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Nickel production from laterites using electro metal electrowinning (EMEW) process

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Abstract. Laterite with low-grade nickel ($< 0.5\%$) was very difficult to process using pyrometallurgy technique. One method which able to process this laterite is solvent extraction process. This process also able to separate cobalt from nickel solutions. The aqueous phase of solvent extraction process which has a high nickel content able to collect using electrowinning methods. Electrometal-electrowinning (EMEW) method is one of the electrowinning methods which has better performance to collect metal from solution. In this work, laterite was leached using H_2SO_4 then was extracted using Cyanex 272 in toluene as an organic solvent. In this research, the effect of a voltage, a duration time of operation, a concentration of boric acid and a temperature on EMEW process were studied and were optimized using Taguchi method.

1. Introduction

Indonesia has nickel laterite ore reserve of 1.391 billion tones which constitute 4.9% of nickel laterite reserves in the world and occupies the world's eighth largest position [1]. However, there are many laterites which have nickel concentration of 0.5%. This laterite is very difficult to be processed. However, it is able to process using solvent which able to process low-grade laterite to produce nickel and cobalt.

Nickel ore processing begins with a leaching process first, which aims to separate the desired components and undesired components [2]. The obtained leaching results still contain nickel, cobalt, and multi-component materials such as Cu, Co, Pb, V, and Fe. To separate the nickel with other multi components it will be extraction process. The separation of nickel from the multicomponent mixture of the material can be done well using cyanex 272 which has been diluted with toluene [3][4][5]

In this work, the nickel metal was processed from solvent extraction able to process using the electrowinning process [6]. Electrometal-electrowinning cell (EMEW) process is one of electrowinning process using the cylindrical electrode to catch the metal ions from the extracted leaching solution. This process is better than traditional electrowinning since it more has low operational cost, friendly for the environment, easy to install, design is compatible, it can be operated in large-scale process, acid electrolyte can be recycle, it can produce high purity of metal and it can be operated in low concentration of metal solution [7].

The parameters which have been studied and optimized such as temperature, time operation, voltage, boric acid concentration. The design of experiment (DOE) of Taguchi was used to



optimize these parameters. Taguchi methods have many advantages such as it able to reduce economically the variability of the response variable and able to find out the optimum process conditions during laboratory experiments [8][9].

2. Experiments

In this experiment using raw materials of laterite nickel ore obtained from Pomala - Southeast Sulawesi (Integra mining Co. Ltd.). The composition of laterite nickel ore can see in Table 1. When the extraction process is used 90% of cyanex solution material from Anhui Jin'ao Chemical Co., Ltd. and 30% of toluene solution from Anugrah visi cemerlang Co. Ltd. The toluene is used as a cyanex solution diluent. The laterite was grinded using a ball mill to get the size less than 177 microns. The laterite was then leached using H_2SO_4 4 M for 8 hours [5]. Then the leaching solution was extracted using cyanex 10% v/v in Toluene. The solvent extraction was carried out in glass separating funnels with capacity 100 ml for 10 minutes. The aqueous phase was separated from the organic phase, the aqueous phase which rich with nickel was then processed using EMEW.

Aluminum cathode and nickel anodes were used in this EMEW process as shown in Figure 1. The design of experiments of Taguchi was used in this work as listed in Table 2. X-ray Fluorescence (Delta Premium XRF – Olympus) was used to analyze the material composition in electrodeposits. The results were analyzed using a signal-to-noise (S/N) ratio of “larger the better” was calculated for each factor level combination. The formula of the larger-is-better S/N ratio was shown in Equation 1.

$$S/N = -10 \cdot \log(\Sigma(1/Y^2)/n) \quad (1)$$

where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

Table 1. XRF analysis of laterite

El	wt (%)	El	wt (%)
Light Elements (LE)	79.2882	MnO	0.216
Fe	10.998	Co	0.046
Si	3.88	S	0.046
K	2.079	Sb	0.02
Al	0.701	Cd	0.013
Ni	0.488	Sn	0.014
Ca	0.65	Ti	0.022
Cl	1.253	Zn	0.0076
Cr	0.284		

Table 2. EMEW experiment design using Taguchi method

Run	Design of Experiment				Results
	Temp. (°C)	Time (hour)	Voltage (V)	Boric acid concentration (M)	Nickel electrodeposits (mg)
1	50	2	3	0.0	0.04
2	50	4	4	0.5	0.28
3	50	6	5	1.0	60.48
4	60	2	4	1.0	2.64

5	60	4	5	0.0	75.06
6	60	6	3	0.5	0.84
7	70	2	5	0.5	3.5
8	70	4	3	1.0	0.72
9	70	6	4	0.0	31.68

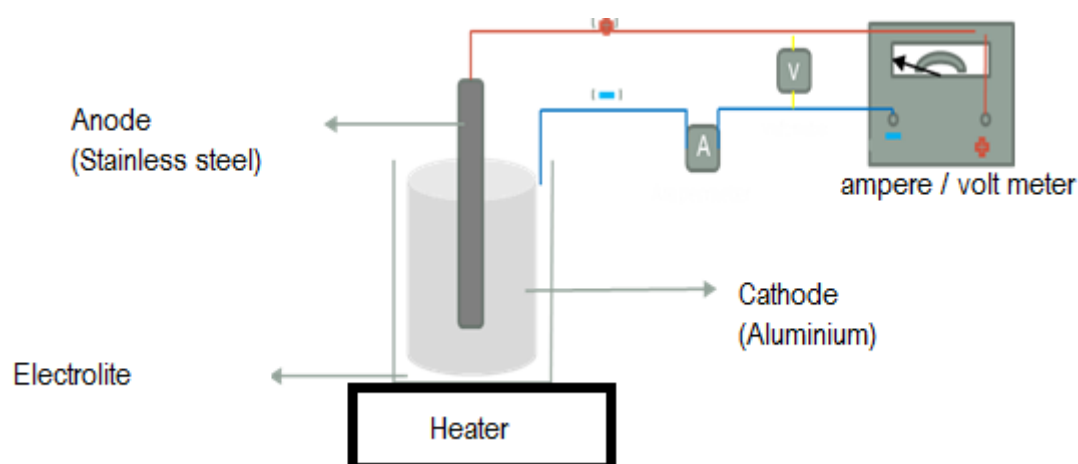


Figure 1. Experimental set up of electro metal-electrowinning (EMEW)

3. Results and discussion

3.1. Taguchi analysis for electrometal-electrowinning (EMEW)

The experiments have been conducted following Taguchi orthogonal array as shown in Table 2. A signal to noise (SN) ratio of larger the better of Taguchi was used to analyze using the results of this work as listed in Table 3. From the table shows that highest value of delta is the parameter of Voltage of DC power supply, hence this parameter is the first rank of the parameter which affects the amount of nickel electrodeposits. The second, third and fourth rank are the time, temperature and boric acid, respectively.

Table 3. Response for signal to noise ratios larger is better

SN Larger is better				
Factor Level	Temperature	Time	Voltage	Borid Acid Concentration
1	-1.1278	-2.8818	-10.7755	13.1884
2	14.8086	7.866	9.1303	-0.5633
3	12.6812	21.3778	28.0073	13.737
DELTA	15.9364	24.2596	38.7828	14.3003
RANK	3	2	1	4

3.2. Effect of voltage on nickel products

To study the effect of Voltage towards the amount of nickel in electrodeposits, the voltages were varied from 3 to 5 volt as shown in Fig. 2. The result shows that the increment of voltage between the two electrodes will increase the weight of nickel in electrodeposits. This due to, the ncrease of this voltage increased the mass transport in an electrochemical cell. In addition, the electric field between the two electrodes is getting bigger. In a large electric field, the ions or

electrons will move faster. The formation of layers on the cathode will be faster. Hence, the optimum of voltage for this process was 5 V.

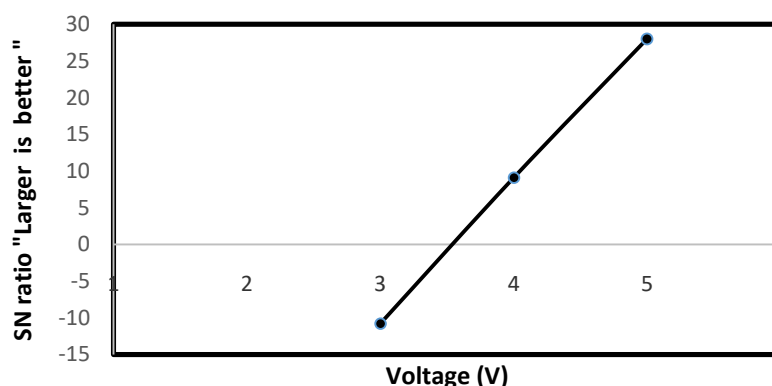


Figure 2. Effect of voltage on nickel products

3.3. Effect of the operation duration on nickel products

To study the effect of the operation duration towards the amount of nickel electrodeposits, the operation duration was varied from 2 to 6 hours as shown in Fig. 3. The figure shows that the amount of nickel electrodeposits were increase as the increase of the duration of the operation. Since the enhancing the operation duration will increase total mass transport during the electrochemical reaction. Hence the total amounts of nickel electrodeposits were increased. The Taguchi analysis shows that the 6 hours operation is the optimum of duration operation. At this condition, large number nickel ions in the solutions were deposited at the cathode.

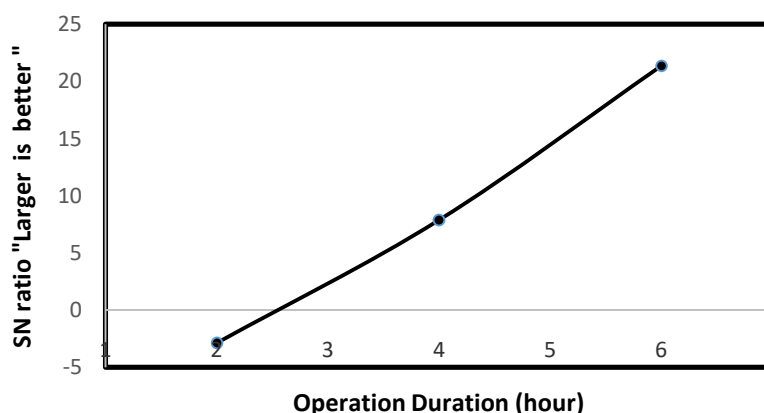


Figure 3.Effect of time on nickel products

3.4. Effect of boric acid on nickel products

The effect of boric acid as electrolyte additive towards the amount of nickel electrodeposits was studied by varied boric acid concentration from 0.5 to 2 M as shown in Fig.4. The results show that the increase of boric acid concentration caused the decrease of nickel electrodeposits since it caused the increment of electrolyte viscosity as shown in 1 M of boric acid. However, at the certain concentration of boric acid, it gives the better result of the amount of electrodeposits as

shown in 2 M of boric acid. According to Zhang, et al [6] boric acid may increase the polarization of the cathode. In electrodeposition process, boric acid is absorbed on the surface of the cathode results in increasing the Ni^{2+} potential deposition. Boric acid and Ni^{2+} can form boric nickel which can increase hydrogen over potential and decrease the evolution of H_2 gas.

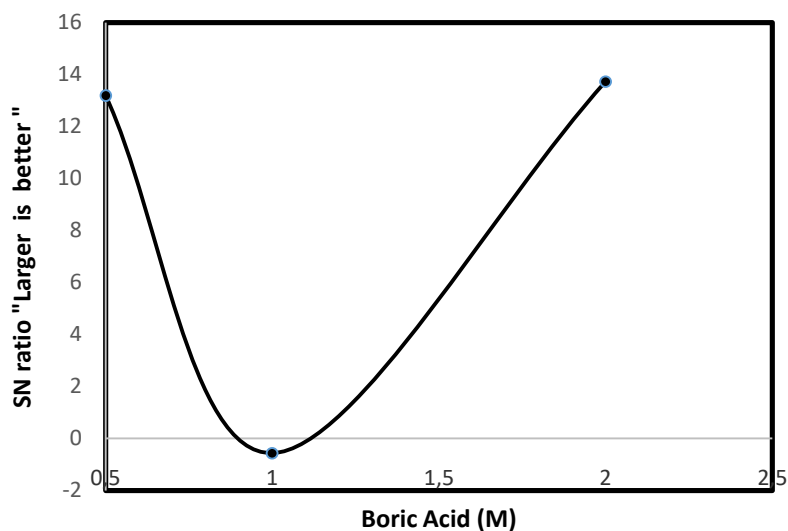


Figure 4. Effect of boric acid on nickel products

3.5. Effect of temperature on nickel products

The effect of temperature on nickel product has been studied by varied temperature from 50°C to 70°C as shown in Fig. 5. The result shows that the optimum temperature is at 60°C. The increment of temperature will increase the rate of electrochemical reactions [10]. The increasing of temperature also enhances the electrolyte conductivity and mass transfer [11]. However, the increment of temperature in the acidic electrolyte will enhance the hydrogen evolution which decreases the current efficiency. The increasing temperature also reduces the hydrogen over potential which able to reduce, hydrogen evolution problem [11]. The optimum temperature is important to solve the hydrogen evolution problem. At the temperature of 70°C, the mass of nickel electrodeposits decrease as shown in Fig. 3. The increasing temperature over the optimum condition caused the increasing the hydrogen evolution effect. The increment of temperature over the optimum condition will increase the overall mass transfer include the impurities mass transfer [10][11]. Hence it caused the decreasing of the mass of nickel electrodeposits.

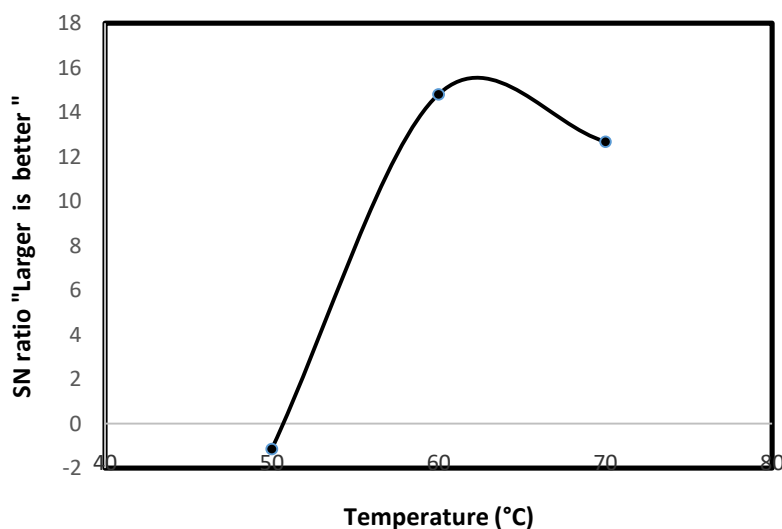


Figure 5. Effect of temperature on nickel products

4. Conclusions

Electrometal-electrowinning (EMEW) process to produce nickel from low-grade laterite was conducted in laboratory scale. Amount of nickel electrodeposits was affected by without boric acid additions, voltage, temperature, and operation duration. These results have been analyzed using Taguchi analysis of "Larger is better". The result shows that the optimum condition was at 60°C of the electrochemical reactor, 2 M of Boric acid concentration, 6 hours of operation duration and 6 V of DC power supply. From Taguchi analysis also shows that the voltage of DC power supply is the first rank of the parameter which affects the amount of nickel electrodeposits. Meanwhile, the second, third and fourth ranks are the time, temperature and boric acid, respectively.

Acknowledgments

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