CHAPTER I
INTRODUCTION

1.1 Background

The electrodeposition of metals such as chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and other metals as coatings is widely used in industry to enhance performance. The metal-plating industry generates waste containing heavy metals, such as chromium (Cr), copper (Cu), nickel (Ni), and lead (Pb), which may cause environmental pollution if not properly managed (Boguniewicz-Zabłocka et al., 2026). High concentrations of heavy metals in water may also have toxic effects on aquatic organisms (Santosh et al., 2024). Metal-plating processes are generally carried out in electroplating baths. Therefore, recovering metals from spent electroplating solutions is necessary to reduce adverse environmental impacts.

Disposal of waste from the metal-plating industry without prior treatment may adversely affect environmental components and thereby degrade their quality. According to Government Regulation of the Republic of Indonesia Number 18 of 1999 concerning the Management of Hazardous and Toxic Waste, waste containing heavy metals must be treated before discharge to ensure that heavy-metal concentrations do not exceed the established threshold limits. Precipitation is one of the waste treatment methods that can be used to separate heavy metals from liquid waste. However, some heavy metals are difficult to precipitate directly; therefore, specific treatment processes are required to improve their removal efficiency. One such method that can be used is electroplating, in which an electric current is passed through the electrodes, causing heavy-metal ions in the waste to be reduced to their elemental forms and deposited on the cathode surface. Compared with other methods, this method offers the advantages of requiring no additional chemicals and having relatively low operating costs (Babilas et al., 2024).

Chemical Engineering students need to study the reduction of heavy metals in waste from the metal-plating industry and their deposition through electrolysis. It is also necessary to study the kinetics of heavy-metal reduction and deposition to evaluate process performance and identify potential improvements. The reducing agent must be present in excess to ensure that the reduction and deposition processes proceed optimally.

1.2 Problem Statement

The metal-plating industry may generate hazardous and toxic (B3) waste containing heavy-metal ions, which can pollute the environment if not properly treated. One approach to reducing the metal content of this waste is electroplating, in which metal ions are reduced and deposited as metals on the cathode surface. The effectiveness of this process is influenced by contact time, electric current, and electrolyte concentration, which determine the mass of the resulting deposit. Therefore, this practicum investigates the effects of these three variables on the mass of the deposit formed on the cathode, as well as the effect of concentration on the rate constant of the electroplating reaction. The findings are expected to provide a basis for improving process efficiency and supporting efforts to reduce the heavy-metal content of industrial waste.

1.3 Objectives

1. To study the effect of contact time on the mass of metal deposited on the cathode.
2. To study the effect of electric current on the mass of metal deposited on the cathode.
3. To study the effect of electrolyte concentration on the mass of metal deposited on the cathode.
4. To study the effect of electrolyte concentration on the rate constant of the electroplating reaction.

1.4 Benefits

1. Students are able to understand the effects of operating variables on the efficiency of the electroplating process.
2. Students are able to understand the reduction of Cu^{2+} ions in a $CuSO_4$ solution and the subsequent deposition of copper through electrochemical processes or electrolysis.
3. Students are able to understand the kinetics of the electrochemical reduction of Cu^{2+} ions in a $CuSO_4$ solution and the subsequent deposition of copper.

CHAPTER II
LITERATURE REVIEW

2.1 Basic Concepts of Electrochemical Reactions

The study of the relationship between chemical reactions and electric current based on the principles of redox reactions is known as electrochemistry. Electrochemical cells that convert chemical energy into electrical energy through spontaneous redox reactions are called voltaic or galvanic cells, whereas electrochemical cells in which redox reactions do not occur spontaneously and therefore require electrical energy to drive the reactions are called electrolytic cells (Zhao et al., 2024). Chemical changes resulting from electrolysis and redox reactions within a system form part of the study of electrochemistry.

Electrochemical reactions are highly important in the study of chemistry and in everyday life. Information about changes in chemical energy can be obtained from electrochemical reactions, thereby facilitating the analysis of chemical systems. Electrochemistry continues to play an important role in both industrial and household applications. The impact of electrochemical reactions on modern society can be found almost everywhere. In the field of chemical analysis, electrochemistry is applied in processes such as electroanalysis, electrosynthesis, electrocoagulation, electrodialysis, electrowinning, electrorefining, and electroplating. Chemical products such as $AlCl_3$ and NaOH are also produced through electrolysis. Moreover, batteries, as small electrical energy sources, generate electricity through electrochemical redox reactions.

Before understanding the electrochemical systems, it is necessary to first understand how electrical conduction occurs. The mechanism of electrical conduction in metals differs from that in chemical systems. Metals are conductors that can transfer electric charge in the form of electrons from one point to another when electrons are added to or removed from one end. The metallic conductors used in electrochemical systems are called electrodes. In an electrolytic cell, the electrode connected to the positive terminal (+) is called the anode, whereas the electrode connected to the negative terminal (−) is called the cathode (Parthasaradhy, 1989). Electrical conduction resulting from the transfer of electrons is known as metallic conduction. Molten ionic compounds and electrolyte solutions can also conduct electricity, although these systems do not contain freely moving

electrons. Therefore, it is necessary to study how these systems conduct electricity by examining the phenomena that occur in the solution and at the electrodes in an electrolysis apparatus.

2.2 Electrolysis Reaction Mechanism

The mechanism of an electrolysis reaction involves complex interactions among ions in the electrolyte solution, the flow of electrons through an external circuit, and redox reactions occurring at the electrode surfaces. The phenomena that occur in the electrolyte solution and at the electrodes when electricity is supplied by a DC power supply can be explained as follows:

1) DC power supply has a negative terminal (−) connected to the cathode and a positive terminal (+) connected to the anode.
2) Electrons flow from the negative terminal of the DC power supply through a cable to the cathode, while electrons from the anode flow through another cable to the positive terminal. Consequently, the cathode has an excess of electrons, whereas the anode continuously loses electrons.
3) Because the cathode is connected to the negative terminal, it has an excess of electrons and attracts positively charged ions, or cations, in the electrolyte solution. In a $CuSO_4$ solution, Cu^{2+} ions accept electrons at the cathode surface and undergo reduction:

$$Cu^{2+} + 2e^- \rightarrow Cu_{(s)}$$

4) At the same time, the anode is connected to the positive terminal of the DC power supply. Consequently, the anode loses electrons and attracts negatively charged ions, or anions, from the solution. Oxidation occurs at the anode, during which the oxidized species releases electrons. When a copper anode is used, the oxidation reaction can be written as follows:

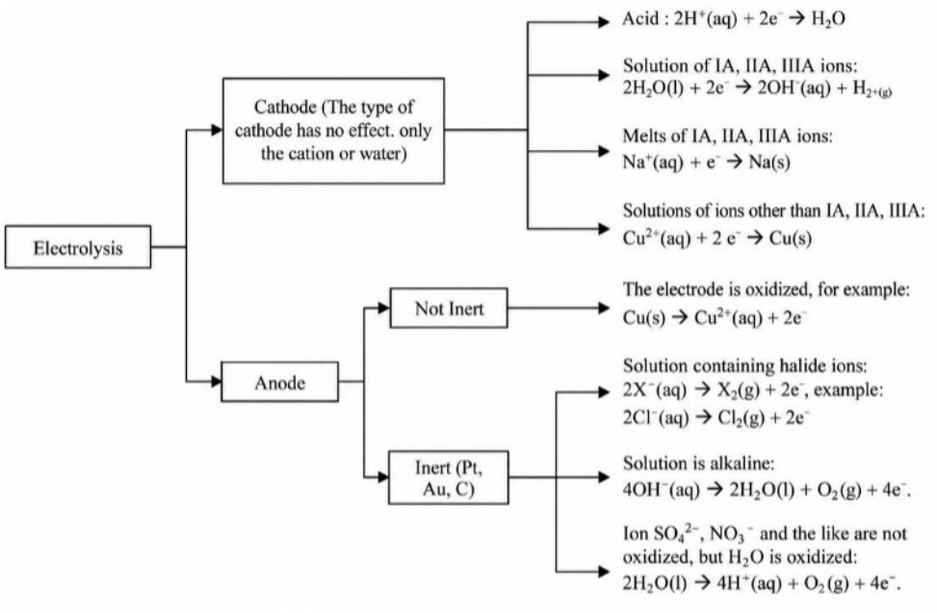
$$Cu_{(s)} \rightarrow Cu^{2+} + 2e^-$$

5) The electrons released during oxidation at the anode flow through the external circuit to the positive terminal of the DC power supply. The power supply then delivers electrons from its negative terminal through the cable to the cathode, where they are consumed by cations during the reduction reaction.
6) As long as the electric current continues to flow, oxidation at the anode and reduction at the cathode occur simultaneously. The ions or species

reduced at the cathode may form products on its surface, including a metallic coating during electroplating. At the same time, the anodic reaction may produce ions or other products in the solution, depending on the type of anode used.

Thus, during a redox reaction, electrons move through the external circuit, while ions migrate through the electrolyte solution. The movement of ions through the solution is known as electrolytic conduction. During electrolytic conduction, any local charge imbalance caused by ion migration and an unequal distribution of cations and anions is counterbalanced by further ion movement, thereby maintaining the electrical neutrality of the solution.

Chemical reactions that occur at the electrodes during electrolytic conduction are known as electrolytic reactions. The system in which these reactions take place is called an electrolytic cell. An ideal electrolyte should possess several properties, including high ionic conductivity over a wide temperature range, the presence of electrically charged particles, environmental friendliness, low cost, and ease of processing (Yi et al., 2024). Several factors determine the reactions that occur during electrolysis, including the type of electrode and electrolyte solution used. Based on their oxidation behaviour, electrodes can be classified into two types: inert and reactive (non-inert) electrodes. An inert electrode is a conductive material that does not participate in the chemical reactions occurring in an electrochemical cell. It provides a surface for electron transfer without undergoing a redox reaction. Inert electrodes conduct electrons during electrolysis without reacting with the solution or other reactants involved in the process. Examples of inert electrodes include platinum, carbon, and gold, which are selected because of their low reactivity. By contrast, reactive electrodes participate directly in electrolysis reactions (Wang et al., 2025).



Gambar 2.1 Electrolytic cell reactions

One of the uses of electrolysis is the refining of copper (Cu). After being separated from its ore, copper metal has a purity of 99%, with iron (Fe), zinc (Zn), silver (Ag), gold (Au), and lead (Pb) as the main impurities. In the copper electrorefining process, impure copper is used as the anode in a $CuSO_4$ electrolytic cell, whereas the cathode is made of high-purity copper. The electrolysis process is carried out by controlling the voltage so that only Cu and more active metals, such as Fe and Zn, are oxidised. Silver, gold, and platinum (Pt) do not dissolve but instead fall and settle at the bottom of the electrolytic cell. At the cathode, only Cu^{2+} ions are reduced, forming a copper deposit. The overall results of this electrolytic cell process are as follows:

1) Copper (Cu) is transferred from the anode to the cathode.
2) Iron (Fe) and zinc (Zn) impurities remain in the solution as ferrous ions (Fe^{2+}) and zinc ions (Zn^{2+}).
3) Other metals, such as Ag, Au, and Pt settle at the bottom of the cell.

If Ag, Au, and Pt are recovered and subsequently sold, the proceeds can offset the electricity costs incurred during electrolysis. Copper produced through this process has a purity of 99.96%.

If the cathode is replaced with iron (Fe) during the production of pure copper, copper is still be deposited on the iron cathode. The process of coating a cathode with another metal by electrolysis is called electroplating. This process is widely used commercially to coat car bumpers with chromium (Cr) to prevent corrosion and improve their appearance.

2.3 Electrode Potential

Electrode potential is fundamental to understanding electrochemical cells, particularly redox reactions. A redox reaction consists of coupled oxidation and reduction reactions occurring in an electrochemical cell. Oxidation is a chemical change in which a substance loses electrons, whereas reduction is a chemical change in which a substance gains electrons. In an electrochemical cell, oxidation occurs at the anode, while reduction occurs at the cathode. In a redox reaction, the species that causes another species to undergo oxidation is called the oxidising agent, whereas the species that causes another species to undergo reduction is called the reducing agent. A reduction reaction can generate a specific electrical potential known as the electrode potential (E). The more readily a species undergoes reduction, the more positive its electrode potential. The actual electrode potential of an individual reduction reaction cannot be determined directly because reduction cannot occur without a corresponding oxidation reaction. Therefore, electrode potentials are expressed relative to a standard reference and reported as standard reduction potentials, also known as standard electrode potentials (E_0). The standard hydrogen electrode (SHE) is used as the reference electrode for determining electrode potentials. It is established by passing pure hydrogen gas over a platinum (Pt) electrode in contact with an acidic solution containing H^+ ions, thereby producing the following equilibrium:

$$H_2 \rightarrow 2H^+ + 2e^-$$

The electrode potential of this reaction is assigned a value of 0 V. The standard reduction potentials of all reduction half-reactions are determined relative to the standard hydrogen electrode (SHE).

Based on their E_0 values, species can be arranged from the lowest to the highest E_0 value in a sequence known as the electrochemical series (Volta series), as follows:

Li – K – Ba – Ca – Na – Mg – Al – Mn – Zn – Cr – Fe – Cd – Co – Ni – Sn – Pb – H – Cu – Hg – Ag – Pt – Au

The electrochemical series (Volta series) has the following characteristics:

1) Metals located to the right of hydrogen (H) have positive E_0 values, whereas metals located to the left of H have negative E_0 values.
2) The farther to the right a metal is located in the Volta series, the higher its E_0 value. This indicates that metals located to the right of H are readily reduced and difficult to oxidise. These metals are referred to

as passive or noble metals.

3) The farther to the left a metal is located in the Volta series, the lower its E_0 value. This indicates that the metal is difficult to reduce and readily oxidised. These metals are referred to as active metals.

(Parthasaradhy, 1989)

2.4 Quantitative Aspects of Electrochemical Reactions and Electrolysis

Michael Faraday established a quantitative relationship between the extent of chemical change in an electrochemical reaction and the quantity of electric charge passed through the system. The extent of chemical change is proportional to the number of moles of electrons involved in the oxidation-reduction reaction. An example of a reaction occurring at the cathode is as follows:

$$Ag^{+}_{(aq)} + e \rightarrow Ag_{(s)}$$

When 1 mol of electrons is supplied to the cathode, 1 mol of silver (Ag) is deposited. In the SI system, 1 mol of electrons is equivalent to 96,494 coulombs (C), which is commonly approximated as 96,500 C. One coulomb is the amount of electric charge that passes through a point in an electrical circuit when a current of 1 ampere (A) flows for 1 second (s), as expressed by the following equation:

$$1\ C = 1\ A.\ 1\ S$$

By measuring the electric current (I) and the duration of current flow (t), the total electric charge (Q), expressed in coulombs, can be determined. The number of moles of electrons can then be calculated from the electric charge, allowing the number of moles of the substance involved to be determined. Faraday established the following relationships in his laws of electrolysis:

1) The amount of substance decomposed during electrolysis is directly proportional to the electric current (I) and the electrolysis time (t).

2) The amount of chemical change produced is proportional to the quantity of electricity passed through the electrolyte.

These relationships are expressed by the following equation:

$$W = \frac{e \times I \times t}{96500}$$

Where:

W : mass of the coating deposit (g)

I : electric current (A)

t : time (s)

e : chemical equivalent weight (atomic mass divided by valence)

The volume of the deposit can be calculated using the following equation:

$$\text{Volume } (cm^3) = \frac{\text{Deposit mass (g)}}{\text{Density } (\frac{g}{cm^3})} = \frac{W}{\rho}$$

Where:

W : mass of deposit (g)

ρ : density of the coating metal (g/cm^3)

The coating thickness can then be calculated as follows:

$$\text{Thickness (cm)} = \frac{\text{Volume } (cm^3)}{\text{Surface area } (cm^2)}$$

Faraday's law explains the effect of electroplating time on the amount of metal deposited. The longer the electroplating time, the greater the amount of metal deposited. The thickness of the metal coating is also influenced by the chemical equivalent weight of the element used as the anode. The equations indicate that an increase in the total mass of the metal deposit results in a thicker coating. Therefore, the coating time and the type of anode affect both the amount of metal deposited and the thickness of the resulting coating.

2.5 Electrochemical Reaction Kinetics and Electrolysis

Reaction kinetics studies the rate of chemical reactions quantitatively and the factors that affect it. The rate of a chemical reaction is the number of moles of reactants per unit volume that reacts in a given unit of time. If a curve is made for decreasing the concentration of a reactant as a function of time, then the slope of the curve at any point is always negative because the concentration of the reactants always decreases. So, the rate of reaction at any point along the curve is $-\frac{dC}{dt}$. If the reaction rate is written as the rate of formation of products, then the reaction rate will be positive. If the concentration of the product after the reaction has taken place t seconds is mol/dm^3, then the reaction rate is $+\frac{dC}{dt}$. The rate of reaction at each time is proportional to the concentration (C) remaining at each time. It can be written mathematically as:

$$-\frac{dC}{dt} = k.C$$

With:

$\frac{dC}{dt}$: differential rate expression

k : reaction rate constant

A general rate equation for reaction is:

$$v = k[A]^x[B]^y[C]^z$$

with total reaction order = x + y + z + ...

$$\text{The rate of reaction} = \frac{\text{Concentration changes}}{\text{Time changes}} = \pm \frac{\Delta X}{\Delta t}$$

The negative sign is used if X is the reactant and the positive sign is used if X is the product of the reaction. The rate of a chemical reaction generally increases when the concentration of one of the reactants is increased. The relationship between reaction rate and concentration can be obtained from experimental data.

For the reaction:

$$A + B \rightarrow \text{Product}$$

it can be found that the reaction rate is directly proportional to $[A]^x$ dan $[B]^y$.

$$\text{The rate of reactions} = k[A]^x[B]^y$$

x and y are integers that represent the order of x to A and order of y to B, while (x + y) is the order of the overall reaction. The rate law of the reaction was obtained experimentally and does not depend on the stoichiometric equation. The order of the reaction is the sum of the powers of concentration in differential form. Theoretically, the order of a reaction is a small whole number, but in some cases form as a fraction or zero. In general, the reaction order of a particular substance is not the same as the coefficient in the stoichiometric equation of the reaction (Zhen et al., 2024).

- Zero Order Reaction

  A reaction is said to be zero order to a reactant if the rate of the reaction is not affected by the concentration of that reactant. If [A] is the concentration and $[A]_0$ is the concentration at time t = 0, then:

  $$\frac{-d[A]}{dt} = k$$

  Then, it is integrated into:

  $$[A]_0 - [A] = k\,.t$$

- First Order Reaction

  $$\frac{-d[A]}{dt} = k\,[A]$$

  The integral results to obtain the correlation between the concentration of the reactants to time:

  $$\ln\frac{[A]}{[A]_0} = k.t$$

- Second Order Reaction

  $$\frac{-d[A]}{dt} = k\,[A]^2$$

The integral results to obtain the correlation between the concentration of the reactants to time:

$$\frac{1}{[A]} - \frac{1}{[A]_0} = k.t$$

- Third Order Reaction

$$\frac{-d[A]}{dt} = k\,[A]^3$$

The integral results to obtain the correlation between the concentration of the reactants to time:

$$\left(\frac{1}{[A]}\right)^2 - \left(\frac{1}{[A]_0}\right)^2 = 2k.t$$

2.6 Factors Affecting the Electroplating Process

1. Electrolyte Concentration

   The concentration of metal ions in the electrolyte solution determines the availability of metal ions required to form a metallic coating on the cathode surface. Ion concentration also affects the electrical conductivity of the solution and the rate of ion transport from the bulk solution to the cathode surface. The electrolyte concentration must be maintained within an appropriate range to ensure that the availability of metal ions in the solution remains balanced with the rate of metal deposition on the cathode surface.

2. Electric Current

   Electric current is one of the key parameters in the electroplating process because it represents the rate at which electric charge flows through an electrochemical cell. The flow of electric charge causes electron transfer at the electrodes and drives the reduction of metal ions at the cathode surface, enabling the ions to accept electrons and form a metallic coating. Increasing the electric current increases the rate at which electrons participate in the electrochemical reaction, thereby increasing the amount of metal deposited and accelerating coating formation during the electroplating process.

3. Electrode Type

   The electrode type refers to the materials selected for the anode and cathode in the electroplating process. A reactive (non-inert) anode, also known as a soluble anode, may be used in electroplating. This type of anode dissolves during the process, helping to maintain the concentration of metal ions in the electrolyte solution. Alternatively, an

inert anode, also known as an insoluble anode, may be used. This type of anode does not participate in the electrochemical reaction and serves as a conductor of electric current. The electrode type must be selected according to the type of metal involved and the characteristics of the electrolyte solution used.

4. Plating Time

Plating time is one of the operating parameters that determines the duration of the electroplating process. During this process, metal ions undergo reduction at the cathode surface, resulting in the gradual formation of a metallic coating. Variations in plating time can affect the thickness and surface condition of the resulting coating. Therefore, the plating time must be controlled to maintain the quality of the resulting coating.

(Akbar et al., 2025)

CHAPTER III
PRACTICUM METHOD

3.1 Experimental Design

3.1.1 Experimental Scheme

3.1.2 Experimental Variables

1. Independent Variables
2. Controlled Variables

3.2 Materials and Tools Used

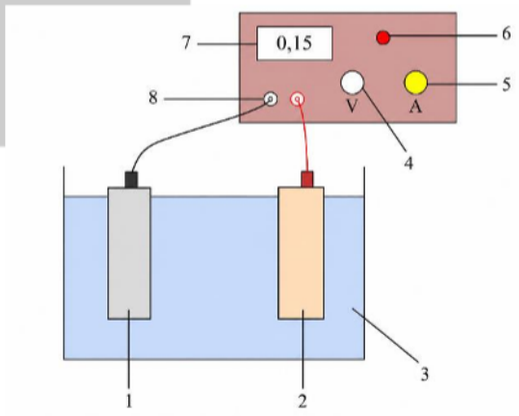
3.2.1 Materials

1. $CuSO_4$
2. Aquadest

3.2.2 Tools

1. DC power supply
2. Electroplating bath
3. Electrode holder
4. Zinc plate (Zn)
5. Copper plate (Cu)
6. Alligator clip
7. Watch glass
8. Scales digital
9. Beaker glass 1000 mL
10. Beaker glass 500 mL
11. Glass stirring rod
12. Sandpaper

3.3 Instrument Design



Gambar 3.1 Electropating instrument design

Where:

1) Cathode
2) Anode
3) The electroplating bath and the electrolyte solution
4) Voltage adjustment button
5) Current adjustment button
6) Maximum current marker
7) Current display
8) Power source cable

3.4 Procedure

1. Determine the optimum contact time

   The waste solution or synthetic solution in the electroplating bath was taken every ... seconds for ... seconds. Other variables are ... A current and ... g/L solution. The obtained sample were analysed and the efficiency of reducing copper content is being calculated. Variable with the highest efficiency is chosen to be the optimum contact time of the process and being used for further process.

2. Determine the optimum electric current

   The solution is fed into the electroplating bath with a fixed concentration. However, the process uses various electric current, i.e., … A, ... A, and ... A, each at the optimum contact time. All the efficiency of each variable is being analyzed, and the highest one is chosen to be the optimum electric current. Hereinafter, the optimum current is being used for the next process.

3. Determine the optimum solution concentration

   The solutions that are fed into the electroplating bath come with various concentration, i.e., ... g/L, ... g/L, and ... g/L. Process run at the optimum contact time and electric current conditions. All the efficiency of each variable are being analysed and the highest one is chosen to be the optimum solution concentration.

$$\text{Efficiency (\%)} = \frac{\text{Actual weight of cathode}}{\text{Theoritical weight of chatode}} \times 100\%$$

$$\text{Actual weight} = W_t - W_0$$

$$\text{Theoritical weight} = \frac{B \times i \times t}{E \times F}$$

Where:

B = Anode molecular weight

I = Electric current (A)

t = Time (second)

E = Atomic valency of anode

F = Faraday constant (96.500 C/mol)

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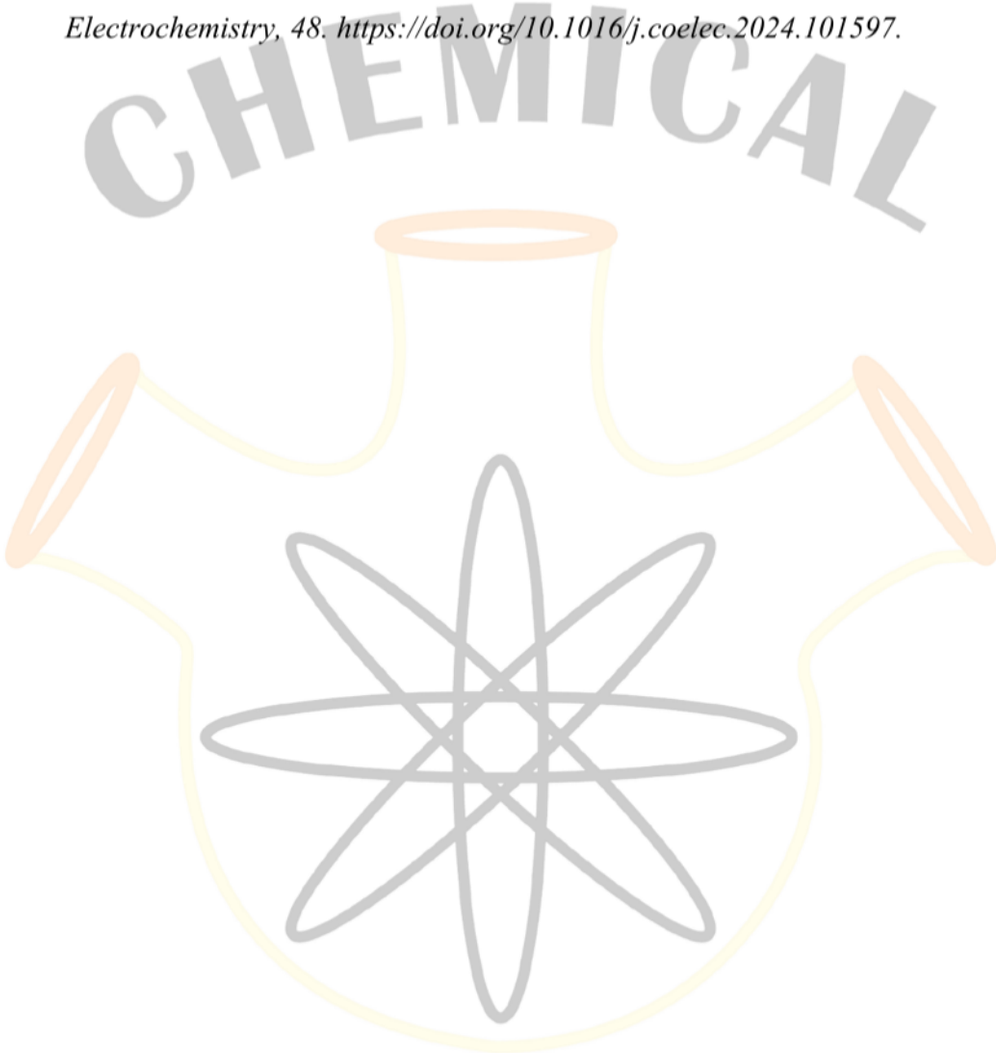

HAZARD IDENTIFICATION AND RISK ANALYSIS

MATERIAL: ELECTROPLATING

HAZARD IDENTIFICATION (HI)											
A	**Mechanic**		**D**	**Environment**		**E**	**Chemical Materials**		**G**	**Another Hazard**	
A1	Manual handling	✓	D1	Noise		El	Poison	✓	GI	Compressed gas	
A2	Moving parts		D2	Vibration		E2	Irritant	✓	G2	lonizing radiation	
A3	Rotating parts		D3	Lighting		E3	Corrosive		G3	UV radiation	
A4	Cutting		D4	Humidity		E4	Carcinogenic		G4	Fatigue	
B	**Biology**		D5	Temperature		E5	Flammable		G5	Narrow space	
B1	Bacteria		D6	Danger journey		E6	Explosive		G6	Crowded	
B2	Virus		D7	Slippery surface	✓	E7	Cryogenic		G7	Thermometer	
B3	Mold		D8	Solid waste	✓	**F**	**Equipment**				
C	**Electricity**		D9	Air quality		F1	Pressure vessel				
C1	High voltage	✓	D10	Solitary work		F2	Hot equipment				
C2	Static electricity		D11	Splash/ drip/ flood	✓	F3	Laser				
C3	Cable	✓	D12	Powder spill	✓	F4	Glass vessel				

RISK DETAILS							
HI	**Risk (After Control Action)**				**Risk Identification**	**Control Measures to Minimize The Risk**	**First Aid Measures**
	High	**Medium**	**Low**	**Minimum**			
1. PREPARATION/ FIRST STAGE							
			✓		When sanding the electrodes, there is a risk of scarping.	- Wear full PPE. - Sanding in one direction. - Make sure not to do sanding in a narrow space.	- Treat wounds with aid wound medicine.
2. MAIN EXPERIMENT							
		✓			When turning on the electricity, there is a risk of electric shock.	- Make sure the wires/ electrical terminals are not wet. - Wear full PPE.	- Cut off the power source. - Pushing the victim's body by insulating objects. - Seek medical help. - Treat burns
		✓			When attaching and/ or removing alligator clips from the electrodes, there is a risk of electrocution	- Make sure it doesn't come into direct contact with the cable or alligator clips. - Wear full PPE	- Cut off the power source. - Pushing the victim's body by insulating objects. - Seek medical help. - Treat burns
3. ANALYSIS/ FINAL STAGE							
			✓				