Recycling Aluminum Can by Using Ionic Liquid

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Chemical Engineering Programme
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Approved by,

(AP DR.MOHAMAD AZMI BIN BUSTAM)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgment, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(NURUL 'AEIN BINTI MAZLAN)

ABSTRACT

Recycling aluminum can by using ionic liquid will be investigated. The objectives of this experimental works are to investigate electrodeposition of aluminum by using ionic liquid, to optimize condition of electrolyte cell in ionic liquid and also to recycle aluminum can with less pollution produced. For aluminum to be recycled, electrolysis process at low temperature will be used.

Electrolysis is a process where elements that are bonded chemically will be separated by passing an electric current through them. Ionic liquid will be used as one of the component in the mixture of the electrolyte. Ionic liquid used is 1-Butyl-3-Methylimidazolium Chloride (BMIM Chloride) .The electrolyte consist of a mixture of Aluminum Chloride,$AlCl_3$ and 1-Butyl-3-Methylimidazolium Chloride, BMIM Chloride.

At the end of this experiment, aluminum is expected to be dissolved at anode electrode which is aluminum can and deposited at the cathode electrode which is copper. For this experimental work, parameter that will be studied is temperature. Two different voltages which is at 1.0 V and 1.3 volt is applied at three different temperature which is at 25°C, 70° C and 100° C. The presence of aluminum at cathode is determined by difference in weight before and after electrolysis.

X-ray diffraction, XRF studies is done on the Aluminum Can to ensure the presence of aluminum. XRD test also done for the copper to ensure the component presence in the Copper. For the aluminum can, Energy Dispersive, EDX Test is done in order to identify the composition of aluminum can. The EDX test also has been done at the copper electrode after they undergo electrolysis to confirm the presence of aluminum at the cathode electrode.

The energy use to recycle aluminum can by using ionic liquid is lower compared to the current process. Besides that, the pollution produced also less compare to the current process.

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Last but definitely not the least, I also want to thank you to all individuals who had contributed and provide aid in any ways towards the completion of the project. Hence, I would like to take the opportunity to express our sincere appreciation and gratitude for their support and assistance.

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ABBREVIATIONS

XRD	: X-ray Diffractions
EDX	: Energy Dispersive X-Ray
XRF	: X-ray Fluorescence
BMIM Chloride	: 1-Butyl-3-Methylimidazolium
NaCl	: Sodium chloride
$AlCl_3$	: Aluminum chloride
MEIC	:1-Methyl-3-ethylimidazolium

CHAPTER1

INTRODUCTION

1.1 BACKGROUND STUDY

The average person consumes 43,371 aluminum beverage cans (12 packs per week) in their lifetime. 43, 371 cans is approximately 1434 pounds of aluminum. If a person recycled all the aluminum cans they consumed, it could power a television for 130,000 hours, which is a lot of energy could be safe [28]. Since the awareness of saving the environment is increasing among the communities, they start to recycle the aluminum can that they used.

In general, there is no limit to the number of times that aluminum can be recycled. By recycling aluminum, 95% less energy is used compared to produce aluminum from ore [1]. The current process to recycle aluminum can required high energy requirement since the can is required to be melted first at 750 °C to 850 °C before cast it into ingots. In

the present study, it is proposed to recycled aluminum can by using ionic liquid since by using this method aluminum can be reclaimed via electrolysis in ionic liquid at low temperature.

This study is originated when ionic liquid is used for electrodeposition metal.

1.1.1 Concept of Electrolysis

Electrolysis is a process whereby a compound is decomposed into its constituent elements when an electric current passes through an electrolyte [5]. Electrolysis system consists of electrode, power supply and also electrolyte.

Electrodes are conductors in the form of wires, rods or plates which pass electricity through the electrolyte during electrolysis. Electrodes that do not take part in chemical reactions during electrolysis are known as inert electrodes. Examples of inert electrodes are graphite and platinum electrodes.

The power supply is required since electrolysis govern a non –spontaneous reaction. It requires external driving force for reaction to occur. Power supply can be batteries or Voltage supplied.

Electrolytes are substances that can conduct electricity either in molten state or in aqueous solution, and undergo chemical changes. In general, examples of electrolytes are acids, alkalis and salt solutions or molten salts. All these are ionic substance. Ionic compound do not conduct electricity in the solid state because the ions are held in lattice and do not move freely. When melted, they can conduct electricity due to free ion moving in the molten salt.

The process of electrolysis involves two stages [5].

<u>Stage 1: Movement of ions</u>

Cations (positive ions) will move towards the cathode. While anions (negatives ions) will move towards the anode, the positively charged electrode.

<u>Stage 2: Discharge of ions</u>

Cations will be discharge at the cathode, which has an excess of electrons. Anions will be discharge at the anode by donating electrons to the anode, which is lack of electrons. Electrons will flow from the anode to the cathode in the external circuit. When ions are discharged, they form atoms or molecules.

Some benefits of the uses of electrolysis in industries are:

1. Reactive metals can be extracted by electrolysis
2. A very thin layer of metal can be coated on an object using electrolysis.
3. Electrolysis can be used to produce a very pure metal.

1.1.2 Electrolytic Cell

An electrolytic cell converts electrical energy to chemical energy. It decomposed chemical compounds by using electrical energy in a process called electrolysis. It requires electrical energy since electrolytic cells are having non- spontaneous reaction. This non–spontaneous reaction occurs because the direction of electron flow in electrolytic cell is reversed from the direction of spontaneous electron flow in galvanic cell. In non-spontaneous reactions, energy must be absorbed for the reaction to occur.

An electrolytic cell consists of:

- Two electrodes (a cathode and anode).
  - -Cathode: negative charge of electrode (where reduction process occur)
  - -Anode: positive charge electrode (where oxidation process occur)
- An electrolyte
  - - Usually a solution of water or other solvents in which ions are dissolved.
  - -Molten salt is also an electrolyte

When external voltage applied to the electrodes, the electrolyte provides ions that flow to and from the electrodes. The reaction takes place when transferring of charge occurs.

Oxidation takes place at the anode and electrons flow from anode to cathode

1.1.3 Ionic Liquid

Ionic liquid is a liquid that contains essentially only ions. Below are the characteristics of ionic liquid [6]:

- o Electrically conductive. Conductivity of ionic liquid is in wide range which is 0.1mS/cm to 18mS/cm.Generally, the conductivity of ionic liquid is 10mS/cm.Good ionic conductivity is suitable for electrolyte in electrochemical system.

- Have extremely low vapor pressure. It is usually assume as nonvolatile chemical due to extremely low vapor pressure. This makes ionic liquid as environmental friendly solvent since no pollution will be produced to the environment.
- Most of ionic liquid are having low combustibility, excellent thermal stability, a wide range and favorable solvating properties for diverse compounds.(Thermal stability and melting point depend on the components of the liquid)
- Miscibility of ionic liquids with water or organic solvents varies with side chain lengths on the cation and with choice of anion. (Can be functionalized to act as acids, bases or ligands)
- For imidazolium ionic liquid, the solubility depends mainly on polarity and hydrogen bonding ability.

Ionic liquid have been considered as having low impact on the environment and human health due to their non-volatility, effectively eliminating a major pathway for environmental release contamination. Thus ionic liquids are recognized as solvents for green chemistry.

1.2 PROBLEM STATEMENT

To produce primary aluminum, it requires a lot of energy. By recycling, 95% of the energy usage to produce aluminum can be reduced. However, it still required high operating temperature. The aluminum produce from recycling process also does not contain high purity. Besides that, current process to recycle aluminum also produces some amount of pollutions. The amount of pollution produced is around 5 to 10% lesser compare to amount of pollution produced while producing aluminum from ore. By using ionic liquid as a medium to recycle aluminum can, besides having low operating temperature, it also consumed a little amount of energy compared to current process. With the excellent properties of ionic liquid that lead to low environmental impact, it gives advantage to the recycling process by using ionic liquid.

1.3 OBJECTIVES

There are three main objectives of doing this experimental work. There are:

1) To investigate electrodeposition of aluminum by using ionic liquid

2) To optimize temperature condition of electrolyte cell in ionic liquid. The chosen condition is the temperature of the system.

3) To recycle aluminum can with less pollution produced.

1.4 SCOPE OF STUDY

In order to achieve all the objectives, a lot of research and some related experimental works have to be done. The study on recycling aluminum can by using ionic liquid need to be completed within the time frame given which is approximately two semesters. The scope of the first semester is more into research planning regarding the topic

For the first semester, literature review that needs to be done is basically on the selection of ionic liquid that is suitable to be as an electrolyte. After done with all the comparison, BMIM Chloride is selected as the ionic liquid. Mixture of aluminum chloride and BMIM chloride is selected as the electrolyte. Besides that, the correct way to prepare the electrolyte also must be identified. Since on of the component which is aluminum chloride react violently with water, water cannot be used in order to prepare the electrolyte. The electrolyte will be heat up to melt them.

Other method must be identified. Besides identifying method to prepare the electrolyte, method for the whole experiment also need to be identified. Thermodynamic calculation also has been done for the electrolytic cell. This is just to help to predict on what is to be expected from the experiment. Chemicals that need to be used also must be listed in the first semester.

For the second semester, work will be more focusing on experimental work. It started with gather all the apparatus needed and also check the availability of the equipment that need to be used. If the apparatus or equipment does not available, possible option need to find immediately. Run the experiment once all the apparatus and equipment is ready. The experiment is done at applied voltage of 1.0V and 1.3 V with temperature at 25 °C, 70°C and 100°C.After the experimental work is done, the electrode need to be sent for further analysis. In order to do this, some procedures must be followed.

CHAPTER 2

LITERATURE REVIEW

2.1 PREVIOUS WORK

Aluminum electrodeposition at low temperature has been started since 1854[9].They first started by using non aqueous electrolyte bath composed $AlCl_3$-Nacl. In 1914 the first ionic liquid ($EtNH_3$-NO_3) was prepared. In 1982, they start to use ionic liquid as electrolyte for aluminum deposition [9].

Ionic liquid is quite different from molten salt [12]. Ionic liquid is a low melting organic salt mixtures. It is different from molten salts. Molten salts have a high boiling point, high viscosity and also very corrosive. Compared to ionic liquid, they have relatively low viscosity and most of the ionic liquid is in liquid phase at room temperature. Ionic liquid also have wide electrochemical windows and electrical conductivities which allowed the ionic liquid to be potential solvents for electrochemical applications.

From the previous works, they have developed new ionic liquid and thus continuing the study on the aluminum electrodeposition. The two journals mentioning about reclaiming aluminum by using new class of ionic liquid is "Recycling of Aluminum Metal Matrix Composite Using Ionic Liquids: Effect of Process Variables on Current Efficiency and Deposit Characteristics" by V.Kamaram, D.Mantha and R.G Reddyand the other one is "Electrorefining of Aluminum Alloy in Ionic Liquids at Low Temperatures" also by the same authors.

Both of the journals are about using ionic liquid to reclaimed aluminum. The different between both journals is just the type of aluminum that they used to recycle. One is using aluminum metal matrix and the other one is using aluminum alloy, A-306.Both of this aluminum act as anode electrode. Both of the journals are using mixture of 1-butyl-3 methylimidazolium chloride and aluminum chloride salt as the electrolyte system. For the cathode electrode, both of them used copper.

Both of the journals show the same results where aluminum will be deposited at the cathode. Both journals also show that they have use low energy consumption. High purity of aluminum also has been produced from both of these journals.

Basically, the idea of doing this experimental work is come from both of the journal. The difference is the type of aluminum used. Aluminum can is chosen as the raw material of recycling process.

2.2 ALUMINUM

2.2.1 Why recycle Aluminum can?

i. Aluminum cans are everywhere
ii. The industry that uses the most aluminum is the beverage industry
iii. Generally, aluminum is a perfect recyclable material. It is the only material that's endlessly recyclable.
iv. It takes 95% less energy to make aluminum from bauxite ore than to recycle old aluminum into new.
v. Making aluminum from bauxite ore is a dirty process and burning it is even worse. By doubling aluminum recycling rate, a million tons of pollutants can be cut.

2.2.2 Producing aluminum from ore

To produce the primary aluminum, it required high energy. It is extracted by electrolysis. The ore first converted into pure aluminum oxide by Bayer process, and this is then electrolyzed in molten cryolite solution together with other aluminum compound. The aluminum oxide has too high a melting point to electrolyze on its own which is around 2980 °C.

The usual aluminum ore is bauxite. Bauxite is essentially an impure aluminum oxide. The major impurities include iron oxides, silicon oxide and titanium dioxide.

Crushed bauxite is treated with moderate concentrated sodium hydroxide solution. The concentration, temperature and pressure used depend on the source of the bauxite and exactly what form of aluminum oxide it contains. Temperatures are typically 140 °C to 240 °C. Pressure can be up to 35atm [1].

High pressures are necessary to keep the water in the sodium hydroxide solution liquid at temperature above 100 °C [1]. The higher the temperature, the higher the pressure needed. With hot concentrated sodium hydroxide solution, aluminum oxide reacts to give a solution of sodium tetrahydroxoaluminate.

$$Al_2O_3 + 2NaOH + 3H_2O \longrightarrow 2\,NaAl(OH)_4$$

The impurities in the bauxite remain as solids. All of these solids is separated from the sodium tetrahydroxoaluminate solution by filtration. They form a 'red mud' which is just stored in huge lagoons.

The sodium tetrahydroxoaluminate solution is cooled, and seeded with some previously produced aluminum hydroxide. This provides something for the new aluminum hydroxide to precipitate around.

$$NaAl(OH)_4 \longrightarrow Al(OH)_3 + NaOH$$

Aluminum oxide is made by heating the aluminum hydroxide to a temperature of about 1100 °C to 1200 °C[7].

$$2Al(OH)_3 \longrightarrow Al_2O_3 + 3H_20$$

The aluminum oxide is then electrolyzed in solution in molten cryolite, Na_3AlF_6. Cryolite is another aluminum ore, but is rare and expensive.

Molten aluminum is siphoned out of the cell from time to time, and new aluminum oxide added at the top.

The cell operates at a low voltage of about 5 to 6 volts, but at huge currents of 100000 amps or more. The heating effect of these large currents keeps the cell at a temperature of about 1000 °C.
At the electrode, aluminum is released at the cathode. Aluminum ions are reduced by gaining three electrons.

$$Al^{3+} + 3e^- \longrightarrow Al$$

At the temperature of the cell, the carbon anodes burn in this oxygen to give carbon dioxide and carbon monoxide. Thus, it needs continual replacement of anodes and its required major expense.

2.2.3Current Method to Recycle Aluminum

According to http://en.wikipedia.org/wiki/Aluminum _recycling, below are the processes involve in order to recycle aluminum:

1) Cans are first separated from municipal waste using an eddy current separator
2) Cans are shredded into small, uniform pieces to reduce volume and simplify automated handling by machines
3) Pieces are mechanically or chemically cleaned to reduce contamination impurities.
4) Pieces are compressed into blocks to minimize oxidation losses when melted.
5) Blocks are loaded into the furnace and heated to 750 °C ± 10 °C to produce molten aluminum.

6) The furnace is tapped, the molten aluminum poured out and the process is repeated again for the next batch. Depend on the end product, it may cast into ingots, billets or rods, formed into large slabs for rolling ,atomized into powder, sent to an extruder, or transported in its molten state to manufacturing facilities for further processing.

2.2.4Economics and Environmental Considerations due to Producing Primary Aluminum

Economic Consideration:

To produce aluminum from its raw material, it require high operating cost High cost of the process is due to the huge amounts of electricity it uses. According to Hemlink Consultant, electricity consumption for alumina is around 260kWh per tonne implying cost of 8 per cent of market value. For aluminum metal, requiring 14 000kWh per tonne the cost is around 45 per cent. Since the anode electrode keeps reducing during the process, it needs to be replaces. Thus, it will increase the operating cost.

Environmental Consideration:

Some environmental problem need to consider while extracting aluminum from bauxite. The environmental problems that need to be consider is based on air pollution, water pollution, solid waste, hazardous waste and also natural resources. In term of air pollution, air emission during producing primary aluminum will lead to greenhouse effect. Air emission can be released during mining, processing (chlorine gas emissions), manufacturing (carbon dioxide, carbon monoxide and sulfur dioxide) and also recovery process (carbon dioxide, nitrogen oxides and sulfur dioxide).

For water pollution, aluminum production can create water pollution during mining due to acid mine drainage. Producing primary aluminum also give solid waste. Metals mining create more than two billion tons of solid waste. Solid waste from mining is called tailings and is produced during both mining and mineral processing. This material typically consists of crushed rock, which can contain toxic heavy metals, and chemical processing agents such as cyanide or sulfuric acid.

Some hazardous waste also obtained from producing primary aluminum. Hazardous wastes are often created during mining and manufacturing. Besides that, another element that needs to be considered is the natural resources. Mining for aluminum materials can contribute to the depletion of and damage to natural resources such as bauxite ore, limestone and salt.

To overcome all the consideration, recycle the aluminum is a good solution.

2.3 IONIC LIQUID

2.3.1 Why Using Ionic Liquid?

Ionic liquid is an electrically conductive liquid. Generally, most of the ionic liquid has conductivity about 10mS/cm.Ionic liquid also have extremely low vapor pressure. Usually, it is assumed that vapor pressure for ionic liquid is neglected. Due to extremely low vapor pressure, ionic liquid is a non volatile component. Most of ionic liquid are having low combustibility, excellent thermal stability, a wide range and favorable solvating properties for diverse compound. Thermal stability and melting point depend on the component of the liquid. Different ionic liquid will have different melting point and different thermal stability. Ionic liquid also can act as acids, based or ligands. Miscibility of ionic liquids with water or organic solvents varies with side chain lengths on the cation and with choice of anion.

For this study, students are using imidazolium based ionic liquid.For imidazolium ionic liquid, the solubility depends mainly on polarity and hydrogen bonding ability.

2.3.3 Selection of Ionic Liquid

There are actually a few possible ionic liquid that can be used for electrodeposition of aluminum. There are [9]:

1) NaCl-$AlCl_3$-butylpyridinium
2) $AlCl_3$-alkyl pyridinium chloride
3) $AlCl_3$ with 1-Methyl-3-ethylimidazolium chloride (MEIC)
4) $AlCl_3$ and 1-Butyl-3-Methylimidazolium Chloride (BMIM Chloride)

For NaCl –$AlCl_3$-butylpyridinium, the operating temperature for this system is 175 °C [10]. The problem of using this system is that they are having a small electrochemical window which is around 0.2 V. Besides that, in term of stabilities, since they are in pyridinium group of ionic liquid, they are having the less stability.

Same goes to $AlCl_3$ –alkyl pyridinium chloride. It has an unstable system and very small electrochemical window. Electrochemical window is the range of voltage where the substance does not get oxidized or reduced. It is important for the efficiency of the electrode.

For $AlCl_3$ with 1-Methyl-3-ethylimidazolium chloride (MEIC), it has a wide electrochemical window and a large liquidus temperature range. However, it yields a very thin deposit which is less that 0.2 μm and also low conductivity,0.85mS/cm [12]. Thus, this ionic liquid requires another solvent which is benzene. After adding benzene, it shows that it is not a suitable mixture for aluminum deposition.

For $AlCl_3$ and 1-butyl-3-methylimidazolium chloride, it shows a good deposition of aluminum. Besides that, it also have large electrochemical window. From the previous worked done, it shows thick aluminum deposit which is >0.2mm without adding any co solvent .Therefore, $AlCl_3$ and 1-butyl-3-methylimidazolium chloride is chosen to be the electrolyte for this experimental work.

2.4 ELECTROLYSIS

2.4.1 Selection of Electrode

For the selection of electrode, basically only for the cathode electrode the selection need to be made. This is because, at the anode electrode the material is based on what we want to reclaim. For the cathode electrode, basically the selection made is based on the journals. However, this selection is acceptable due to the electronegativity of copper compare to aluminum. Electronegativity is the measure of the ability of an atom of that element to attract the electrons in bond [32].

From Pauling Electronegativities [4], it shows that copper has large values of electronegativities compare to aluminum. This mean that copper has tendency to attract electrons from aluminum thus makes the deposition of aluminum at the copper electrode possible .Eelctronegativity cannot be directly measure .It must be calculated from other atomic or molecular properties.

Besides that, the chosen electrode for cathode must suitable or provide a suitable condition for collection of deposited aluminum.

2.4.2 Selection of electrolyte

For electrolyte, mixture of $AlCl_3$ and 1-butyl-3-methylimidazolium chloride has been selected. It is prove that it yields a good deposition of aluminum [9]. Besides that, it also have large electrochemical window. From the previous worked done, it shows thick aluminum deposit which is >0.2mm without adding any co solvent. Therefore, $AlCl_3$ and 1-butyl-3-methylimidazolium chloride is chosen to be the electrolyte for this experimental work.

2.4.3 Thermodynamic of Electrolytic Cell

Cell Potential

Cell potential is calculated from electrode potentials (reduction potentials) by using the following formula:

$$E_{cell} = E_{right} - E_{left}$$

$$E_{cell} = E_{reduction} - E_{oxidation}$$

Electrode reactions are half reactions. Each has associated with it standard electrode potential E°. Standard electrode potential is the measure of individual potential of reversible electrode at standard state.

For half reactions at equilibrium, the potential E, can be related to standard electrode potential through Nernst equation.

Nernst Equation

This equation can be used to determine the equilibrium reduction potential of half- cell in an electrochemical cell and also to determine the total voltage for full electrochemical cell[18].

This equation relates the activities of the species involved with the electrode potential, of the half reaction and its standard electrode potential, E°.

$E_{red}=E^{\circ}_{red} - (RT/zF) \ln (\alpha_{red} / \alpha_{oxi})$ ⟶ half cell reduction potential

$E_{cell} = E^{\circ}_{cell} - (RT/zF) \ln Q$ ⟶ total cell potential

Where:

E_{red} - half cell reduction potential

E°_{red} - standard half cell reduction potential

R - Cell potential

T - Temperature (in K)

α - chemical activity for the relevant species

z - Number of electrons transferred

F - Faraday constant; 9.6485309×10^4

Q - Reaction quotient

The cell potential also tells the maximum energy that the cell can supply by the following formula:

$$\Delta G = -\ nFE_{cell}$$

Where:

G – Gibbs free energy

n – number of electron transfer

F – Faraday constant; 9.6485309×10^4

E - half cell reduction potential

By calculation Gibs free energy, the spontaneity of reaction can be determined.
Based on the previous thermodynamic properties, mass of metal deposited can be calculated by using the formula below:

$$m = \frac{QM}{nF}$$

where

m=mass of deposited metal

M=molecular weight

n= number of electrons transfer

F=Faraday constant

Q=electric charge.

Q can be calculated by using the following formula

$$Q=It$$

Where

I=current

t=time

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 BRIEF DESCRIPTION ABOUT THE EXPERIMENTAL WORK

The methodology for the experiment can be divided into three parts which are the preparation of electrode, preparation of electrolyte and set up of the electrolysis experiment.

Preparation of electrode

1) Aluminum can and copper is chopped according to specific size.

2) For aluminum can, the coating inside the can and also the paint outside the can need to be removed by using sand paper.

3) Both electrodes have been sent to undergo XRD and also EDX test.

4) Both electrodes are weight before start the experiment.

Preparation of electrolyte

1) 8.7g of BMIM Chloride is placed in the beaker

2) 10g of $AlCl_3$ is introduced into the beaker that contains BMIM Chloride. $AlCl_3$ must be introduced in small amount because exothermic reaction will occur.

3) Apply heat if heat from exothermic reaction does not enough to melt the mixture.

4) The preparation of electrolyte must be done under inert condition.

Electrolysis setup

Anode: Aluminum Can

Cathode: Copper

Electrolyte: Mixture of aluminum chloride and BMIM Chloride

Brief methodology about this experimental work is present in flow chart below:

Chop the aluminum can and copper according to the appropriate size.

↓

Check the composition of the aluminum can by using EDX. Weigh the copper electrode and also the aluminum can

↓

Set up experiment

↓

Prepare the electrolyte:

1) Introduce small amounts of $AlCl_3$ into beaker containing BMIM Chloride. (Exothermic reaction)
2) Check the temperature of the mixture. If it is below the predetermined experimental temperature, heat up the mixture. If the mixture is above the predetermined temperature, cool it down.

*note:

1) Mixing and weighing of the components will be done in a controlled atmosphere glove box filled with argon and then the electrolyte will be

↓

Electrolysis will be done for 2 hours.

↓

End of electrolysis.

1) Weight the cathode electrode
2) The deposit will be clean with water to remove any organic impurities present on electrode.

Figure 3.1: *Flow chart of overall experimental work*

Figure 3.2: Plastic glove, for preparation of electrolyte

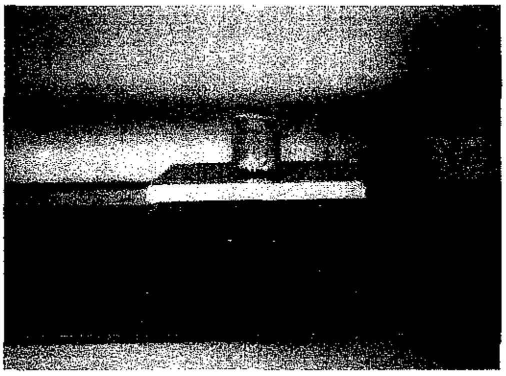


Figure 3.3: Part of the step in preparing the electrolyte

Figure 3.4: Electrolyte and electrode for the experimental work

Figure 3.5: Electrolysis process

3.2 DETAIL EXPLANATION ON EXPERIMENTAL WORK.

For the setup of the experiment, a small bottle with diameter 3.9cm and 4.7 cm height is used. This is due to the unavailability of 50ml beaker. Then, this bottle is fitted with parafilm. Schematic diagram of the experimental set up is shown in Figure 3.2. Aluminum can were used as anode and copper were used as a cathode. Electrodes need to be cut into appropriate size. The paint outside of the aluminum can, the coating inside the aluminum can need to be remove by using sand paper. A constant potential, supplied by Programmable DC Power Supply (BK Precision 1775) is applied across the electrode. This power supply also measures the current across the electrode.

The electrolyte was stirred at constant speed using a magnetic stirrer. The temperature of electrolyte was controlled by using hot plate (Bibbly).The electrolyte was prepared by slowly mixing the $AlCl_3$ and BMIM Chloride in that small bottle. The process is exothermic. So, the $AlCl_3$ must be introduced in small amount into the beaker containing BMIM Chloride. Heating is necessary since the heat from exothermic reaction does not enough to melt the mixture. Do not melt this mixture with water since $AlCl_3$ react violently with water. Then, the melt was cooled to predetermine experimental temperature before start the electrolysis.

For this experiment, 2.02g of BMIM Chloride (Merk) and 2.24g of $AlCl_3$ (Fluka, 06230) is used. The experiments were done at two different voltages which are at 1.0V and 1.3 V at three different temperatures which is at 25°C, 70 °C and 100° C.$AlCl_3$ was used without further purification. Mixing and weighing of the components were done under plastic glove filled with inert. Then the electrolyte was transferred to the fume cupboard for the experiment to be done.

Once the electrolysis done, washed the electrodes with distilled water to remove impurities. Deposits obtained were sent for EDX test to check the composition of the deposits. The original aluminum can and also copper electrodes were also sent for XRD test.

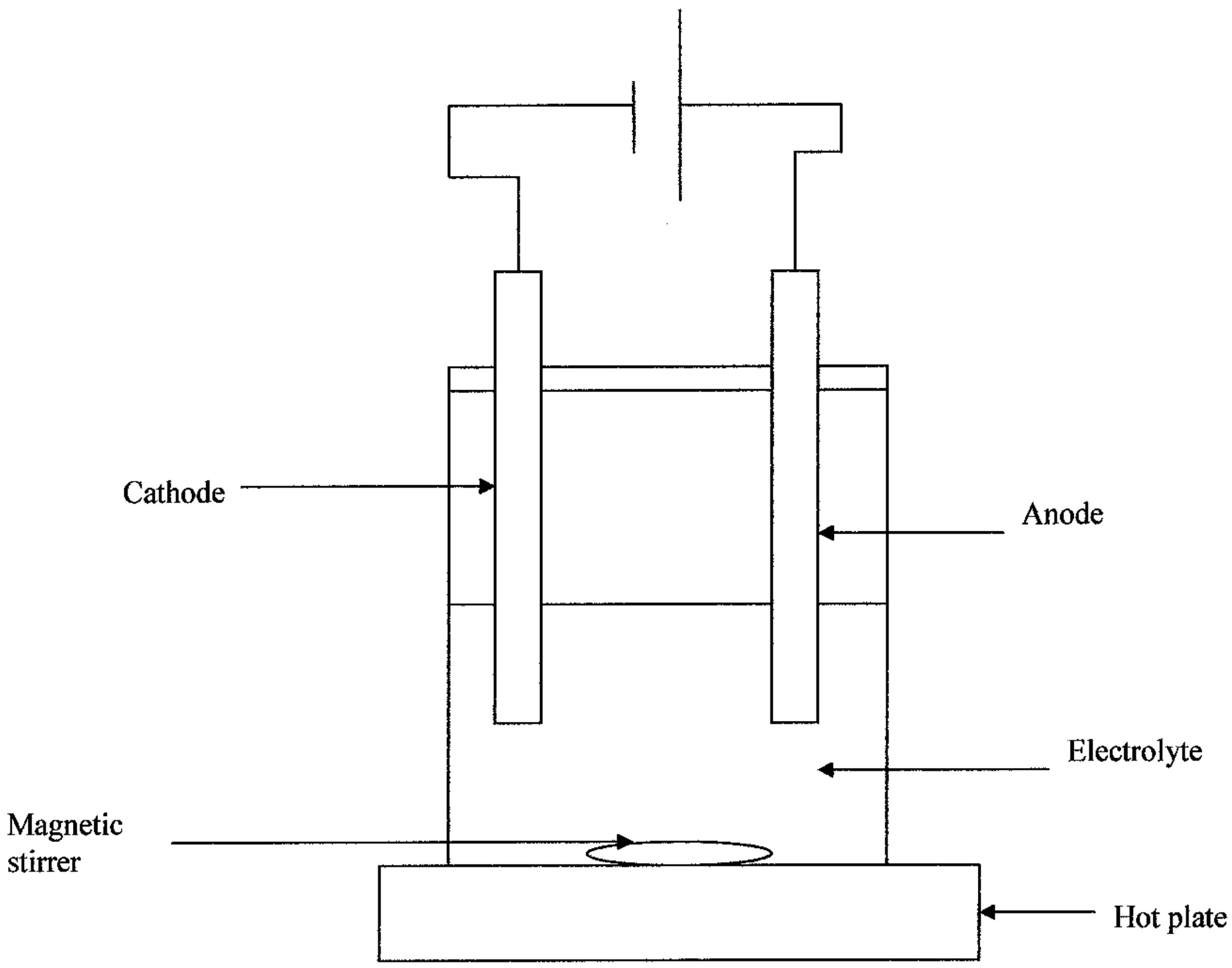


Figure 3.6: *Schematic diagram of experimental work*

CHAPTER 4

RESULTS

4.1 THERMODYNAMIC CALCULATION FOR ELECTROLYTIC CELL

Electrochemical cell of the experiment can be shown below:

.Cu|Al|Bmim Cl¦$AlCl_3$|Cu

4.1.1Calculation of standard electrode potentials

At anode: $Al \rightarrow Al^{3+} + 3e$

At cathode: $Cu^{2+} + 2e \rightarrow Cu$

Total reaction: $2Al + 3Cu^{2+} + 6e \rightarrow 2Al^{3+} + 6e + 3Cu$

: $2Al + 3Cu^{2+} \rightarrow 2Al^{3+} + 3Cu$

From table of Standard Electrode Potential;

$Al \rightarrow Al^{3+} + 3e$; $E^{o}{}_{,R} = -1.667V$

$Cu^{2+} + 2e \rightarrow Cu$; $E^{o}{}_{,L} = 0.339V$

$E^{o} = E^{o}{}_{,R} - E^{o}{}_{,L}$

$E^{o} = -1.67V - 0.339V$

$= -2.067\ V$

The negative value indicates that this cell is having non-spontaneous reaction. For electrolytic cell, it requires an input of electricity, which in this experiment voltage supply is used.

4.1.2 Calculation of total cell potential

By using Nernst equation, cell's emf can be calculated

$E_{cell} = E^{\circ}_{cell} - (RT/zF) \ln Q$

Where;

E_{red}	- half cell reduction potential
E°_{red}	- standard half cell reduction potential
R	-constant=8.314
T	- Temperature (in K)
z	- Number of electrons transferred
F	- Faraday constant; 9.6485309×10^4
Q	- activity quotient

$$Q = \frac{[0.4]^2[1]^2}{[1]^2[0.6]^3}$$

$=0.7407$

$\ln Q = \ln 0.7407$

$= -0.3$

<u>For temperature=25°C</u>

$E=-2.067 - [(8.314 x 298)/(0.06 x 96485)](-0.3)$

$=-1.93$ V

For temperature=70°C

E=-2.067- [(8.314x343)/(0.06x96485)](-0.3)

=-1.767 V

For temperature =100 °C

E=-2.067- [(8.314x398)/(0.06x96485)](-0.3)

=-2.24 V

4.1.3 Calculation of Gibbs free energy

$\Delta G = - nFE_{cell}$

Where:

G – Gibbs free energy

n – Number of moles

F – Faraday constant; 9.6485309×10^4

E - Half cell reduction potential

For temperature=25°C

ΔG=-(0.06x96485x-1.93)

=11172.96

For temperature=70°C

ΔG=-(0.06x96485x-1.767)

=10229.34

For temperature =100 °C

ΔG=-(0.06x96485x-2.24)

=12967.58

From the calculation above, it shows that electrolytic cell is having non spontaneous reaction since the Gibb free energy give the positive value [34].That is why electrolytic cell requires external power supply.

4.1.4 Calculation of theoretical amount of aluminum that can be deposited

$$m=QM/(z+F)$$

where;

m= mass of deposited metal

Q=theoretical charge

M=molecular weight of aluminum

Z=charge of aluminum

F=faraday constant

$m= (16488x27)/(3x96485)$

$=1.538g$

4.2 EXPERIMENT AT APPLIED VOLTAGE =1.0V

4.2.1 Experiment 1

Temperature: 25°C

Condition:

-No heating

-No stirring

Result:

	Weight before	Weight after	ΔW
Aluminum Can	0.040g	0.038g	0.002g
Copper	2.379g	2.383g	0.004g

Table 4.1: *Results for experiment at V=1.0 and T=25°C*

Length of copper immersed in the electrolyte = 0.4cm

Diameter of copper electrode=0.5 cm

Radius of copper electrode=0.25cm

Length of copper electrode= 2.98cm

Area of copper that immersed in the electrolyte

$$\text{Area} = 2\Pi r(h+r)$$

$$= 2\text{x}3.142\text{x}0.25(0.4+0.25)$$

$$= 1.0211\text{cm}^2$$

Calculation of current efficiency

$$\eta = \frac{\text{actual amount of deposited}}{\text{Theoretical amount of deposited}}$$

$$= \frac{0.004}{1.538}$$

$$= 0.0026 \approx 0.26\%$$

Calculation of current density

$$\text{Current density} = \frac{\text{current applied (A)}}{\text{Area that immersed in electrolyte (cm}^2\text{)}}$$

$$= \frac{2.29}{1.0211}$$

$$= 2.2427 \text{A/cm}^2$$

4.2.2 Experiment 2

Temperature: 70°C

Condition :

-Heating

-Stiring with speed 2

Result:

	Weight before	Weight after	ΔW
Aluminum Can	0.048g	0.047g	0.001
Copper	2.320g	2.334g	0.014g

Table 4.2: *Results for experiment at V=1.0 and T=70°C*

Length of copper immersed in the electrode=0.4cm

Diameter of copper electrode=0.5 cm

Radius of copper electrode=0.25cm

Length of copper electrode= 3 cm

Area of copper that immersed in the electrolyte:

$$\text{Area} = 2\Pi r(h+r)$$
$$= 2 \times 3.142 \times 0.25(0.4+0.25)$$
$$= 1.02115 \text{ cm}^2$$

Calculation for current efficiency

$$\eta = \frac{\text{actual amount of deposited}}{\text{Theoretical amount of deposited}}$$

$$= \frac{0.014}{1.538}$$

$$= 0.009 \approx 0.91\%$$

Calculation for current density

$$= \frac{\text{current applied (A)}}{\text{Area that immersed in electrolyte (cm}^2\text{)}}$$

$$= \frac{2.29}{1.02115}$$

$$= 2.24256 \text{ A/cm}^2$$

4.2.3 Experiment 3

Temperature: 100°C

Condition:

-Heating

-Stirring with speed 2

Result:

	Weight before	Weight after	ΔW
Aluminum Can	0.038g	0.037g	0.001g
Copper	2.485	2.572g	0.087g

Table 4.3: *Results for experiment at V=1.0 and T=100°C*

Length of copper immersed in the electrolyte=0.4cm

Diameter of copper electrode=0.5 cm

Radius of copper electrode=0.25cm

Length of copper electrode= 3 cm

Area of copper that immersed in the electrolyte:

Area =2Πr(h+r)

=2x3.142x0.25(0.4+0.25)

=1.02115cm^2

Calculation for current efficiency

$$\eta = \frac{\text{actual amount of deposited}}{\text{Theoretical amount of deposited}}$$

$$= \frac{0.087}{1.538}$$

$=0.057 \approx 5.7\%$

Calculation for current density

$$= \frac{\text{current applied (A)}}{\text{Area that immersed in electrolyte (cm}^2\text{)}}$$

$$= \frac{2.29}{1.02115}$$

$=2.24256\ A/cm^2$

4.2.4 Summary of result for experiment 1

Temperature (°C)	ΔW_{Copper} (g)	Current Efficiency (%)	Current Density (A/cm^2)
25	0.004	0.26	2.2427
70	0.014	0.91	2.2456
100	0.087	5.7	2.2456

Table 4.4: *Summary of overall result for experiment 1*

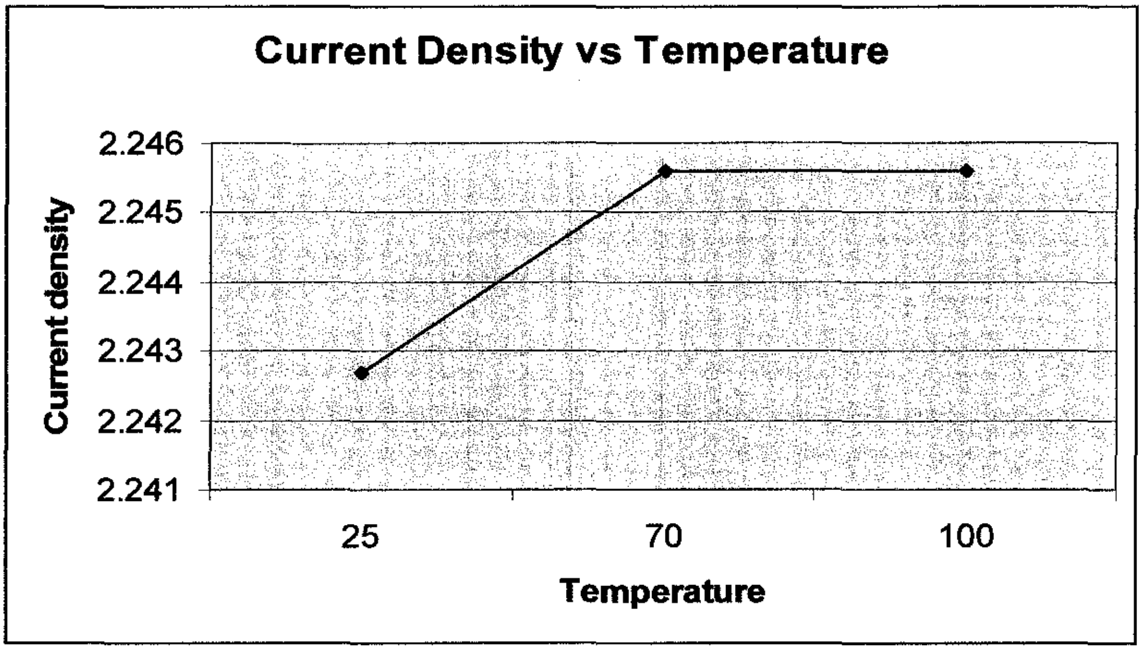


Figure 4.1: *Graph of current density vs temperature for V=1.0*

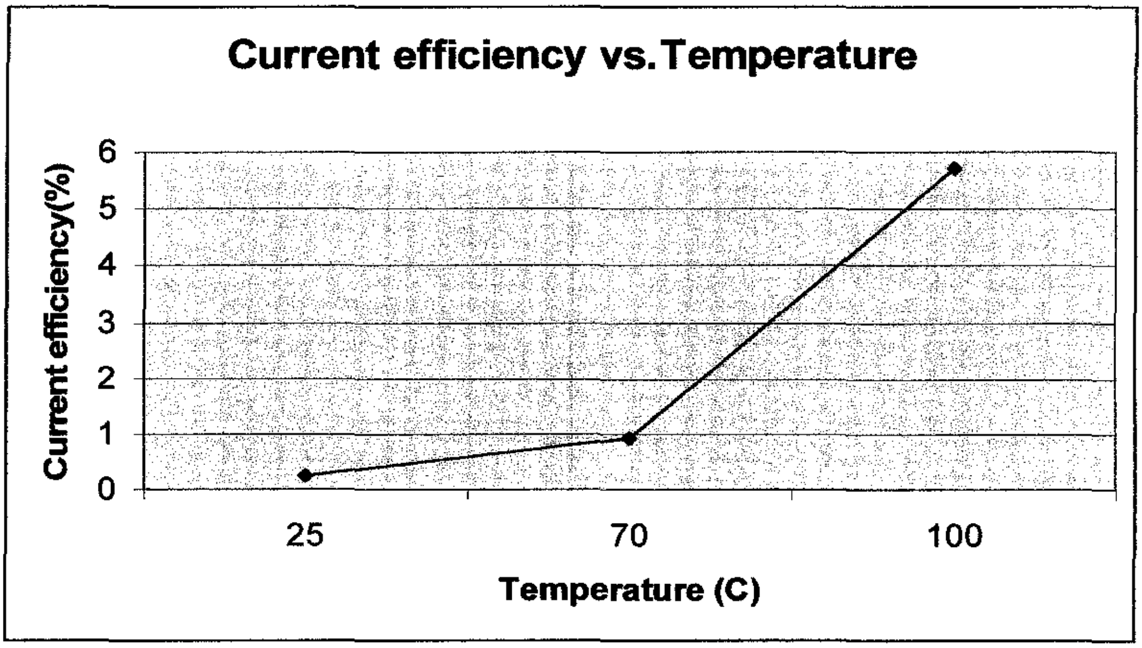


Figure 4.2: *Graph of current efficiency temperature for V=1.0*

4.3 EXPERIMENT AT APPLIED VOLTAGE =1.3V

4.3.1 Experiment 1

Temperature: 25°C

Condition:

-No heating

-No stirring

Result:

	Weight before	Weight after	ΔW
Aluminum Can	0.445g	0.443g	0.002g
Copper	8.776g	9.017g	0.241g

Table 4.5: *Results for experiment at V=1.3 and T=25°C*

Length of copper immersed in the electrolyte =0.5cm

Diameter of copper electrode=0.5 cm

Radius of copper electrode=0.25cm

Length of copper electrode= 10 cm

Area of copper that immersed in the electrolyte:

Area $=2\Pi r(h+r)$

$=2\times 3.142\times 0.25(0.5+0.25)$

$=1.1783cm^2$

Calculation of current efficiency

$$\eta = \frac{\text{actual amount of deposited}}{\text{Theoretical amount of deposited}}$$

$$= \frac{0.241}{1.538}$$

$=0.156 \approx 15.7\%$

Calculation of current density

$$= \frac{\text{current applied (A)}}{\text{Area that immersed in electrolyte } (cm^2)}$$

$$= \frac{2.29}{1.1783}$$

$=1.9435\ A/cm^2$

4.3.2 Experiment 2

Temperature: 70°C

Condition:

- -Heating
- -Stirring with speed 2

Results:

	Weight before	Weight after	ΔW
Aluminum Can	0.065	0.064	0.001g
Copper	2.460g	2.485g	0.025g

Table 4.6: *Results for experiment at V=1.3 and T=70°C*

Length of copper immersed in the electrolyte=0.5cm

Diameter of copper electrode=0.5 cm

Radius of copper electrode=0.25cm

Length of copper electrode= 3 cm

Area of copper that immersed in the electrolyte:

Area =2Πr(h+r)

=2x3.142x0.25(0.5+0.25)

=1.1783cm^2

Calculation of current efficiency

$$\eta = \frac{\text{actual amount of deposited}}{\text{Theoretical amount of deposited}}$$

$$= \frac{0.025}{1.538}$$

=0.016≈1.63%

Calculation of current density

$$= \frac{\text{current applied (A)}}{\text{Area that immersed in electrolyte (cm}^2\text{)}}$$

$$= \frac{2.29}{1.1783}$$

$=1.943\ A/cm^2$

4.3.3 Experiment 3

Temperature: 100°C

Condition:

- -Heating
- -Stirring with speed 2

Result:

	Weight before	Weight after	ΔW
Aluminum Can	0.046g	0.044g	0.002g
Copper	2.472g	2.479	0.007g

Table 4.7: *Results for experiment at V=1.3 and T=100°C*

Length of copper immersed in the electrolyte =0.4 cm

Diameter of copper electrode=0.5 cm

Radius of copper electrode=0.25cm

Length of copper electrode= 3 cm

Area of copper that immersed in the electrolyte:

Area =2Πr(h+r)

=2x3.142x0.25(0.4+0.25)

=1.02115

Calculation of current efficiency

$$\eta = \frac{\text{actual amount of deposited}}{\text{Theoretical amount of deposited}}$$

$$= \frac{0.007}{1.538}$$

=0.005 ≈0.5%

Calculation of current density

$$= \frac{\text{current applied (A)}}{\text{Area that immersed in electrolyte (cm}^2\text{)}}$$

$$= \frac{2.29}{1.02115}$$

=2.24256 A/cm^2

4.3.4 Overall results for experiment 2

Temperature (°C)	ΔW_{Copper} (g)	Current Efficiency (%)	Current Density (A/cm²)
25	0.241	15.7	1.9435
70	0.025	1.63	1.9435
100	0.007	0.5	2.2456

Table 4.8: *Summary of overall result for experiment 2*

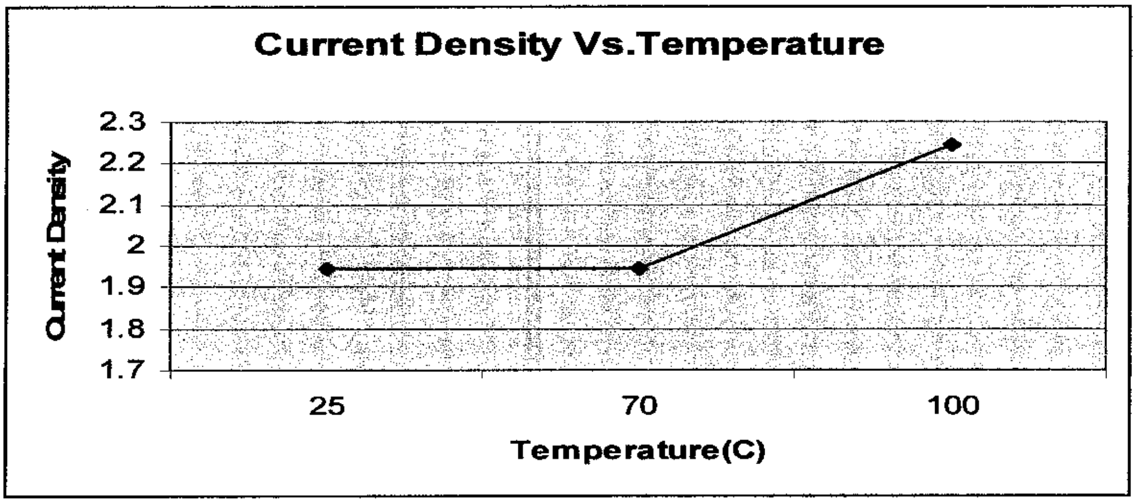


Figure 4.3: *Graph of current density vs temperature for V=1.3*

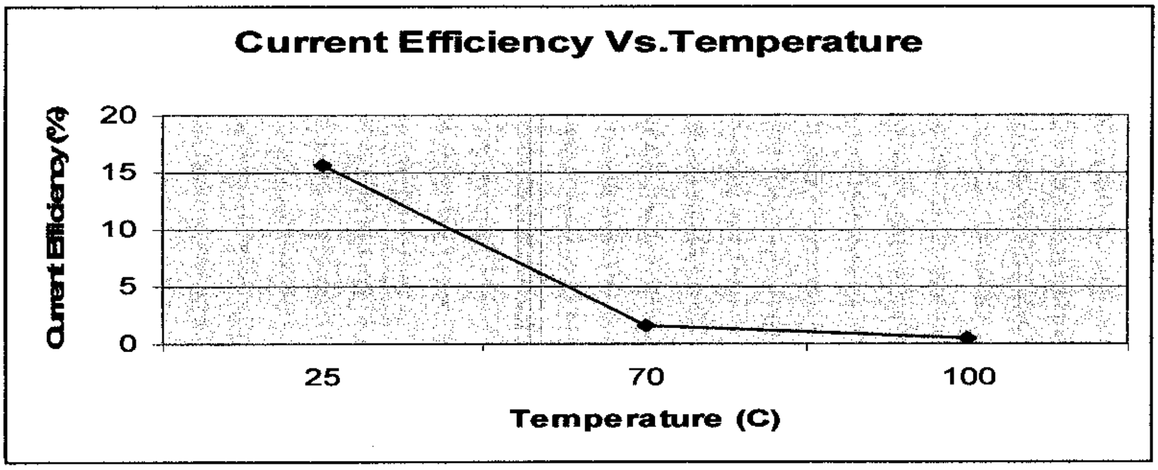


Figure 4.4: *Graph of current efficiency vs temperature for V=1.3*

4.4 SUMMARY OF OVERALL RESULT

Temperature (°C)	ΔW_{Copper} (g)		Current Efficiency (%)		Current Density (A/cm^2)	
	V=1.0	V=1.3	V=1.0	V=1.3	V=1.0	V=1.3
25	0.004	0.241	0.26	15.7	2.2427	1.9435
70	0.014	0.025	0.91	1.63	2.2456	1.9435
100	0.087	0.007	5.7	0.5	2.2456	2.2456

Table 4.9: *Summary of overall result*

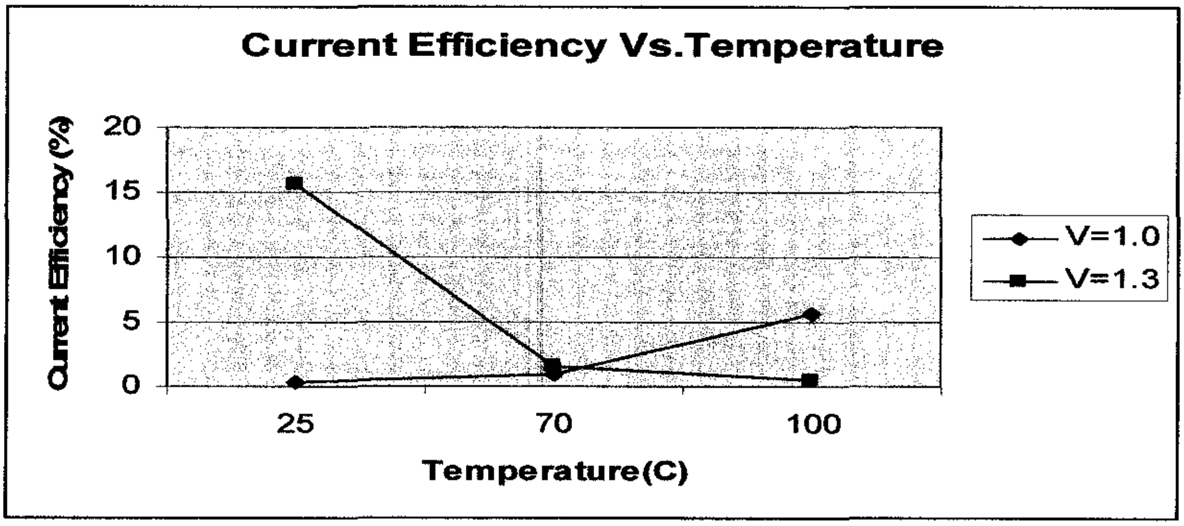


Figure 4.5: *Graph of current efficiency vs temperature for both experiments*

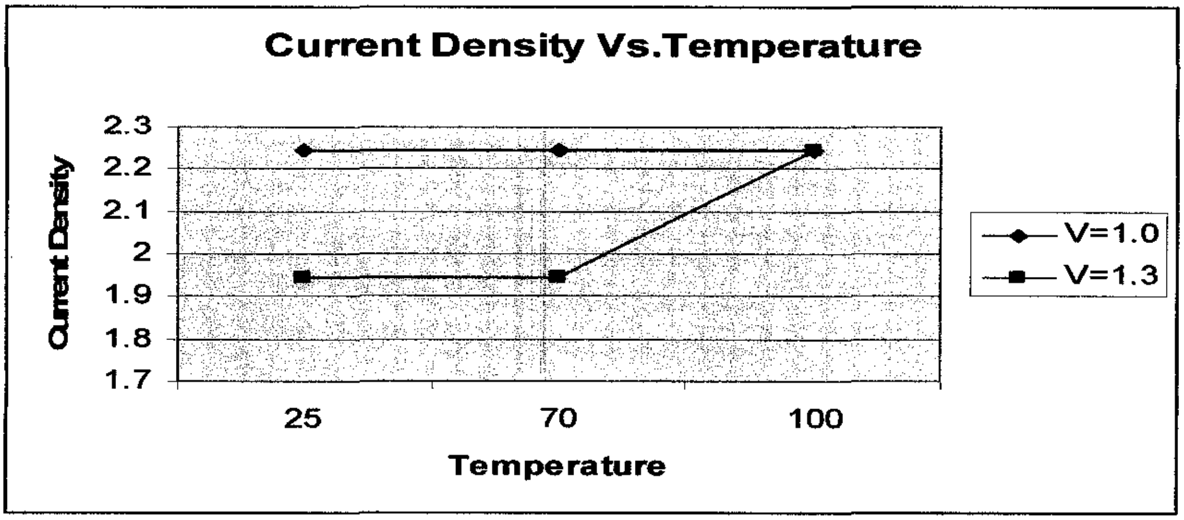


Figure 4.6: *Graph of current density vs temperature for both experiment*

4.5 RESULTS FOR XRD TEST

4.5.1 XRD test for aluminum can

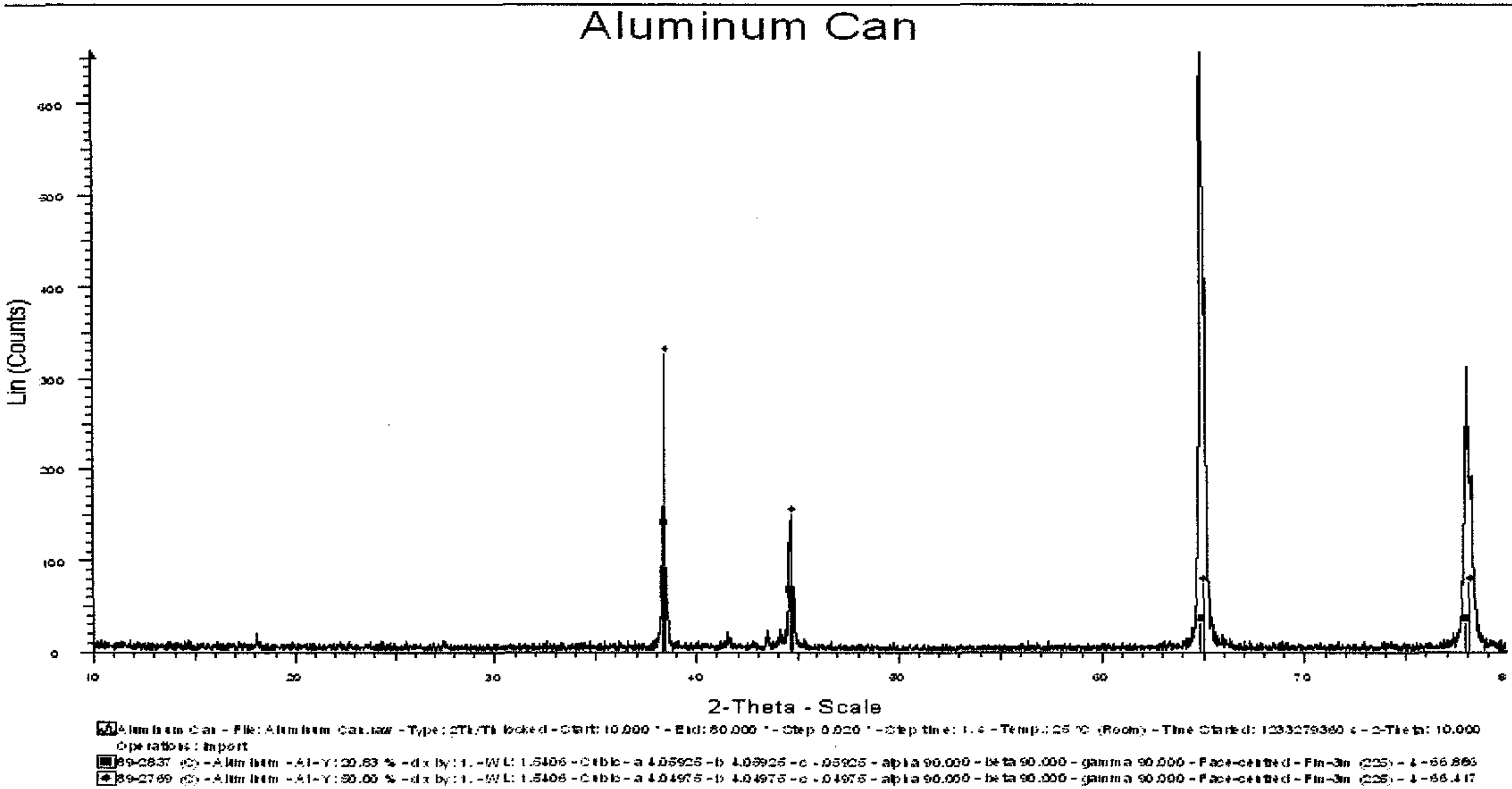


Figure 4.7: XRD results for aluminum can

4.5.2 XRD test for copper

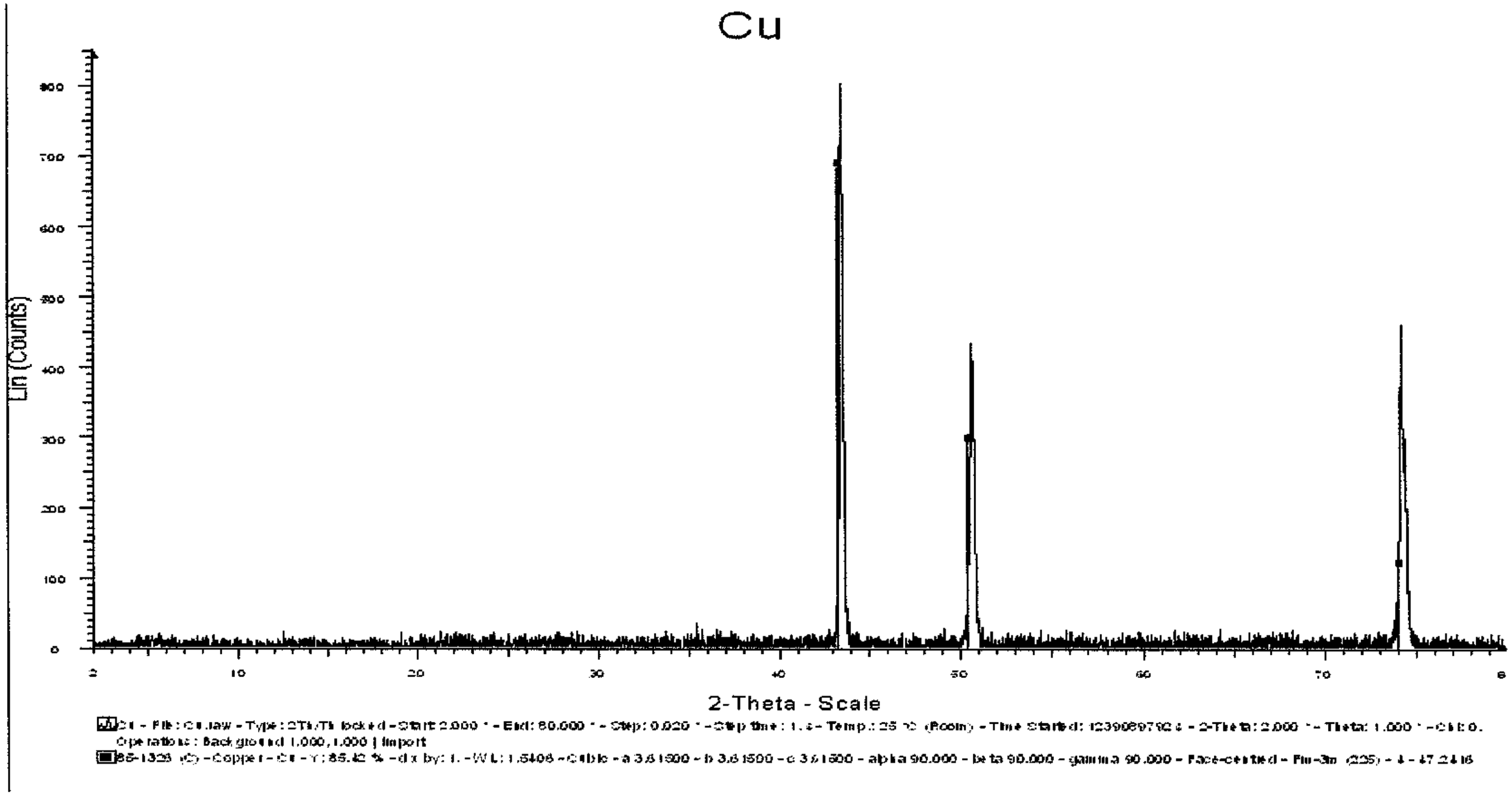


Figure 4.8: XRD results for Copper

4.6 RESULT FOR EDX TEST

4.6.1 Experiment 1at V=1.0 and T=25°C

Element	Weight%
C (Carbon)	7.16
O (Oxygen)	14.84
Al (Aluminum)	0.77
Cl (Chlorine)	2.00
Cu (Copper)	75.23
Totals	100.00

Table 4.10: *EDX results for V=1.0V &T= 25°C*

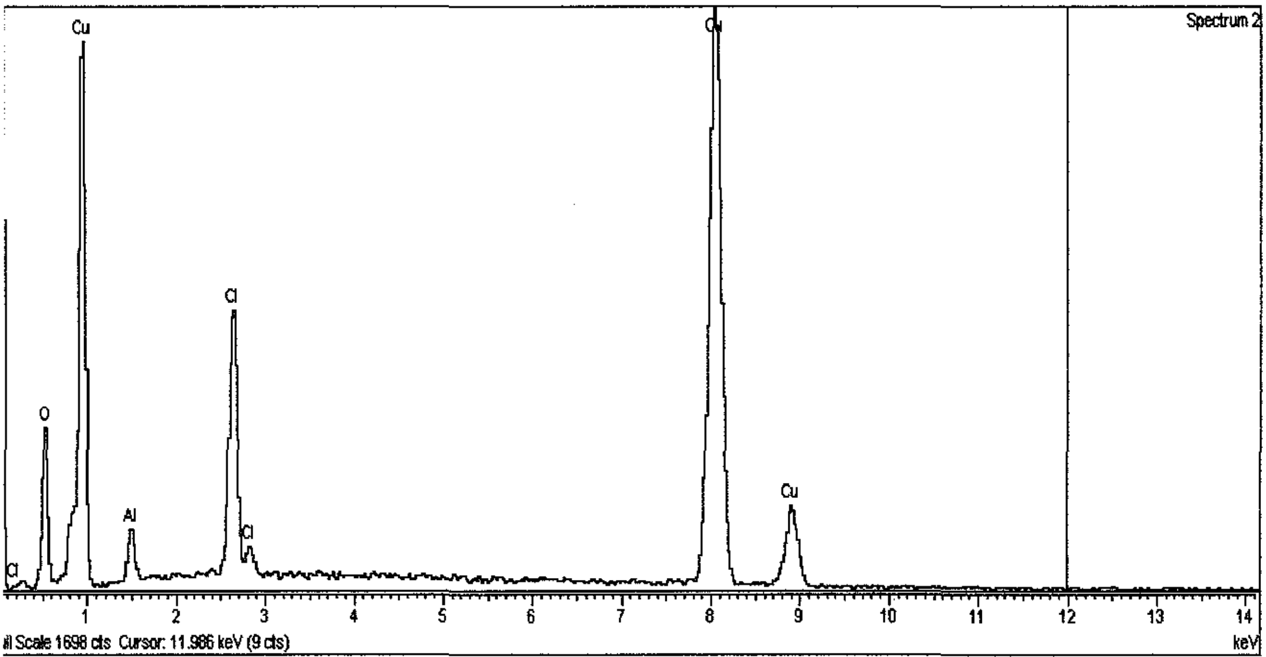


Figure 4.9: *Graph of composition based on weight % obtained from EDX test at V=1.0 &T=25°C*

4.6.2 Experiment 1 at V=1.0 and T=70°C

Element	Weight%
O	19.55
Al	3.38
Cl	9.71
Cu	67.36
Total	100

Table 4.11: *EDX results for V=1.0V &T= 70°C*

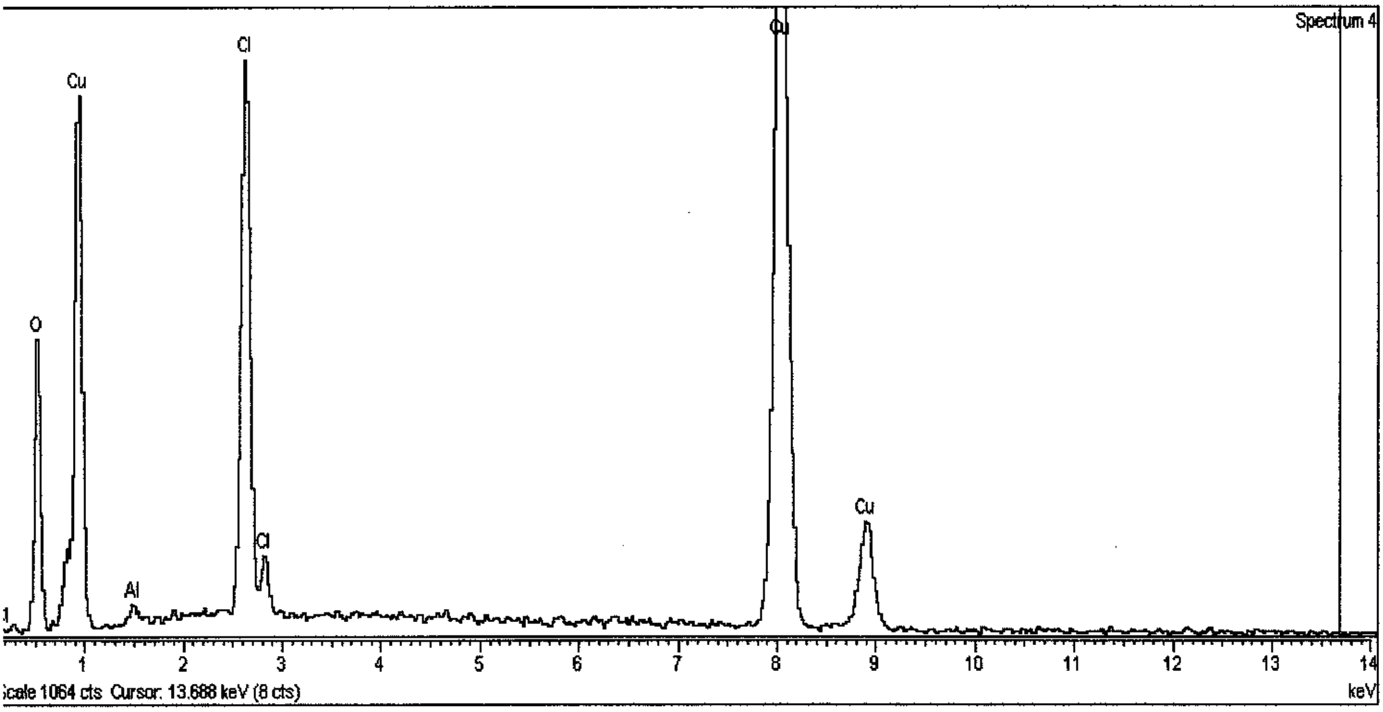


Figure 4.10: *Graph of composition based on weight % obtained from EDX test at V=1.0 &T=70°C*

4.6.3 Experiment 1 at V=1.0 and T=100°C

Element	Weight%
O	24.68
Al	0.64
Cl	12.90
Cu	61.78
Total	100.00

Table 4.12: *EDX results for V=1.0V &T= 100°C*

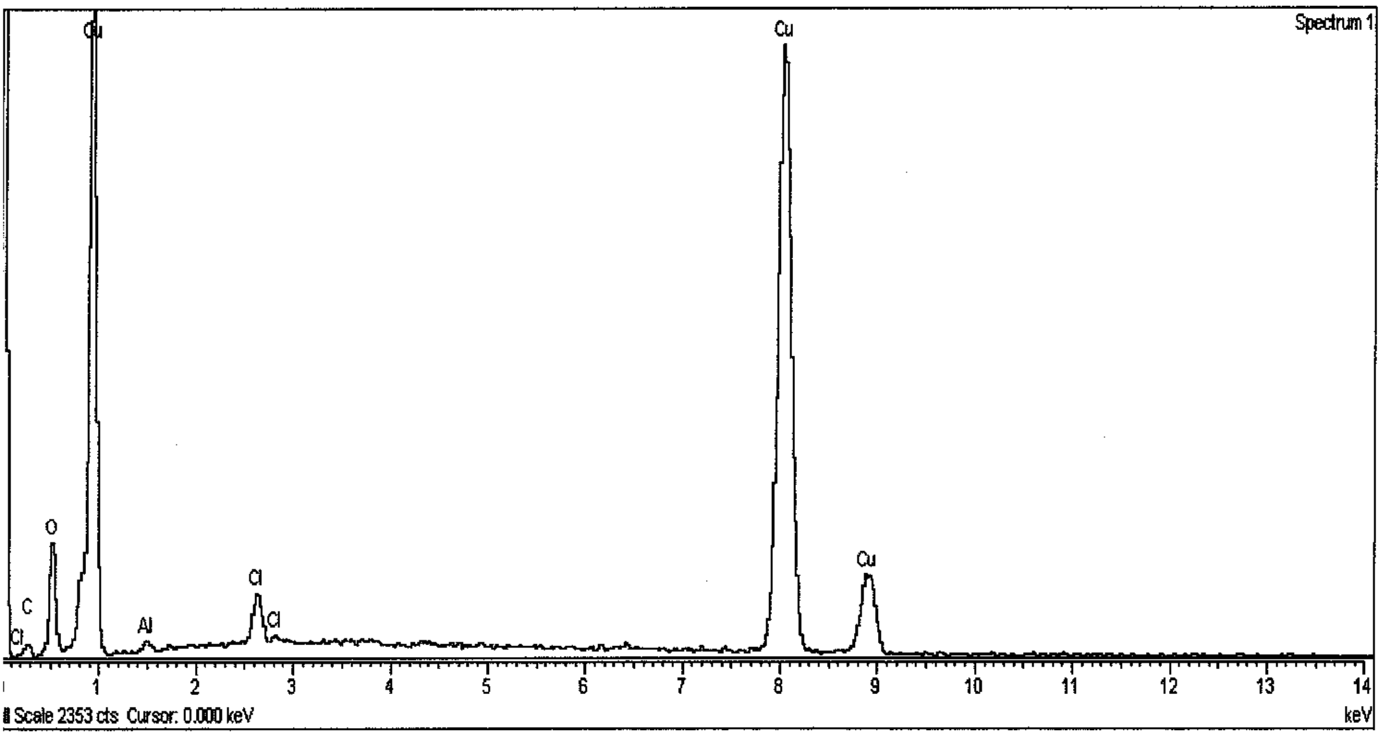


Figure 4.11: *Graph of composition based on weight % obtained from EDX test at V=1.0 &T=100°C*

4.6.4 Experiment 2 at V=1.3 and T=25°C

Element	Weight%
C	13.28
O	11.81
Al	2.65
Cl	1.51
Cu	70.76
Totals	100.00

Table 4.13: *EDX results for V=1.3V &T= 25°C*

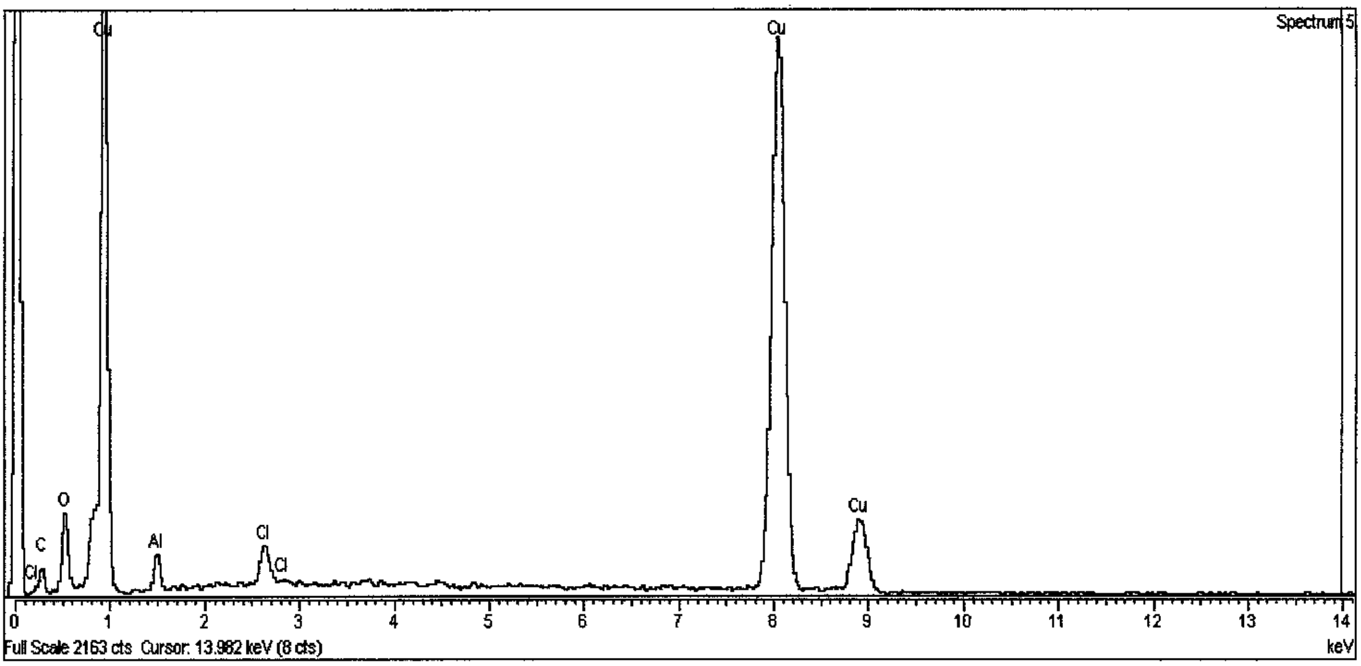


Figure 4.12: *Graph of composition based on weight % obtained from EDX test at V=1.3 &T=25°C*

4.6.5 Experiment 2 at V=1.3 and T=70°C

Element	Weight%
C	5.93
O	20.80
Al	0.57
Cl	7.21
Cu	65.51
Totals	100.00

Table 4.14: *EDX results for V=1.3V &T= 70°C*

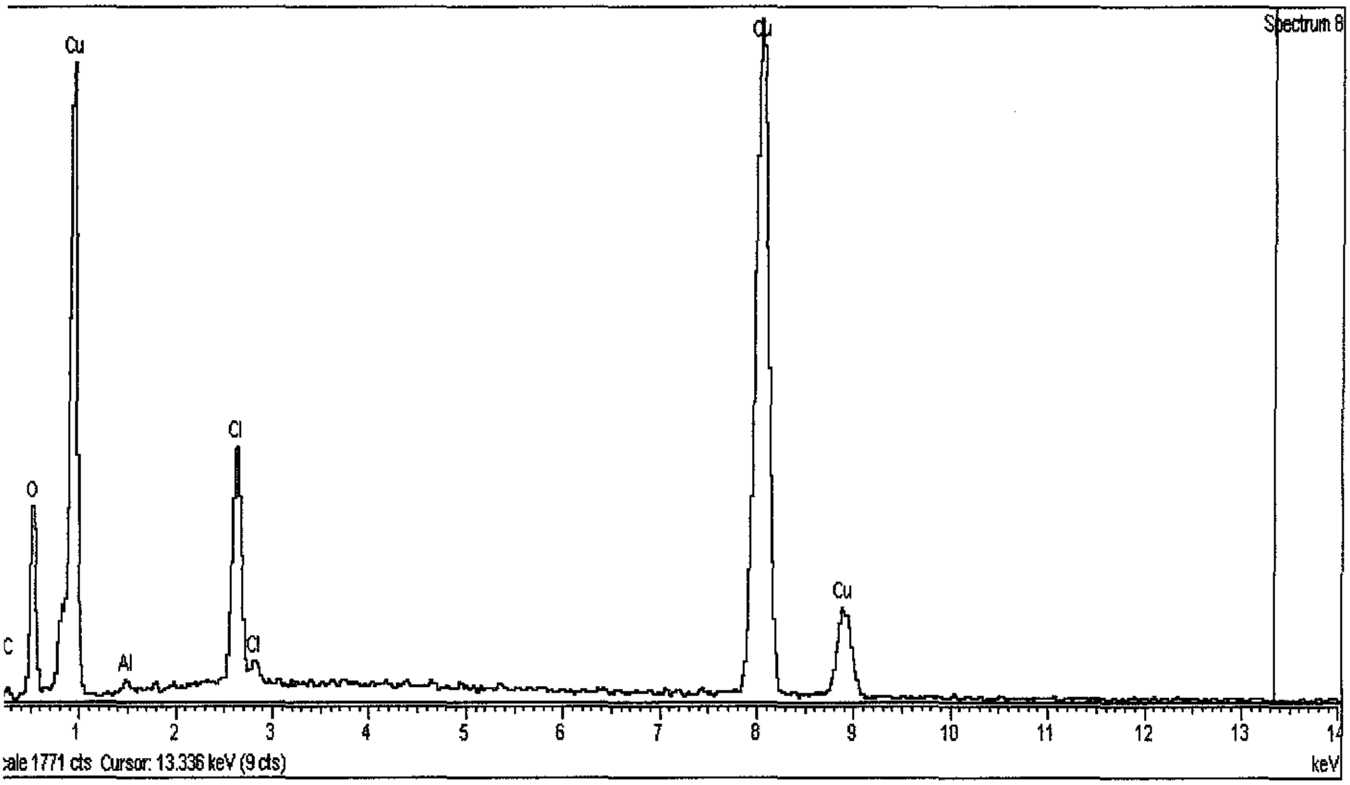


Figure 4.13: *Graph of composition based on weight % obtained from EDX test at V=1.3 &T=70°C*

4.6.6 Experiment 2 at V=1.3 and T=100°C

Element	Weight%
C	16.29
O	15.59
Al	1.20
Cl	4.67
Cu	62.25
Totals	100.00

Table 4.15: *EDX results for V=1.3V &T= 100°C*

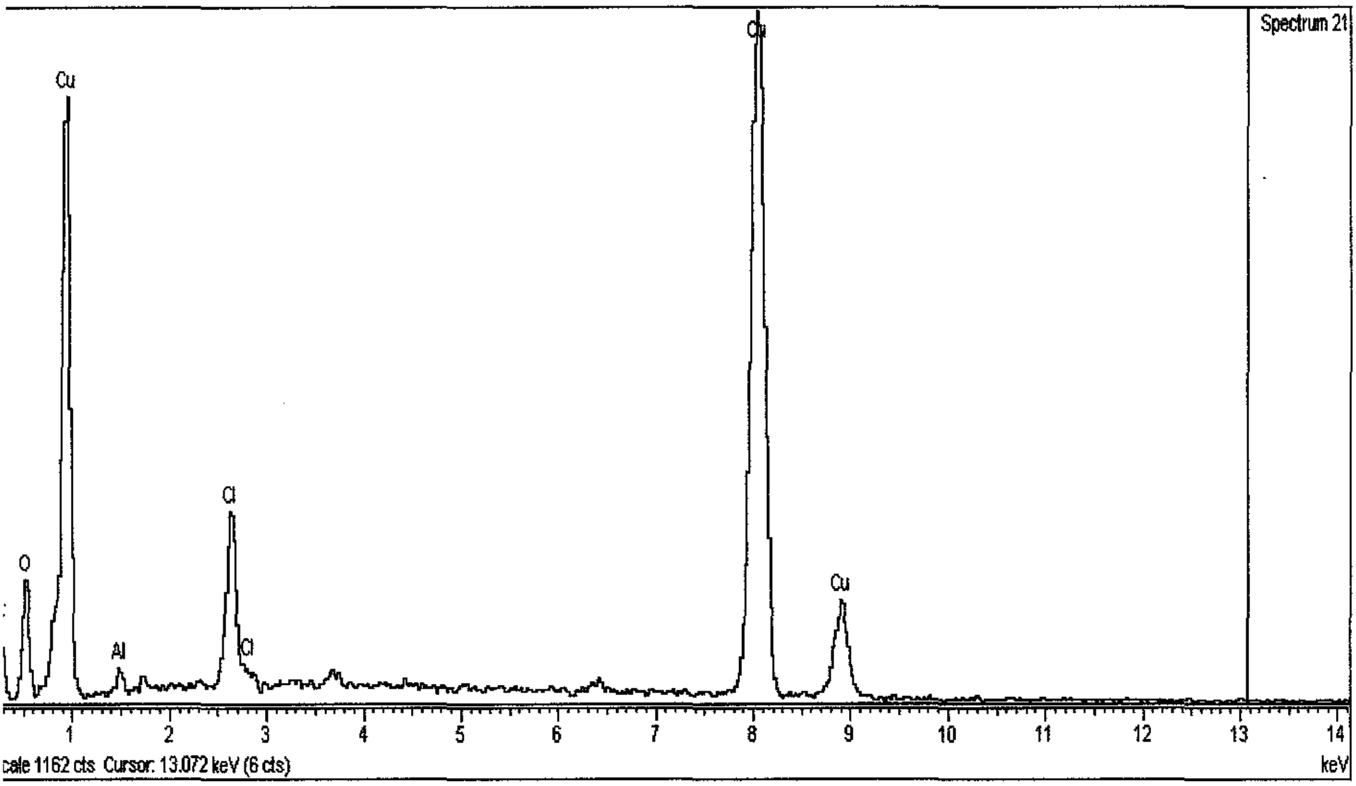


Figure 4.14: *Graph of composition based on weight % obtained from EDX test at V=1.3 &T=100°C*

4.6.7 EDX test for aluminum can

Element	Weight%
C	33.57
O	4.65
Mg	0.88
Al	59.69
Mn	0.47
Cu	0.73
Totals	100.00

Table 4.16: *EDX results for aluminum can*

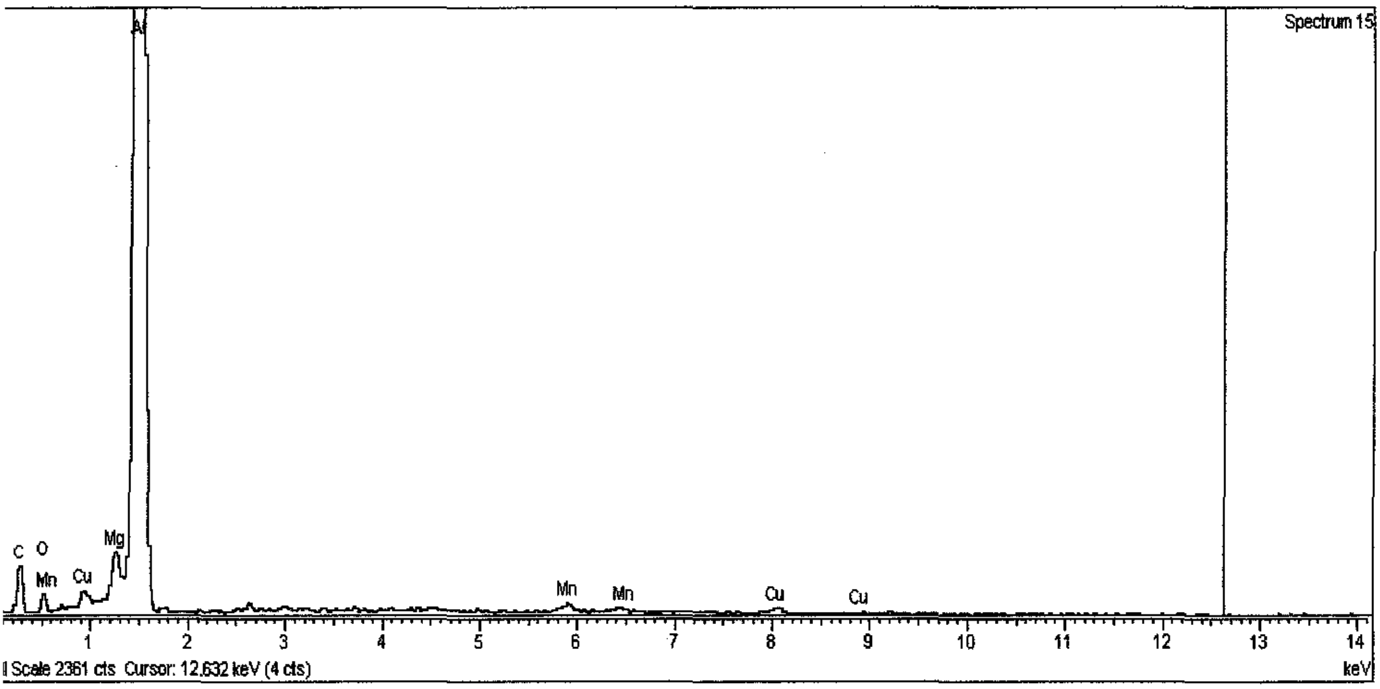


Figure 4.15: *Graph of composition based on weight % obtained from EDX test for aluminum can*

CHAPTER 5

DISCUSSIONS

5.1 ALUMINUM CAN COPPER ELECTRODE

Aluminum can was first sent for XRD test. X-ray diffraction (XRD) test is a analytical technique that reveal information about the crystallographic structure of sample. From figure 4.7,it shows that aluminum exist in aluminum can. The peak obtain from the test is comparable to the peak obtain from the standard aluminum. There are some impurities exist at the aluminum can. But XRD test could not identify it. By using EDX test, impurities exist may be identified. Energy Dispersive X-ray spectroscopy (EDX) is an analytical use for the elemental analysis or chemical characterization of the sample. EDX test was done to the aluminum can.

The purpose of running this test is to identify the components present in the aluminum can. From the results it shows that aluminum can contain 33.57% carbon, 4.65% oxygen, 0.88%magnesium, 59.69% aluminum, 0.47% mangan and 0.73% copper. These results prove that aluminum really exits in aluminum can, but aluminum can also contain other component which may be the impurities shows at the XRD results. However, this results may not accurate enough since EDX results is based on certain spot only, not the overall sample. So, there is a tendency that total aluminum that exists in the aluminum can higher.

Copper electrode was also sent for the purpose of comparing the copper electrode before and after electrolysis. However, due to very small amount of aluminum exist in at the electrode, XRD could not detect the presence of aluminum at the copper electrode. Therefore, all the copper electrodes after the electrolysis only manage to undergo EDX test.

5.1 EXPERIMENT 1

For the first experiment, it were done at applied voltage of 1.0V and at three different temperatures of 25°C ,70°C and 100 °C.EDX test were run at all cathode electrodes. At temperature of 25°C, the difference in weight for copper electrode before and after electrolysis is 0.002g. For temperature of 70°C the weight difference at cathode electrode is 0.014g and at temperature of 100 °C the weight difference is 0.087g.From the EDX results it shows that percentage of aluminum presence at temperature of 25°C is 0.77%, at temperature of 70 °C is 3.38% and at temperature of 100 °C is 0.64%.

This result does not match the results from the different in weight at cathode electrode. This might due to the EDX results itself. This is because, EDX result were done based on that one specific spot only. Since the aluminum can't be seen with our eyes due to very small amount of aluminum presence at the cathode electrode, it is impossible for the analyzer to spot at the place where aluminum may be found at large amount.

Calculations for current density were done. Current density is a measure of density of flow of conserved charge. From figure 4.1, it shows that as the temperature increases, the current density also increases. This might due to the increase in diffusion from ions that reduce from anode electrode to cathode electrode at higher temperature, thus reducing the concentration polarization.

As for the current efficiency, from figure 4.2, it shows that as the temperature getting higher, the current efficiency also getting higher. This is because, the temperature influence the physical properties of the electrolyte. As the temperature increases, the viscosity of the melt decreases. This lead to increasing in mobility of ions in the solutions and thus increasing the reaction occurs at the electrode.

5.2 EXPERIMENT 2

For the second experiment, it were done at applied voltage of 1.3V and at three different temperatures of 25°C ,70°C and 100 °C.EDX test were run at all cathode electrodes. At temperature of 25°C, the difference in weight for copper electrode before and after electrolysis is 0.241g.For temperature of 70°C the weight difference at cathode electrode is 0.025g and at temperature of 100 °C the weight difference is 0.007g.From the EDX results it shows that percentage of aluminum presence at temperature of 25°C is 2.65%, at temperature of 70 °C is 0.57% and at temperature of 100 °C is 1.2%.

This result does not match the results from the different in weight at cathode electrode. This is because, the deposition of aluminum is not even to all surface of copper. Therefore, it is a bit difficult for the X-ray to be on the right spot on where aluminum is deposited. This is because, EDX result were done based on that one specific spot only. Since the aluminum can't be seen with our eyes due to very small amount of aluminum presence at the cathode electrode, it is impossible for the analyzer to spot at the place where aluminum may be found at large amount.

Calculations for current density were done. From figure 4.3, it shows that as the temperature increases, the current density also increases. This might due to the increase in diffusion from ions that reduce from anode electrode to cathode electrode at higher temperature, thus reducing the concentration polarization.

As for the current efficiency, from figure 4.3, it shows that as the temperature getting higher, the current efficiency also getting lower. This results is opposite from what is supposed to be. Some experimental error has occurred. It is suspected that the surface of the electrode does not suitable for ions for aluminum to be deposit at the cathode. So, the aluminum ions are suspected to deposit in the electrolyte. However, no test could be done in order to prove this assumption due to the unavailability of equipment to do the XRF test .XRF is the only equipment that can do test for sample in liquid and solid form.

Further study need to be conduct to study the optimum condition of electrode surface in order for the aluminum to be deposited at cathode electrode.

CHAPTER 6

RECOMMENDATIONS

Some recommendations are proposed in order to improve the experimental work.

1) Use flat electrode

Since the XRD results required it sample to be it flat surface, it is recommended in future work, flat electrode to be used. This is to avoid any unnecessary disturbance occur at the electrode which may lead error in results obtained.

2) Run experiment for longer time at 100°C

Since optimum temperature is at 100°C, it is proposed that electrolysis process be done for longer time (more than two hours) to obtain more aluminum deposition.

3) Run experiment under inert condition

It is also recommended for future experimental work, the experiment run under inert condition. This is because, the electrolyte is very moisture sensitive. This will give better result for the experiment.

4) Use inert electrode

Inert electrode may be used in future work because inert electrode does not take part in chemical reaction during electrolysis. This may lead to a better result and it is not impossible for more aluminum to be deposited at cathode electrode.

CHAPTER 7

CONCLUSION

Aluminum can was successfully reclaimed via electrolysis at the temperature range between 25°C to 100°C. Mixture of aluminum chloride and 1-butyl-3-methylimidazolium was used as the electrolyte. For electrodes, aluminum can and copper had been chosen as anode and cathode electrode. The purity of the aluminum cannot be determined since the presence of aluminum at the cathode electrode is too small. The result obtained from EDX test does not match the result obtained directly from the experiment. This is because, the EDX test is based on specific spot on the sample it self.

The optimum temperature for aluminum to be deposited is at 100 °C since in experiment 1, at 100°C gives the large amount of deposited aluminum compared to other temperature .Highest current efficiency were obtained at the highest temperature. Current efficiency were in the range of 0.26% to 15.7%.The range for current density is in the range of 1.94 to 2.25 A/cm^2 .Energy consumption for the present study is estimated to be in the range of 0.0089 to 0.0091Wh/kg Al.

CHAPTER 8

REFERENCES

[1]Mark E.Schlesinger,*Aluminum Recycling*,2007

[2]Maciej Galiński,Andrzej Lewandowski,Izabela Stępniak,*Ionic Liquids as Electrolytes*, 2006.

[3]Christopher M.A. Brett, *Electrochemistry Principles, Methods*, and Applications, 1993.

[4]Ira N.Levine, *Physical Chemistry*,2003.

[5]Eng Nguan Hong,Lim Eng Wah,Lim Yean Ching,*Chemistry*,2006,Malaysia

[6] Hiroyuki Ohno, *Electrochemical Aspects of Ionic Liquids*, 2005,Japan.

[7] V.S Bagitsky,*Fundamental of Electrochemistry*,2006,Russia.

[8] Hubert H.Girault,*Analytical and Physical Electrochemistry*,2004,Switzerland

[9]V. Kamaran, D. Mantha, R. G. Reddy, *Electrorefining of Aluminum Alloy in Ionic Liquids at Low Temperature*, 2003.

[10]. Maciej Galiński, Andrzej Lewandowski, Izabela Stępniak, *Ionic Liquids as Electrolytes*, 2006.

[11] V. Kamaran, D. Mantha, R. G. Reddy,*Recycling of aluminum metal matrix composite using ionic liquids:Effect of process variables on current efficiency and deposit characteristic*,2004

[12] Mingming Zhang,Venkat Kamaran,Ramana G.Reddy,*New Electrolytes for Aluminum Production:Ionic Liquids*,2003.

[13] Frank H.Hurley,Electrodeposition of Aluminum(2446331),1948,Texas

[14]ThomasP.Wiler,Jr.,BerkeleyCalif,ElectrodepositionofAluminum(2446359),1948, Texas

[15] http://en.wikipedia.org/wiki/Electrolysis

[16] http://en.wikipedia.org/wiki/Electrolytic_Cell

[17] http://www.chemguide.co.uk/inorganic/extraction.aluminum.html

[18] http://en.wikipedia.org/wiki/Nernst_equation

[19]http://en.wikipedia.org/wiki/Reaction_quotient

[20]http://www.sparknotes.com/chemistry/electrolytic /section1.html

[21] http://chemistry.about.com/library/weekly/aa082003a.html

[22] http://en.wikipedia.org/wiki/Electrolytic_cell

[23] http://en.wikipedia.org/wiki/Electrochemical_cell

[24] http://www.tannerm.com/current_density.htm

[25]. http://en.wikipedia.org/wiki/Standard_electrode_potential

[26] http://en.wikipedia.org/wiki/Scanning_electron_microscope

[27] http://en.wikipedia.org/wiki/X-ray_fluorescence

[28] www.recycle.novelis.com

[29] http://en.wikipedia.org/wiki/Aluminum_recycling

[30] http://en.wikipedia.org/wiki/Powder_diffraction

[31] www.recycle.novelis.com

[32] http://en.wikipedia.org/wiki/Electronegativity

[33] http://en.wikipedia.org/wiki/Periodic_table

[34] http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch21/gibbs.php

[35] http://en.wikipedia.org/wiki/Energy_dispersive_X-ray_spectroscopy

[36] http://www.siliconfareast.com/edxwdx.htm

[37] http://en.wikipedia.org/wiki/X-ray_fluorescence

[38] http://en.wikipedia.org/wiki/Aluminum _recycling

[39] http://www.sparknotes.com/chemistry/electrolytic /section1.html

[40] http://epswww.unm.edu/xrd/xrdbasics.pdf

CHAPTER 9

APPENDICES

9.1 MSDS for AlCl3

Science Lab.com
Chemicals & Laboratory Equipment

Health
Fire
Reactivity
Personal Protection

Material Safety Data Sheet
Aluminum chloride, anhydrous MSDS

Section 1: Chemical Product and Company Identification

t **Name:** Aluminum chloride, anhydrous

| **Codes:** SLA1015

7446-70-0

: BD0525000

TSCA 8(b) inventory: Aluminum chloride, anhydrous

t available.

'm:

al Name: Aluminum trichloride

al Formula: AlCl3

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

;ition:

	CAS #	% by Weight
um chloride, anhydrous	7446-70-0	100

ɔgical Data on Ingredients: Aluminum chloride, anhydrous: ORAL (LD50): Acute: 3805 mg/kg [Mouse.].

Section 3: Hazards Identification

ıl Acute Health Effects:
:ardous in case of skin contact (irritant), of ingestion, of inhalation. Hazardous in case of skin contact 'e), of eye contact (irritant). The amount of tissue damage depends on length of contact. Eye contact lt in corneal damage or blindness. Skin contact can produce inflammation and blistering. Inhalation of produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and }. Severe over-exposure can produce lung damage, choking, unconsciousness or death.

ıl Chronic Health Effects:
OGENIC EFFECTS: Not available.
ENIC EFFECTS: Not available.
)GENIC EFFECTS: Not available.
)PMENTAL TOXICITY: Not available.
;tance is toxic to lungs, mucous membranes.
d or prolonged exposure to the substance can produce target organs damage. Repeated exposure of the ı low level of dust can produce eye irritation. Repeated skin exposure can produce local skin destruction,

ıatitis. Repeated inhalation of dust can produce varying degree of respiratory irritation or lung damage. ed exposure to a highly toxic material may produce general deterioration of health by an accumulation in many human organs.

Section 4: First Aid Measures

ntact:
or and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at minutes. Get medical attention.

ontact:
of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated and shoes. Cover the irritated skin with an emollient. Wash clothing before reuse. Thoroughly clean efore reuse. Get medical attention immediately.

s Skin Contact:
ith a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate attention.

ion:
d, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get attention immediately.

s Inhalation:
te the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or nd. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth ation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation e inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

on:
induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an cious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if ns appear.

s Ingestion: Not available.

Section 5: Fire and Explosion Data

ability of the Product: Non-flammable.

nition Temperature: Not applicable.

oints: Not applicable.

able Limits: Not applicable.

ts of Combustion: Not available.

zards in Presence of Various Substances: Not applicable.

on Hazards in Presence of Various Substances:
explosion of the product in presence of mechanical impact: Not available.
explosion of the product in presence of static discharge: Not available.

hting Media and Instructions: Not applicable.

Remarks on Fire Hazards: Not available.

Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

;pill: Use appropriate tools to put the spilled solid in a convenient waste disposal container.

;pill:
ve solid. Poisonous solid.
ak if without risk. Do not get water inside container. Do not touch spilled material. Use water spray to vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on l.

Section 7: Handling and Storage

tions:
cked up.. Keep container dry. Do not ingest. Do not breathe dust. Never add water to this product. In insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately w the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as

: Keep container tightly closed. Keep container in a cool, well-ventilated area.

Section 8: Exposure Controls/Personal Protection

ering Controls:
cess enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below nended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to contaminants below the exposure limit.

al Protection:
goggles. Synthetic apron. Vapor and dust respirator. Be sure to use an approved/certified respirator or ent. Gloves.

al Protection in Case of a Large Spill:
goggles. Full suit. Vapor and dust respirator. Boots. Gloves. A self contained breathing apparatus be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a st BEFORE handling this product.

ire Limits: Not available.

Section 9: Physical and Chemical Properties

al state and appearance: Solid. (Crystals solid.)

lot available.

Not available.

lar Weight: 133.34 g/mole

White to yellowish.

soln/water): Not available.

Point: Not available.

Point: Sublimes.

Temperature: Not available.

: Gravity: 2.44 (Water = 1)

ressure: Not applicable.

ensity: Not available.

ty: Not available.

hreshold: Not available.

il Dist. Coeff.: Not available.

(in Water): Not available.

sion Properties: Not available.

ity: Not available.

Section 10: Stability and Reactivity Data

y: The product is stable.

ity Temperature: Not available.

ons of Instability: Not available.

atibility with various substances: Reactive with metals.

ivity: Non-corrosive in presence of glass.

Remarks on Reactivity: Reacts violently with water especially when water is added to the product.

Remarks on Corrosivity: Not available.

rization: Will not occur.

Section 11: Toxicological Information

of Entry: Eye contact. Inhalation. Ingestion.

to Animals:
NG: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE.
ral toxicity (LD50): 3805 mg/kg [Mouse.].
xicity of the dust (LC50): 5 8 hours [Human/30 min].

Effects on Humans: Causes damage to the following organs: lungs, mucous membranes.

oxic Effects on Humans:
zardous in case of skin contact (irritant), of ingestion, of inhalation.
us in case of skin contact (corrosive).

Remarks on Toxicity to Animals: Not available.

Remarks on Chronic Effects on Humans: Not available.

Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

icity: Not available.

ınd COD: Not available.

ts of Biodegradation:
ʏ hazardous short term degradation products are not likely. However, long term degradation products may

ʏ of the Products of Biodegradation: The products of degradation are more toxic.

Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Disposal:

Section 14: Transport Information

assification: Class 8: Corrosive material

cation: : Aluminum Chloride, Anhydrous UNNA: UN1726 PG: II

Provisions for Transport: Not available.

Section 15: Other Regulatory Information

and State Regulations:
lvania RTK: Aluminum chloride, anhydrous
husetts RTK: Aluminum chloride, anhydrous
(b) inventory: Aluminum chloride, anhydrous

legulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

lassifications:

(Canada):
D-1A: Material causing immediate and serious toxic effects (VERY TOXIC).
D-2A: Material causing other toxic effects (VERY TOXIC).
E: Corrosive solid.

EEC): R36/38- Irritating to eyes and skin.

J.S.A.):

ı Hazard: 3

lazard: 0

ivity: 0

nal Protection: j

ıl Fire Protection Association (U.S.A.):

ı: 3

nability: 0

ivity: 0

fic hazard:

:ive Equipment:

ic apron.
ınd dust respirator. Be sure to
approved/certified respirator or
ənt. Wear appropriate respirator
əntilation is inadequate.
goggles.

Section 16: Other Information

ıces:
ıl safety data sheet emitted by: la Commission de la Santé et de la Sécurité du Travail du Québec.
, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987.

ıpecial Considerations: Not available.

ı: 10/09/2005 03:40 PM

ıdated: 11/06/2008 12:00 PM

9.2 MSDS for BMIM Chloride

MATERIAL SAFETY DATA SHEET

Date Printed: 05/26/2006
Date Updated: 01/28/2006
Version 1.5

Section 1 - Product and Company Information

Product Name	1-Butyl-3-methylimidazolium chloride
Product Number	38899
Brand	FLUKA
Company	Sigma-Aldrich
Address	3050 Spruce Street SAINT LOUIS MO 63103 US
Technical Phone:	800-325-5832
Fax:	800-325-5052
Emergency Phone:	314-776-6555

Section 2 - Composition/Information on Ingredient

Substance Name	CAS #	SARA 313
1-BUTYL-3-METHYLIMIDAZOLIUM CHLORIDE	79917-90-1	No

Formula C8H15ClN2

Section 3 - Hazards Identification

EMERGENCY OVERVIEW
Harmful.
Harmful if swallowed. Irritating to eyes and skin.

HMIS RATING
HEALTH: 2
FLAMMABILITY: 0
REACTIVITY: 0

NFPA RATING
HEALTH: 2
FLAMMABILITY: 0
REACTIVITY: 0

For additional information on toxicity, please refer to Section 11.

Section 4 - First Aid Measures

ORAL EXPOSURE
If swallowed, wash out mouth with water provided person is conscious. Call a physician.

INHALATION EXPOSURE
If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen.

DERMAL EXPOSURE
In case of skin contact, flush with copious amounts of water for at least 15 minutes. Remove contaminated clothing and shoes. Call a physician.

EYE EXPOSURE
In case of contact with eyes, flush with copious amounts of water for at least 15 minutes. Assure adequate flushing by separating the eyelids with fingers. Call a physician.

Section 5 - Fire Fighting Measures

FLASH POINT
192 °C

AUTOIGNITION TEMP
460 °C

FLAMMABILITY
N/A

EXTINGUISHING MEDIA
Suitable: Water spray. Carbon dioxide, dry chemical powder, or appropriate foam.

FIREFIGHTING
Protective Equipment: Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.
Specific Hazard(s): Emits toxic fumes under fire conditions.

Section 6 - Accidental Release Measures

PROCEDURE TO BE FOLLOWED IN CASE OF LEAK OR SPILL
Evacuate area.

PROCEDURE(S) OF PERSONAL PRECAUTION(S)
Wear respirator, chemical safety goggles, rubber boots, and heavy rubber gloves.

METHODS FOR CLEANING UP
Sweep up, place in a bag and hold for waste disposal. Avoid raising dust. Ventilate area and wash spill site after material pickup is complete.

Section 7 - Handling and Storage

HANDLING
User Exposure: Do not breathe dust. Avoid contact with eyes, skin, and clothing. Avoid prolonged or repeated exposure.

STORAGE
Suitable: Keep tightly closed.

Section 8 - Exposure Controls / PPE

ENGINEERING CONTROLS
Safety shower and eye bath. Mechanical exhaust required.

PERSONAL PROTECTIVE EQUIPMENT
Respiratory: Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU). Where risk assessment shows air-purifying respirators are appropriate use a dust mask type N95 (US) or type P1 (EN 143) respirator.
Hand: Compatible chemical-resistant gloves.
Eye: Chemical safety goggles.

GENERAL HYGIENE MEASURES

Wash thoroughly after handling.

Section 9 - Physical/Chemical Properties

Appearance — Physical State: Solid

Property	Value	At Temperature or Pressure
Molecular Weight	174.67 AMU	
pH	7.9	Concentration: 100 g/l
BP/BP Range	N/A	
MP/MP Range	70 °C	
Freezing Point	N/A	
Vapor Pressure	N/A	
Vapor Density	N/A	
Saturated Vapor Conc.	N/A	
SG/Density	N/A	
Bulk Density	N/A	
Odor Threshold	N/A	
Volatile%	N/A	
VOC Content	N/A	
Water Content	N/A	
Solvent Content	N/A	
Evaporation Rate	N/A	
Viscosity	N/A	
Surface Tension	N/A	
Partition Coefficient	Log Kow: < 0.3	
Decomposition Temp.	N/A	
Flash Point	192 °C	
Explosion Limits	N/A	
Flammability	N/A	
Autoignition Temp	460 °C	
Refractive Index	N/A	
Optical Rotation	N/A	
Miscellaneous Data	N/A	
Solubility	N/A	

N/A = not available

Section 10 - Stability and Reactivity

STABILITY

Stable: Stable.
Materials to Avoid: Oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS

Hazardous Decomposition Products: Carbon monoxide, Carbon dioxide, Hydrogen chloride gas, Nitrogen oxides.

HAZARDOUS POLYMERIZATION

Hazardous Polymerization: Will not occur

Section 11 - Toxicological Information

ROUTE OF EXPOSURE

Skin Contact: Causes skin irritation.
Skin Absorption: Harmful if absorbed through skin.
Eye Contact: Causes eye irritation.
Inhalation: May be harmful if inhaled. Material is irritating to mucous membranes and upper respiratory tract.

Ingestion: Harmful if swallowed.

SIGNS AND SYMPTOMS OF EXPOSURE
The chemical, physical, and toxicological properties of this product have not been thoroughly investigated.

Section 12 - Ecological Information

No data available.

ACUTE ECOTOXICITY TESTS
Test Type: EC50 Daphnia
Species: Daphnia magna
Value: > 100 mg/l

Section 13 - Disposal Considerations

APPROPRIATE METHOD OF DISPOSAL OF SUBSTANCE OR PREPARATION
Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber. Observe all federal, state, and local environmental regulations.

Section 14 - Transport Information

DOT
Proper Shipping Name: None
Non-Hazardous for Transport: This substance is considered to be non-hazardous for transport.

IATA
Non-Hazardous for Air Transport: Non-hazardous for air transport.

Section 15 - Regulatory Information

EU ADDITIONAL CLASSIFICATION
Symbol of Danger: Xn
Indication of Danger: Harmful.
R: 22-36/38
Risk Statements: Harmful if swallowed. Irritating to eyes and skin.
S: 26
Safety Statements: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

US CLASSIFICATION AND LABEL TEXT
Indication of Danger: Harmful.
Risk Statements: Harmful if swallowed. Irritating to eyes and skin.
Safety Statements: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

UNITED STATES REGULATORY INFORMATION
SARA LISTED: No

CANADA REGULATORY INFORMATION
WHMIS Classification: This product has been classified in accordance with the hazard criteria of the CPR, and the MSDS contains all the information required by the CPR.
DSL: No

NDSL: No

Section 16 - Other Information

DISCLAIMER

For R&D use only. Not for drug, household or other uses.

WARRANTY

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Inc., shall not be held liable for any damage resulting from handling or from contact with the above product. See reverse side of invoice or packing slip for additional terms and conditions of sale.

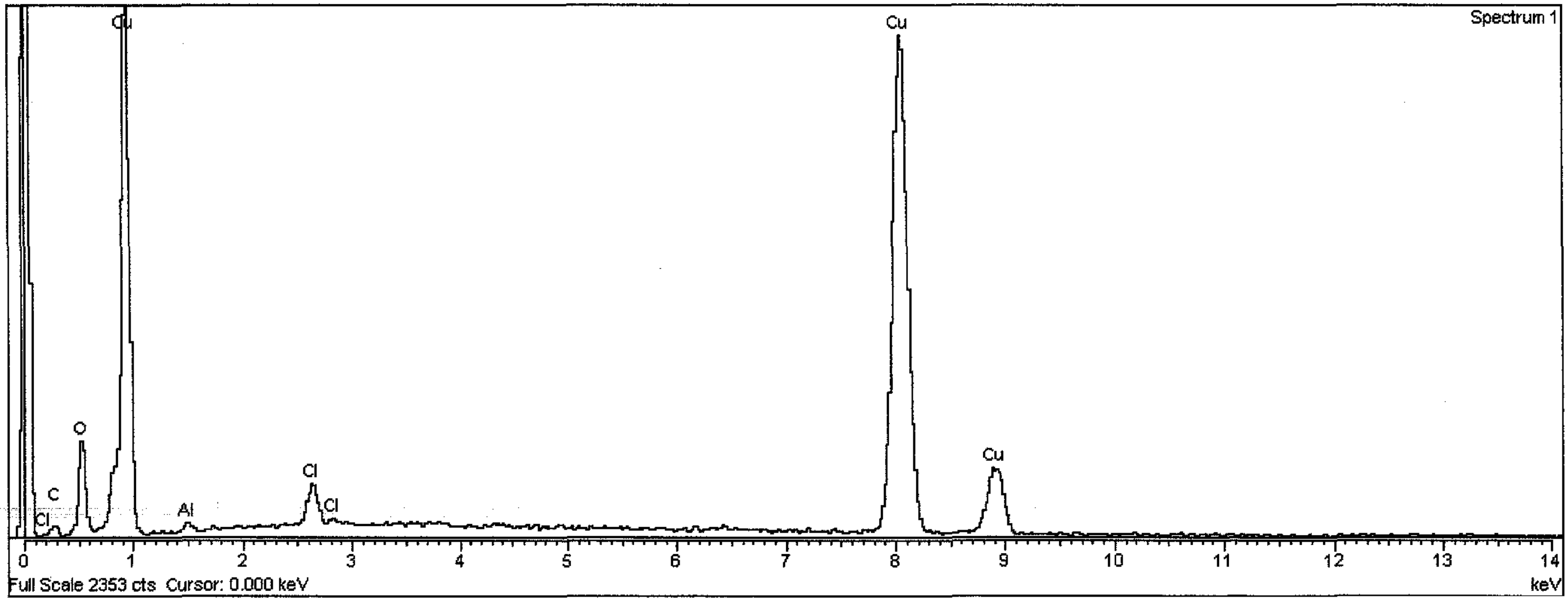
9.3 Results from EDX test

Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 4

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	7.16	21.36
O K	14.84	33.22
Al K	0.77	1.02
Cl K	2.00	2.02
Cu K	75.23	42.39
Totals	100.00	

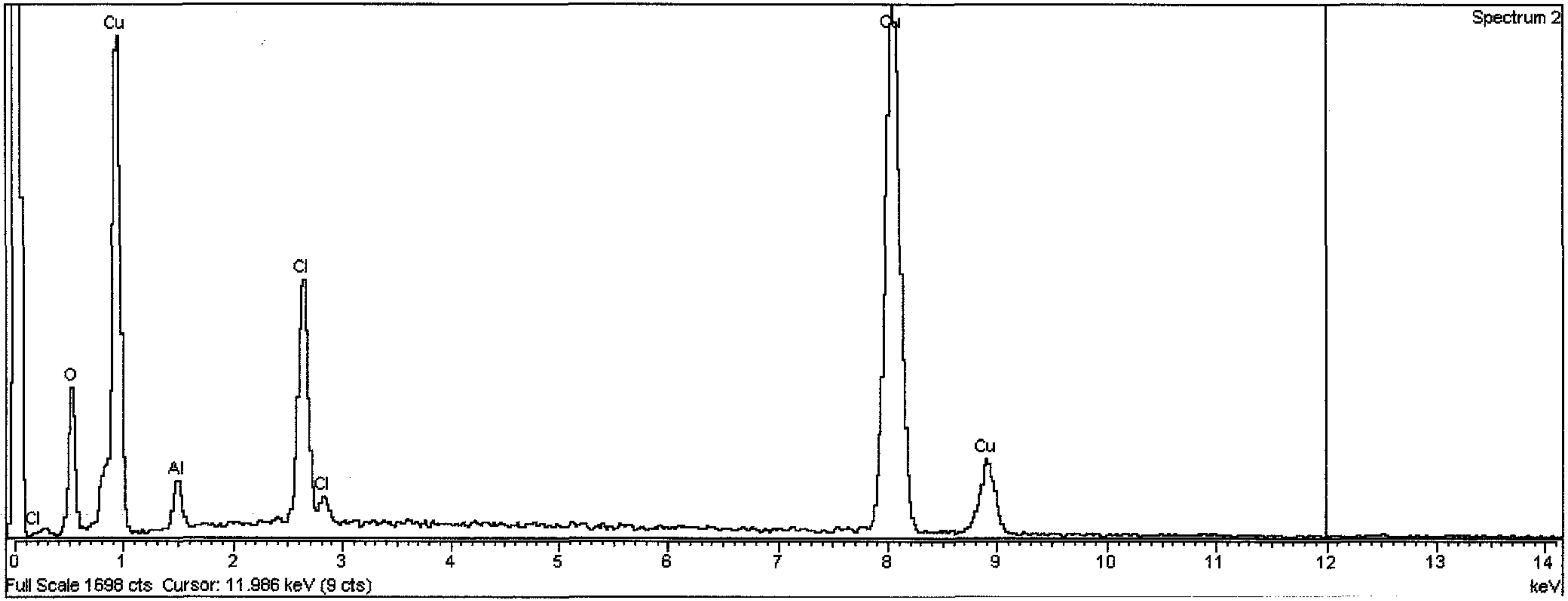


Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 4

Standard :
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
O K	19.55	45.58
Al K	3.38	4.67
Cl K	9.71	10.22
Cu K	67.36	39.53
Totals	100.00	

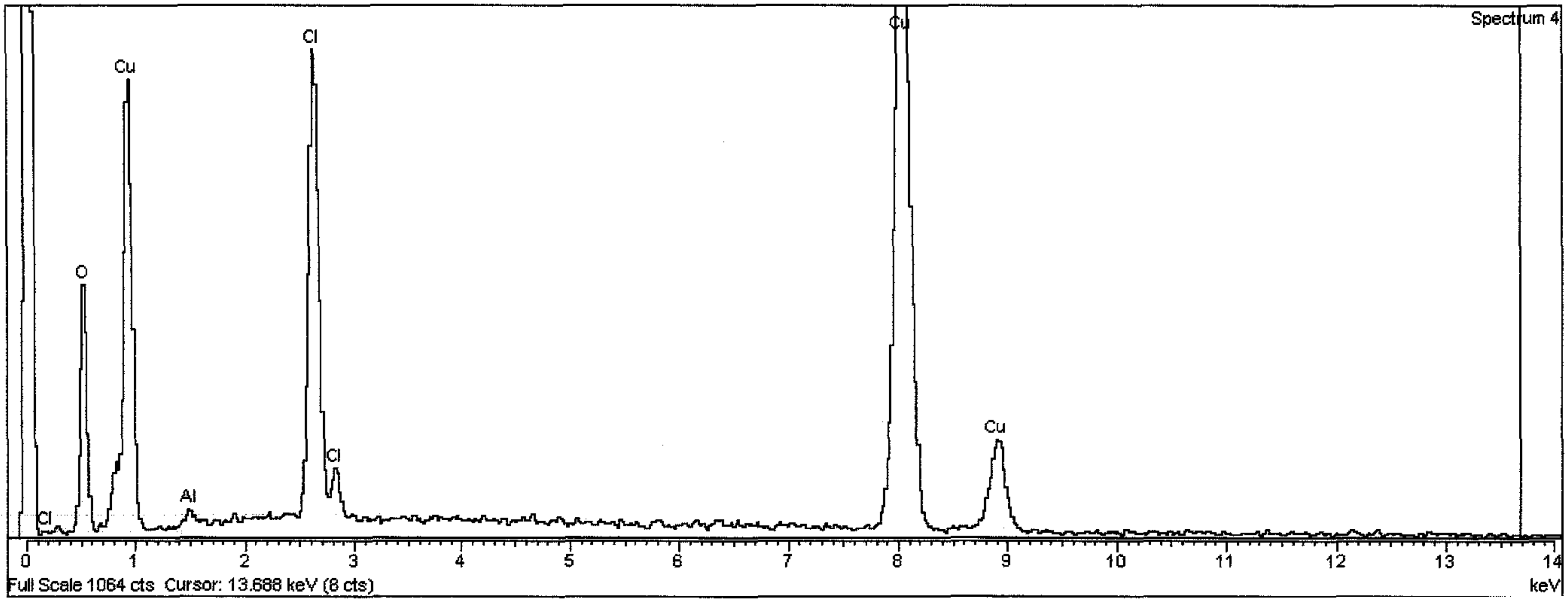


Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 4

Standard :
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
O K	24.68	53.15
Al K	0.64	0.81
Cl K	12.90	12.53
Cu K	61.78	33.50
Totals	100.00	

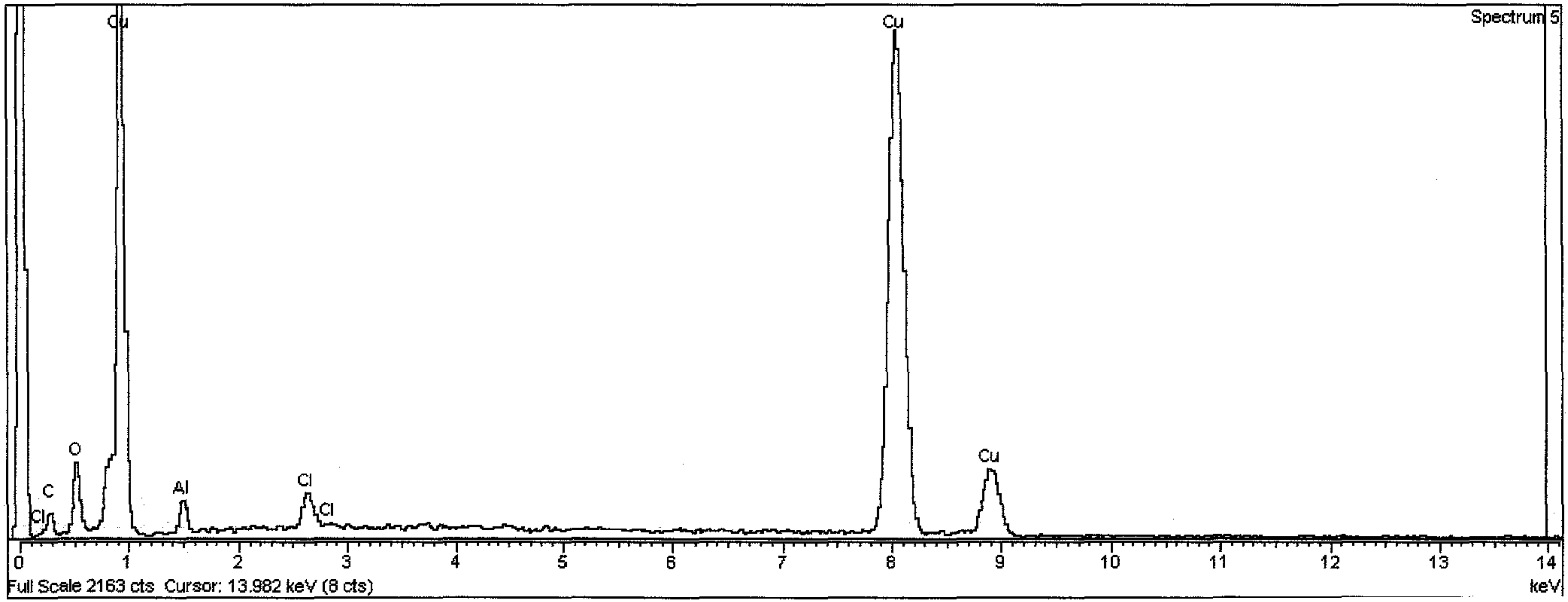


Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 4

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	13.28	35.69
O K	11.81	23.82
Al K	2.65	3.17
Cl K	1.51	1.37
Cu K	70.76	35.94
Totals	100.00	

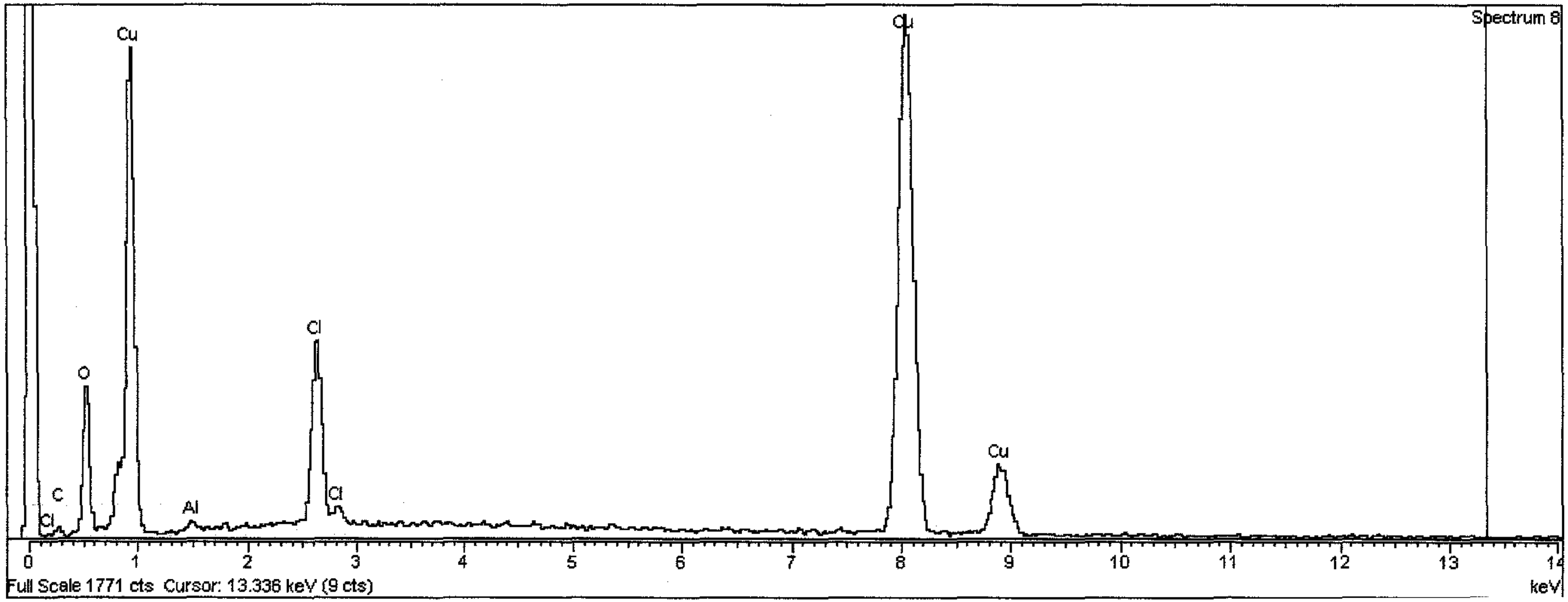


Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 4

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	5.93	16.18
O K	20.80	42.64
Al K	0.57	0.69
Cl K	7.21	6.67
Cu K	65.51	33.82
Totals	100.00	

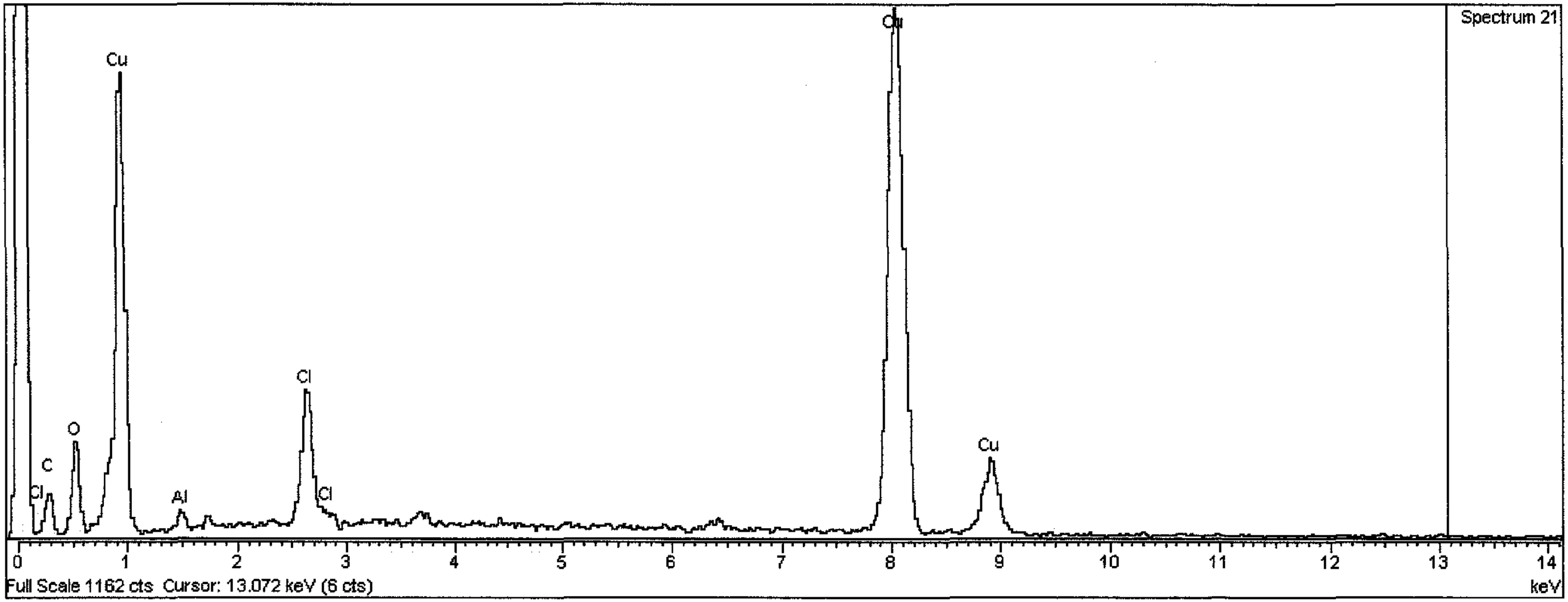


Spectrum processing :
Peaks possibly omitted : 3.691, 6.390 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 5

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	16.29	38.90
O K	15.59	27.95
Al K	1.20	1.27
Cl K	4.67	3.78
Cu K	62.25	28.10
Totals	100.00	



Spectrum processing :
Peak possibly omitted : 2.620 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 5

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Mg MgO 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Mn Mn 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	33.57	52.20
O K	4.65	5.43
Mg K	0.88	0.67
Al K	59.69	41.32
Mn K	0.47	0.16
Cu K	0.73	0.22
Totals	100.00