due mainly to the much finer particle size of the leach test, compared with the bottle roll test.

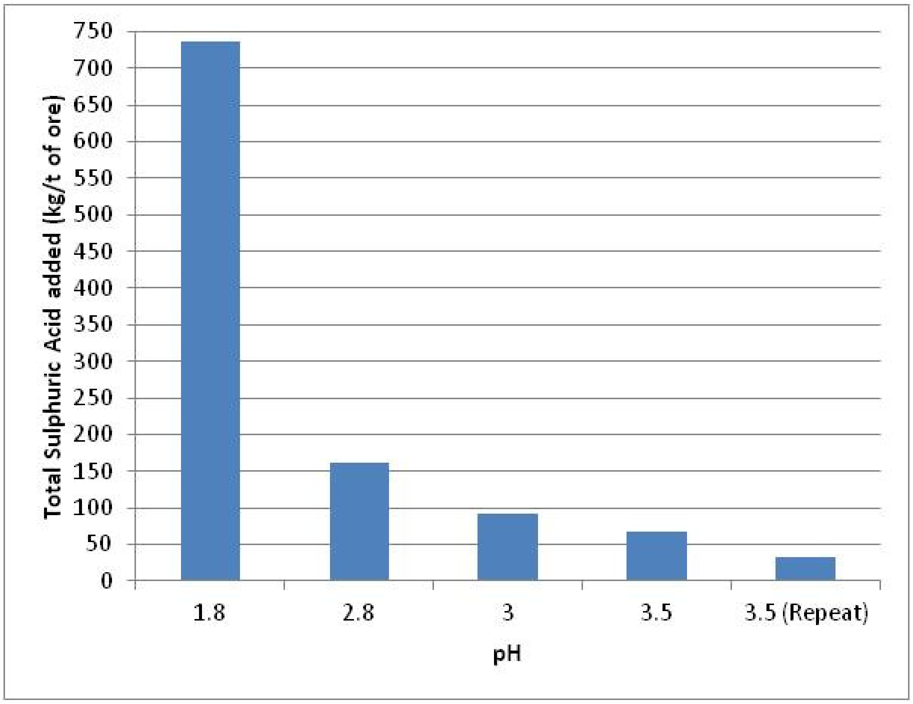


Figure 4: Total cumulative quantity of acid added to each culture in order to maintain the pH at the respective value of 1.8 2.8, 3 and 3.5

FUTURE WORK

A follow up testwork program is planned to critically compare the performance of the high pH bacteria developed during this study with bacteria that operate at standard pH, as well as to expand the pH range of the existing BioHeap™ cultures.

CONCLUSIONS

A microbial culture capable of leaching at high pH, and in saline solution of 100 g/L Cl^- was developed using BioHeap's patented procedures. The preliminary results have shown the culture is capable of leaching ore containing high levels of magnesium with solution pH values of 3 to 3.5 resulting in nickel recovery greater than 70%. Under these conditions, initial test work has indicated low levels of iron in solution and the acid consumption was reduced significantly, from approximately 736 kg t^{-1} of ore at pH 1.8 to 33 kg t^{-1} of ore at pH 3.5.

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