Middle East Technical University

Department of Metallurgical and Material Engineering

Mete215 – Materials Processing Laboratory

Experiment 5: Leaching and Electrowinning

Instructor: Prof. Dr. İshak Karakaya

Assistant: Olgun Yılmaz

Experiment Date: 21.11.2019

Submission Date: 1.12.2019

Name: Doruk Sınayuç

No: 2379808

Group Members: Murathan Cugunlular, İklim Ozturk, Melisa Yildirim, Ezgi Eylen, Mehmet Oguz Yavuz, Darin Azzam Ahed Alaryan, Bahattin Emre Boran, Ekin Kursun, Arslan Korcan Ozal, Olgu Cagan Ozonuk, Bahadir Akman, Onur Das

ABSTRACT

The two processes leaching and electrowinning were observed in this experiment. 19.6 grams of $ZnSO_4.H_2O$ was mixed with 0.5 ml of H_2SO_4 and 100 ml of water to make a solution that will undergo the electrowinning process. In this process 3.3 Volts was applied and after 60 minutes 0.208 grams of zinc was deposited in the cathode. During this process the current fluctuated in the first five minutes but an eventual increase was noted. 85% current efficiency, 61% energy efficiency and 3.2 KJ of energy consumption were calculated. The current density and power consumption with the change of time was calculated and were shown in a graph. From this graph it was seen that current density showed a behavior similar to that of current while the power consumption showed an linearly increasing behviour.

INTRODUCTION

Leaching is the solubilization of important components in ores or other metallurgical materials in an aqueous solution, generally done with the use of an acid that acts as the medium in the leaching process (Mark E.Schlesinger, 2011). The solution resulting from the leaching process is fit to be used as an electrolyte in Electrowinning.

Electrowinning is the process where a current pass through a solution that is electrolyte. With the passing of this current the metal ions in the solution precipitates and deposits to the cathode.

To give an example let Calcine be leached. Zn^{2+} and SO_4^{2-} ions in the form of $ZnSO_4$ will be created. The Zn ion will undergo:

$Zn^{2+} + 2e^- \rightarrow Zn$ at the cathode.

At the same time if there exist water in the solution it will undergo the reaction;

$H_2O_{(l)} \rightarrow 1/2\ O_2 + 2H^+ + 2e^-$ in the anode

This reaction leads to the H^+ ions concentration increasing, meaning that the acidity of the solution will increase.

Decomposition will also occur with the reaction

$ZnSO_4(aq) + H_2O(l) \rightarrow Zn(s) + H_2SO_4\,(aq) + 1/2\ O_2\ (g)$

It is important to note that the metal that is deposited to the cathode during the electrowinning process is of high purity. This property of electrowinning makes it a valuable method to produce metals, though electrowinning is not efficient for every metal. It can be said that electrowinning is most efficient for metals that has high electro-potential (Corrosion Doctors, n.d). Another advantage that makes electrowinning attractive is the relatively less harm that it does to the nature (Dresher, 2001).

There are some parameters that affect the electrowinning process. One of them is Temperature. It is said that with the increase in temperature the resistance of the electrolyte solution and cell is decreased and the kinetics of the reactions increased (Arman Ehsani, 2016). Another parameter is the current density. It is known that:

$$\frac{MW * I * t}{n * F} = Weight\ of\ Substance\ deposited$$

And I is proportional to current density, meaning that with higher current density the higher weight of deposited substance. The amount of voltage that is applied to the system is also important. There are many factors that needs to be considered when calculating the applied voltage and it can be shown by the equation

$V = -E + (R_e + R_l)I + \eta$

R_l: Resistance of leads, **I**: Current, **η**: Overvoltage, **V**: the total voltage,
E: decomposition Voltage, **R_e**: Resistance electrolyte

EXPERIMENTAL

Materials that were used;

- Zinc sulfate
- Sulfuric acid
- Water

Equipment that were used in the experiment;

- D.C power supply
- Ampermeters
- 150 ml beakers
- aluminum cathodes
- lead anodes
- Balance and weights
- Magnetic stirrer

Procedure

The experiment started with the pouring of 60 ml of water to a beaker that has a volume of 150ml. Then, 0.5 ml of H_2SO_4 was added to the beaker. Now, to the solution the calculated value of 19.6 grams of $ZnSO_4.7H_2O$ was added. After putting the magnetic stirrer inside our beaker, stirring started. While the solution was stirring, the weight of the cathode was measured. As the stirring ended 40 ml of water was once again put on the solution making the beaker consist of 100 ml of water. Next, the electrodes were put in the electrolyte and positioned such that the distance between the electrodes was about 2cm. After connecting our system to a D.C source, the voltage was adjusted to be 3.3 V. Starting from the adjustment of voltage every minute for five minutes the current passing through the cell was noted. After 5 minutes the period of getting the data was increased to 5 minutes. When this process ended, the cathode was once again weighted after rinsing and drying it.

RESULT AND DISCUSSION

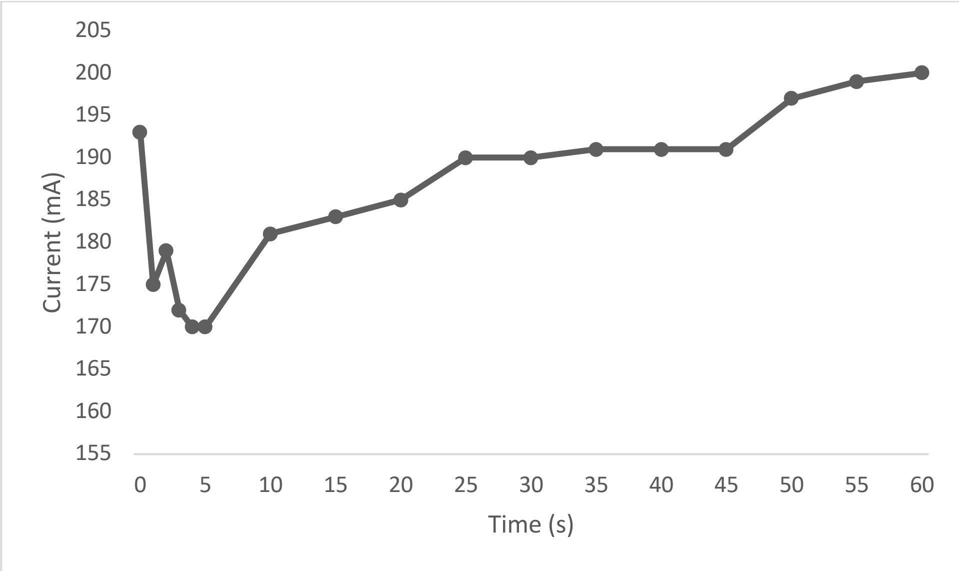

Figure 1. The change in current with time

In figure 1 the data of current as time passes can be found when a constant voltage of 3.3 volt is applied. It can be seen that there is an overall increase in the current passing through the cell with the increase in time. The increase was expected as in time the amount of hydrogen ions in the solution was increasing and hydrogen is a better conductor than zinc ions but our data has points where the current stays stagnant and even decreases. The decrease may be because, at the start of the experiment for a short time a region that acts as a resistivity region manifests from the movements of the ions. However, it should happen for a brief period of time. The mistakes made while reading the records or the machine giving faulty result may also be the reason for the decrease happening in the first five minutes. The stagnation that happens can also be correlated with the measuring machine being not precise enough. The data the graph of consists of can be found in appendix (table 3).

	Before deposition	**After deposition**
Weight of Cathode(gram)	12.143	12.351

Table 1. The weight of cathode before and after electrowinning

Table 1 shows us the increase in the weight of cathode after the electrowinning process where the metal ions inside the electrolyte deposits at the cathode.

Current density in amperes per square meter of cathode surface, J:

J = total current (A) / Area (m^2)

J_0	J_1	J_2	J_3	J_4	J_5	J_{10}	J_{15}	J_{20}	J_{25}	J_{30}	J_{35}	J_{40}	J_{45}	J_{50}	J_{55}	J_{60}
482.5	437.5	447.5	430.0	425.0	425.0	452.5	457.5	462.5	475.0	475.0	477.5	477.5	477.5	492.5	497.5	500.0

Table 2. The calculated current density with time

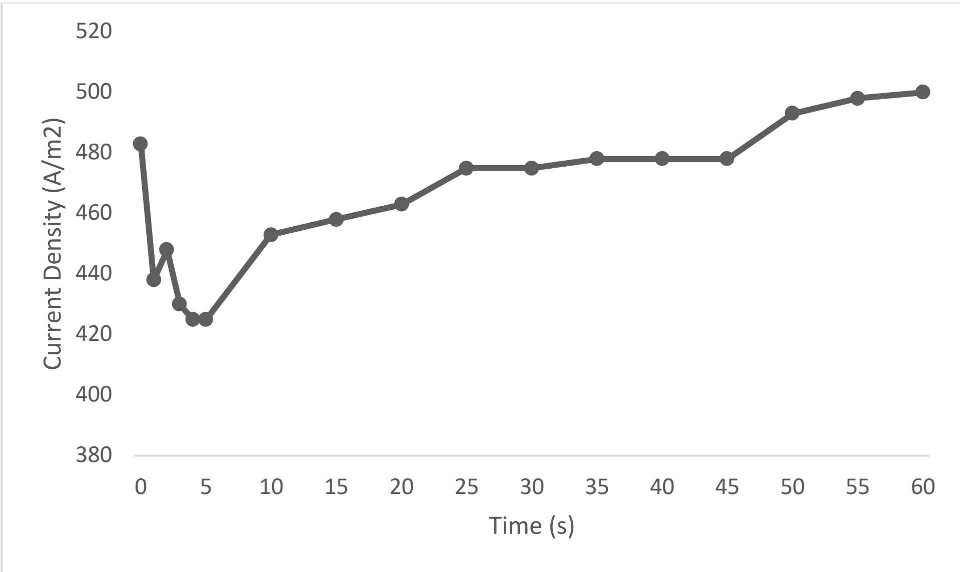

Figure 2. Current density vs time graph

The graph in figure 2 that has been made by the data shown by table 2, shows how the current density changes over time. Since current is proportional to current density, a parallel increase and decrease can be observed. This graph was also expected to increase with a slight decrease in the beginning but since it has a relation with current, the reason for the decreases and stagnations are the same.

Power consumption, W:

Power consumption = Watt * time , Watt = Voltage * Current

Therefore;

Power consumption = Voltage * Current * time

The values of power consumption can be found in the appendix.

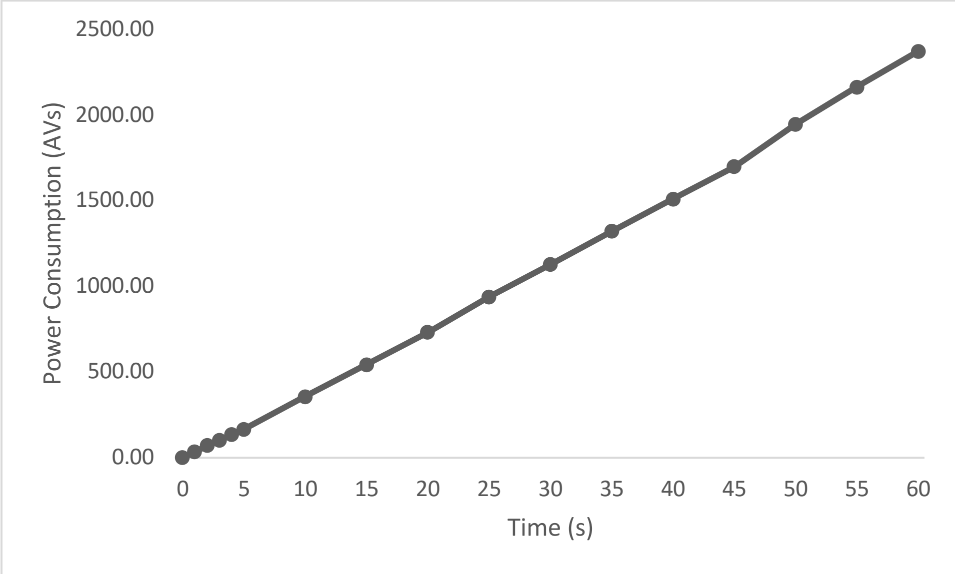

Figure 3. Change in power consumption over time

From figure 3 it can be concluded that power consumption increases linearly with time. The increase

Current efficiency is obtained by dividing the weight of the actually deposited substance by the weight of theoretically deposited substance.

Current Efficiency = Weight Actual Deposited / Weight theoretical deposited

From our experiment we have found that 12.351 – 12.143 gram which is 0.208 was deposited. Theoretically the amount of substance that is deposited is found by the equation;

$$\frac{MW * I * t}{n * F} = Weight\ of\ Substance\ deposited$$

For our experiment it has the value:

(65.4 g/mol * 0.2 A * 3600 second) / (2*96500 C/mol) = 0.244 gram

Therefore, current efficiency percentage is: 0.208 / 0.244 * 100 = %85

To find energy efficiency = (V_t / V_a) * (current efficiency)

Therefore, for our experiment energy efficiency is (2.35 / 3.3) * %85 = %61

To find energy consumption:

Energy consumption = (V*I*t) / (W*3600*1000)

Therefore, (3.3V* 0.2 A * 3600 second) / (0.208 * 10^{-3} kg * 3600 * 1000) = 3.2 KJ

E.m.f or Electro motor force is a very important concept as it is the transformation of one type of energy to another. Any energy source that can drive an electric charge has the characteristic e.m.f. For our case there exist a current passing through the electrolyte that causes the deposition of zinc meaning that with e.m.f zinc can be produced. E.m.f is also in relation with the gibbs energy therefore, it can be said that e.m.f also is a factor in the determination on whether the reactions happen and the direction of the said reactions.

CONCLUSION

In this experiment, the process of leaching and electrowinning was both used to produce zinc. This combination of using leaching and electrowinning together to produce a desired metal is gaining attraction. The reason for this is that as calculated above, the energy efficiency and current efficiency for this experiment is 61% and 85% which can be considered a fairly efficient process. Another reason as also mentioned above is that electrowinning/leaching combination is relatively better for the environment than the other methods that are used in pyrometallurgy to produce zinc. To recap our experiment water, sulfuric acid and zinc sulfate was mixed in the beaker. Afterwards 3.3 Volt was given to the system which resulted in the deposition of zinc in the cathode. There were some errors in the change in current with time that was attributed to human and machine error but the overall increase in current was observed. It was also observed that the process happened in relatively high efficiency and with again relatively low energy consumption.

REFERENCE

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Dresher, W. H. (2001, August). *Copper Development Association*. Retrieved from Copper Development Association: https://www.copper.org/publications/newsletters/innovations/2001/08/hydrometallurgy.html

Mark E.Schlesinger, M. J. (2011). *Extractive Metallurgy of Copper.* Elsevier.

APPENDIX

Time(s)	**0**	**1**	**2**	**3**	**4**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Current(mA)	193	175	179	172	170	170	181	183	185	190	190	191	191	191	197	199	200

Table 3. The Data of Figure 1

The calculations of current density with time (with the unit A/m^2):

$\mathbf{J_0} = (193\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 482.5$

$\mathbf{J_1} = (175\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 437.5$

$\mathbf{J_2} = (179\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 447.5$

$\mathbf{J_3} = (172\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 430.0$

$\mathbf{J_4} = (170\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 425.0$

$\mathbf{J_5} = (170\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 425.0$

$\mathbf{J_{10}} = (181\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 452.5$

$\mathbf{J_{15}} = (183\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 457.5$

$\mathbf{J_{20}} = (185\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 462.5$

$\mathbf{J_{25}} = (190\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 475.0$

$\mathbf{J_{30}} = (190\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 475.0$

$\mathbf{J_{35}} = (191\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 477.5$

$\mathbf{J_{40}} = (191\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 477.5$

$\mathbf{J_{45}} = (191\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 477.5$

$\mathbf{J_{50}} = (197\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 492.5$

$\mathbf{J_{55}} = (199\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 497.5$

$\mathbf{J_{60}} = (200\ mA*1A / 10^3\ mA) / (4.0\ cm^2 * 1m^2 /10^4\ cm^2) = 500.0$

The power consumption of current density with time (with the unit : AVs):

$W_0 = 3.3V * (193\ mA * 1A / 10^3\ mA) * (\ 0\ minute * 60\ seconds / 1\ minute) = 0$

$W_1 = 3.3V * (175\ mA * 1A / 10^3\ mA) * (\ 1\ minute * 60\ seconds / 1\ minute) = 35$

$W_2 = 3.3V * (179 mA * 1A / 10^3 mA) * (2 minute * 60 seconds / 1 minute) = 71$

$W_3 = 3.3V * (172 mA * 1A / 10^3 mA) * (3 minute * 60 seconds / 1 minute) = 102$

$W_4 = 3.3V * (170 mA * 1A / 10^3 mA) * (4 minute * 60 seconds / 1 minute) = 135$

$W_5 = 3.3V * (170 mA * 1A / 10^3 mA) * (5 minute * 60 seconds / 1 minute) = 168$

$W_{10} = 3.3V * (181 mA * 1A / 10^3 mA) * (10 minute * 60 seconds / 1 minute) = 358$

$W_{15} = 3.3V * (183 mA * 1A / 10^3 mA) * (15 minute * 60 seconds / 1 minute) = 544$

$W_{20} = 3.3V * (185 mA * 1A / 10^3 mA) * (20 minute * 60 seconds / 1 minute) = 733$

$W_{25} = 3.3V * (190 mA * 1A / 10^3 mA) * (25 minute * 60 seconds / 1 minute) = 941$

$W_{30} = 3.3V * (190 mA * 1A / 10^3 mA) * (30 minute * 60 seconds / 1 minute) = 1129$

$W_{35} = 3.3V * (191 mA * 1A / 10^3 mA) * (35 minute * 60 seconds / 1 minute) = 1324$

$W_{40} = 3.3V * (191 mA * 1A / 10^3 mA) * (40 minute * 60 seconds / 1 minute) = 1513$

$W_{45} = 3.3V * (191 mA * 1A / 10^3 mA) * (45 minute * 60 seconds / 1 minute) = 1702$

$W_{50} = 3.3V * (197 mA * 1A / 10^3 mA) * (50 minute * 60 seconds / 1 minute) = 1950$

$W_{55} = 3.3V * (199 mA * 1A / 10^3 mA) * (55 minute * 60 seconds / 1 minute) = 2167$

$W_{60} = 3.3V * (200 mA * 1A / 10^3 mA) * (60 minute * 60 seconds / 1 minute) = 2376$