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Influence of selected parameters on nickel bioleaching from spent Ni-Cd batteries

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Abstract

Bioleaching is an effective way of obtaining heavy metals from the waste containing heavy metals. High yield of leaching process can be achieved by selecting appropriate parameters. The goal of this work was the study of leaching conditions and their effects on the Ni recovery from discarded Ni-Cd batteries. The experiments studied the impact of the quantity of the waste, the impact of bacteria *Acidithiobacillus ferrooxidans (AF)* and the mixture of *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans (AT)* bacteria, the impact of bacteria adaptation and temperature on the yield of Ni. The amount of nickel in the solution has increased with increasing temperature as well as by the use of adapted bacteria. The recovery achieved during the experiment, being in the range 33 – 84 %, confirms the dependence of nickel amount in solution at selected conditions. The highest yield was achieved under the following conditions: ratio L : S = 100, temperature 30 °C and usage of the adapted mixture of bacteria.

Key words: bioleaching, recycling, Ni-Cd batteries, *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*

Introduction

Unprocessed discarded nickel-cadmium batteries pose a danger to the environment, mainly due to the high content of heavy metals. On the other hand, due to the high content of these metals, they are a suitable source for nickel and cadmium recovery. The content of these metals in batteries in comparison with the content of Ni and Cd in the primary raw material is much higher.

Nickel-cadmium battery is composed of three layers: a cathode, anode and a steel container. Positive electrode consists of nickel hydroxide, negative electrode consists of cadmium. In the charged state:

• The active material of positive electrode consists of nickel oxide-hydroxide – NiO(OH). During the discharging process following reaction at the positive electrode takes place:

$$2NiO(OH) + 2H_2O + 2e^- \rightarrow 2Ni(OH)_2 + 2OH^- \quad (1)$$

• Negative electrode is composed of cadmium – Cd. During the discharging the following reaction takes place on negative electrode:

$$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^- \quad (2)$$

At charging process given reactions appear vice versa.

Separator containing electrolyte separates both electrodes. Alkaline aqueous solution of potassium hydroxide (KOH) is commonly used as an electrolyte.

In the recent years, several technologies were developed to process and to obtain usable materials from discarded Ni-Cd batteries (Bartolozzi et al., 1995; Freitas et al., 2005; Rudnik et al., 2007). Among the newer methods of heavy metals obtaining from used Ni-Cd batteries are bioleaching processes. Bioleaching processes are less expensive and as effective as traditional techniques of the heavy metals obtaining. More species of microorganisms have an ability to tolerate the presence of heavy metals in solution (Nemati and Webb, 1997) and they have the ability to dissolve heavy metals and transform them into ionic form, e.g. bacteria *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans* or bacteria of the genus *Acidiphilium* (Ballester et al., 1992; Cabrera et al., 2005).

Leaching process and thus its yield can be influenced by choosing appropriate parameters and conditions of leaching. Several authors (Cerruti et al., 1998; Nogueira et al., 2004; Zhu et al., 2003) examined the effect of temperature, type of leaching medium and amount of the waste (Nemati et al., 2000; Shen et al., 2001) on the efficiency of the bioleaching process. By optimizing of leaching conditions it is possible to increase the yield of the process and reduce its cost.

Not only conditions of leaching process but also the treating of the waste before leaching affect the yield of heavy metals. Method of crushing or grinding affects the granularity and morphology of particles that reflects in the amount of metal in solution and in required time to achieve maximum yield.

The aim of this paper was to analyse the influence of selected parameters on Ni leachability. The experiment was realized at different temperatures, two types of leaching medium and different ratios of L : S (100, 40 and 20) were used.

Experimental materials and methods

Grinded electrodes from discarded Ni-Cd batteries were used for the leaching experiments and solution of *Acidithiobacillus ferrooxidans* bacteria and the mixture of *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* bacteria were used for bioleaching.

Electrode powder was manually separated from the rest of the battery and crushed to grain below 40 μm. Totally 19 to 20 g of powder was obtained from one battery. Powders treated this way were used in the leaching experiments in the amount 10, 25 and 50 g/l.

Leaching medium was prepared as follows:

• Adapted and non-adapted bacteria *Acidithiobacillus ferrooxidans* – 180 ml 9K nutrient solution and 20 ml solution of the bacteria were added into 9K nutrient solution,

• a mixture of adapted and non-adapted bacteria *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* in quantity of 20 ml of bacteria mixture (10 ml

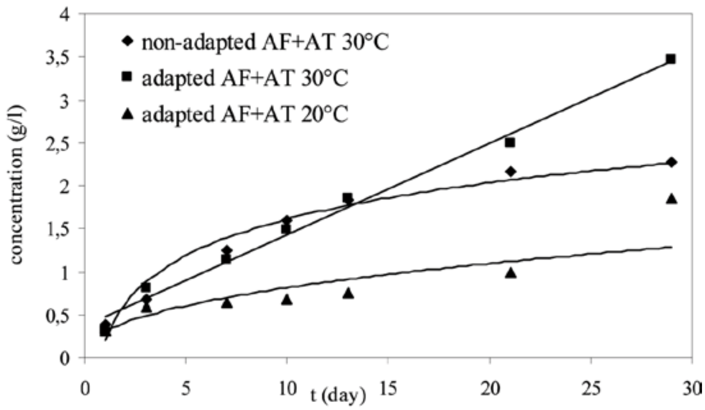

Fig. 1. Influence of adaptation and temperature on Ni bioleaching by bacteria *Acidithiobacillus ferrooxidans* (AF).

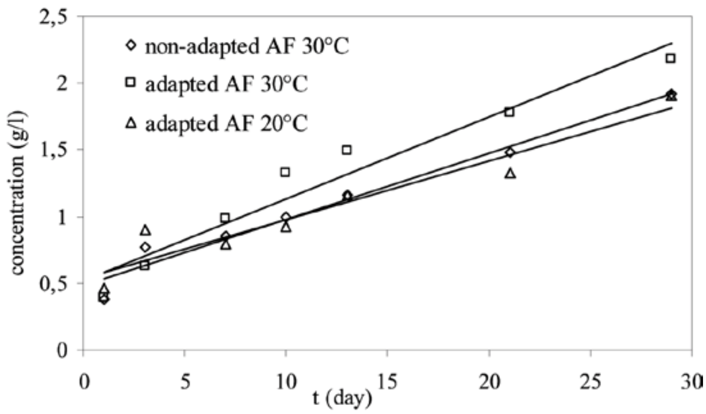

Fig. 2. Influence of adaptation and temperature on Ni bioleaching by the mixture of bacteria *Acidithiobacillus ferrooxidans* and bacteria *Acidithiobacillus thiooxidans (AF + AT)*.

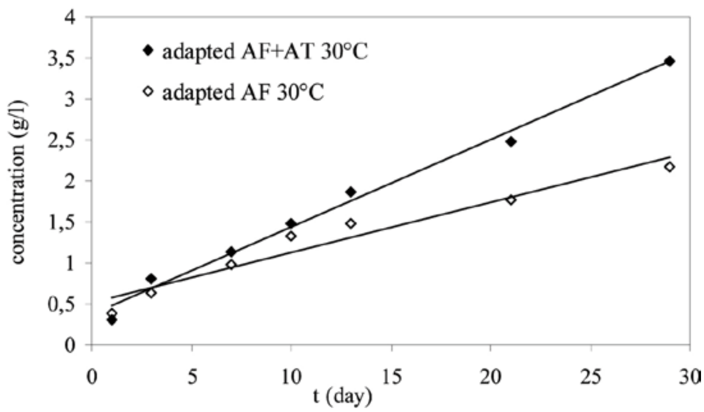

Fig. 3. Dependence of Ni concentration in solution on leaching medium type.

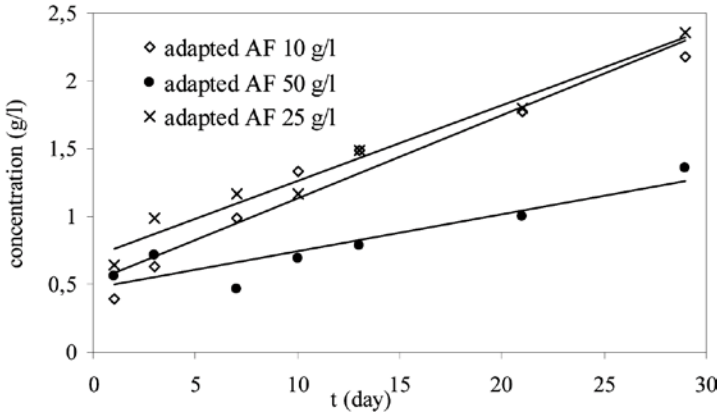

Fig. 4. Influence of L : S on nickel leaching by 30 °C.

AF + 10 ml AT) in 180 ml 9K nutrient solution was added into 9K nutrient solution.

The experiment was carried out at 20 °C and 30 °C. 2 g of electrode powder were added into the prepared solutions with adapted and non-adapted bacteria *Acidithiobacillus ferrooxidans* and a mixture of bacteria. All leaching experiments lasted 28 days and samples were taken at the following intervals: 1, 3, 7, 10, 13, 21, 28 days. The nickel content in the samples was estimated by AAS analysis.

Results and discussion

The average composition of the electrodes before leaching, determined by AAS analysis is provided in Tab. 1. Electrodes are mixture of nickel, cadmium and iron, the contents of nickel was approximately 40 %, cadmium 17 % and Fe 4.5 %.

The results of AAS analysis, Fig. 1, confirm that the higher temperature and the adaptation of bacteria help to increase the efficiency of the Ni leaching.

Assuming that all amount of Ni is leached into the solution and according to Tab. 1, the maximum achievable amount of nickel in the solution is 4.1 g/l (100 % of Ni from battery). The amount of Ni 2.2 g/l in the solution has been achieved after 28 days of leaching at temperature 30 °C and with using adapted bacteria *Acidithiobacillus ferrooxidans.* This is 54 %. The lowest yields of Ni were obtained at the temperature of 20 °C.

In the case of using the mixture of bacteria *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* (AF and AT), Fig. 2, better results were obtained using adapted bacteria and leaching at a higher temperature (30 °C). In this experiment the amount of Ni in leaching solution reached 3.5 g/l, it is 84 % of Ni leaching efficiency.

Tab. 1
Chemical analysis of spent Ni-Cd battery electrode (average compound)

Ni (%)	Cd (%)	Fe (%)
41.1	16.7	4.5

Comparison of the leaching efficiency at the temperature 30 °C in the adapted mixture of bacteria to adapted bacteria *Acidithiobacillus ferrooxidans* only: The analysis of results shows that using a mixture of bacteria it is possible to achieve higher yields than in the case of leaching in solution with adapted bacteria *Acidithiobacillus ferrooxidans* only, Fig. 3. While by leaching in solution with the bacteria *Acidithiobacillus ferrooxidans* was reached only 54 % efficiency of Ni leaching, using the mixture of bacterial allows to reach the leaching efficiency 84 %.

Comparison of the influence of the solid phase amount on leaching of nickel at 30 °C to usage bacteria *Acidithiobacillus ferrooxidans* is in Fig. 4. Comparing the ratios L : S = 100 to 40, it is obvious that the amount of Ni in solution is about the same ~55 % in both cases. However, increasing the concentration of solid components to 50 g/l, L : S = 20 leads to sharp decrease of leaching ability of solution. Under these conditions was reached only 33 % leachability of nickel after 28 days of leaching experiment. This confirms that the increase in the quantity of toxic substances in the solution causes a decrease of bacteria vitality that reflects in their ability of leaching. Probably, increasing of the concentration of the waste by the process of adaptation of bacteria could lead to achievement of the higher amount of heavy metals in solution. However, these assumptions need further experimental verification.

Conclusions

Crushed electrode powder from the discarded Ni-Cd batteries was leached at different temperatures, different ratios L : S and in four different leaching medias:

- 9K solution with adapted bacteria *Acidithiobacillus ferrooxidans*,
- 9K solution with non-adapted bacteria *Acidithiobacillus ferrooxidans*,
- 9K solution with a mixture of adapted bacteria *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans*,

• 9K solution with a mixture of non-adapted bacteria *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans*.

The results of the experiments are as follows:

1. The yield of Ni in leaching solution increases with increasing temperature;

2. The yield of Ni increases by using of adapted bacteria;

3. The highest amount of Ni in the solution, 93 %, was achieved using the mixture of adapted bacteria *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans*;

4. Reducing of L : S ratio, i.e. increasing the amount of electrode powder in a solution, causes a decrease of Ni dissolution, which implies that the concentration of toxic substances in the solution may raise above the tolerance limits of the bacteria.

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