

# **ELECTROPLATING OF FERROUS METAL USING MIXTURE OF ELECTROLYTES**

*By*

**AKUEWULU BENJAMIN IFEANYI  
2000/10620EH**

**DEPARTMENT OF CHEMICAL ENGINEERING,  
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA  
NIGER STATE NIGERIA.**

**DECEMBER, 2005.**

# **ELECTROPLATING OF FERROUS METAL USING MIXTURE OF ELECTROLYTES**

*By*

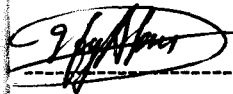
**AKUEWULU BENJAMIN IFEANYI  
2000/10620EH**

**A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF  
CHEMICAL ENGINEERING SCHOOL OF ENGINEERING AND  
ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF  
TECHNOLOGY, MINNA NIGER STATE, NIGERIA. IN PARTIAL  
FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF  
BACHELOR DEGREE IN ENGINEERING (B. ENG.) IN CHEMICAL  
ENGINEERING.**

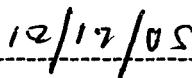
**DECEMBER, 2005.**

# DECLARATION

I, Akuewulu. B. Ifeanyi, with matriculation number 2000/10610EH, declare that this thesis; electroplating of ferrous metal using mixture of electrolytes, has not been presented for the award of bachelor of engineering in chemical engineering else where.



Signature



Date

# CERTIFICATION

This is to certify that this project titled “Electroplating of ferrous metal using mixture of electrolytes” was supervised, moderated and approved by the following underlisted persons on behalf of the Chemical Engineering Department, School of Engineering and Engineering Technology, Federal University of Technology, Minna.

---

Engr. Akpan U. G .  
*Supervisor*

---

Date

---

Dr. F. Aberuagba  
*Head of Department*

---

Date

---

*External Examiner*

---

Date

# DEDICATION

dedicate this project to Almighty God, who made it possible for the successful completion of my Chemical Engineering Degree Program.

## **ACKNOWLEDGEMENT**

I wish to acknowledge the grace of God Almighty in my life, for sparing my life throughout my course of study and successful completion of my first degree.

I sincerely thank my supervisor Engr. Akpan U. G. and Dr. Duncan Aloko, whose support and encouragement made it possible for the completion of this project.

An immeasurable and unquantifiable debt of appreciations to my parents for their love, care, understanding, encouragement, financial and moral support from childhood till this level, may they live to eat the fruit of their labour.

My appreciation goes to my elder brother Mr. Amaco R. Akuewulu for his financial and moral support.

Finally my appreciation goes to friends Mr. Ojabo John, Engrs. Effiong, Vincent Obi, Christian Mgbeahuru, Abel Gin, Jerome Chukwudoziri, Godwin Nwaonuma, Agada Benjamin and others, too numerous to mention and my classmates for making my stay in Minna joyous and memorable.

# TABLE OF CONTENTS

Cover page	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledge	v
Table of Content	vi
Abstract	vii

## CHAPTER ONE

1.0 Introduction	1
1.1 Summary of how electroplating works	2
1.2 Aims and objectives	3
1.3 Scope of work	3

## CHAPTER TWO

2.0 Literature review	5
2.1 An overview of electroplating	5
2.1.1 Principle of electrolysis	6
2.0 Electrolysis of molten sodium chloride	7
2.1 Fundamental laws of electrolysis	8
2.2 Rate of deposition	9
3 Chemistry of electroplating	9
3.1 The ionic theory	10
3.2 Electroforming	11
4 Preparation of the object	11
5 Electrical conductance of a solution	12

2.5.1 Presence of ion and electrical conductance-----	12
2.5.2 Cathode and anode-----	12
2.6 General applications of electroplating -----	13
2.6.1 Plating for appearance (decorative plating) -----	13
2.6.2 Plating for protection-----	13
2.6.3 Plating for special surface and engineering-----	13
2.7.0 Electric current -----	14
2.7.1 Electrical conductance of a solution and concentration of ions -----	14
2.7.2 Electrolytes-----	14
2.7.3 Metals used in electroplating -----	14
2.8.0 Properties-----	15
2.8.1 How a layer of zinc prevent ion rusting -----	15

**CHAPTER THREE**

0 Methodology-----	17
1 Equipment used-----	17
2 Material used -----	17
2.1 Design of the bath-----	17
3 Preparation of the bath-----	18
4 Plating procedure-----	18
4.1 Pretreatment (cleaning of base metal) -----	18
5 Electroplating-----	19
6 Composition of the electrolyte-----	20
7 Post treatment-----	20



## CHAPTER FOUR

4.0 Results and discussion	22
4.1 Results	22
4.2 Discussion of result	25
4.3 Effect of electric density	26
4.3.1 Effect if impurity	26
4.3.2 Effect of proper agitation	26
4.3.3 Effect of voltage	26
4.4.0 Predicted value of Y	27
4.5 Discussion of predicting equation	29

## CHAPTER FIVE

5.0 Conclusion and Recommendations	30
5.1 Conclusions	30
5.2 Recombination	30
Appendix	31
References	34

## ABSTRACT

Electroplating is the process of electro-deposition by which a thin smooth sound metallic deposit produced over the base metal. The objective of the experiment was to beautify, protect, insulate, or to increase corrosion resistance and surface properties of the base metal. In the experiment, a mixture of Sodium Cyanide, Zinc Cyanide, Sodium Hydroxide and brightener was used as the electrolyte. The zinc metal was used as the anode while the base metal is (iron bolts) made-up the cathode. With the aid of rectifier, a direct current is supplied to the electroplating bath which was used to plate 27 pieces of the work piece or the base metal. Using different values of voltage, current and time, the mass deposited at the base metal was determined with the corresponding thickness of the deposit. The best result was achieved using 1.4volts, 1.5Amps, and plating time of 9 minutes, to produce a mass deposit of 0.270g with a corresponding thickness of  $1.84 \times 10^{-3}$  cm. The surface properties and corrosion resistance of the base metal was improved to a considerable value at the end of the experiment.

## CHAPTER ONE

### 1.0 INTRODUCTION

The relation between chemical and electrical phenomena was investigated by M. Lomonov as early as in the middle of 19<sup>th</sup> century. He made much progress in the study of electrolyte solution. In 1853, I. Hillorf establishes that ions in a solution, in an electric field moves at different velocities determined by the nature of the ions. In 1874, F Kohidensch established the law of independence of electric conductivities of ions. In 1887, the Swedish scientist S. Arrhenius formulated the theory of electrolytic dissociation, which remains useful at the present time. In 1891. Kablukor (Ankøren, 1993) noted that Arrhenius theory must be used in combination with Medeleev's hydrated theory and pointed out that ions formed in molecular dissociation becomes hydrated. In 1923, strong electrolytes were invented. The work of the Soviet scientists, advanced to a considerable extent. Developing the concept of the theory of electrolysis. The development of theoretical concept of electrochemistry was accompanied by practical electrochemical process.

In 1805, Michael Faraday discovered the quantitative laws with reference to the amount of substances formed at the electrodes which depends on the quantity of electricity passed through the system. In 1838, Russian academicians, B. Yakobi used an electric current and metal deposited on different shaped electrode to obtain different metal articles. Yakobi's discovery subsequently gives birth to a new field of applied electrochemistry.

It also involves preferential or selective discharge of ion in an electrolyte, which depends on the position of the ion in the electrochemical series, concentration of the ion in the electrolyte and the nature of electrode. Electrolysis is defined as a chemical decomposition of a substance when an electric current is passed through it. The substance that decomposes is called an electrolyte and it is usually an acid, base or salt that conducts electricity when in solution or in molten form. Science of electroplating has been developed from this principle, if a direct current passed through an electrolyte, metal will be eaten away from the anode; the composition of the electrolyte remains unchanged. (Graham .A et'al)

Electroplating beautifies, protects, insulates, or increases the corrosion resistance, conductivity or solderability of metal objects, generally of iron or copper alloys, but sometimes other metals as well.

The process involves dissolving metal at the anode and depositing it at the cathode. Direct current applied between the electrodes is conducted through the solution containing metallic salts. Because the ions depleted by the plating process at the cathode are replenished at the anode. The process is essentially self maintaining.

### 1.1 Summary of how Electroplating Works

Anode	+	<p>Metal ball or slabs are placed in a weakly acid or alkaline solution. The acid or base helps the metal dissolve. The metal in solution is in ionic form. An electric current passes through the solution causing the metal ion to gain electrons and causes the object to be plated.</p> <p>To attract a coating of the metal in solution. The solution usually also contain one or more wetting agents and gain refiners which produce an attractive plated finish.</p>
Cathode	-	

Electroplating is the techniques by which solid metals is deposited on different articles to render their surface specific properties. Electroplating is the process whereby an object usually metallic is coated with one or more relative thin smoothly adherent layer of other metal. Electroplating is need when there is a need for surface characteristics that the base metal, selected for structural reasons does not posses. Electroplating protects, beautifies, insulates, or increases the corrosion resistance, conductivity or solderability of metal objects as well.

Electroplating was originally introduced as a means of applying a deposit of nickel, gold, or silver as a decorative finish to jewellery, cutlery and bicycle spare parts. It was the mastery of

the science of British, German and American manufacturers and consequent superiority of their product that brought about the limelight of electroplating industry. Now, it has been developed to such an extent that there is hardly a branch of industry, which does not make use of the process, not only as a means of adding finishing to a product, but also to add a protective coating such as cadmium plating and anodizing. Common examples of electroplated materials are chromium plated steel for automobile accessories. Tin-plated steel for food containers and silver plated table wares such as spoon, forks, knives, gold plated jewellery and chromium plated automobile. The metal to be plated as well as the plating material is usually metal. Plating operation is important and necessary part of the manufacturing process and should be planned with the same care accorded to fabrication operations.

Electroplating works with the principle of electrolysis i.e. the reaction at the anode (anode half reaction) and at the cathode (cathode half reaction), which are oxidation and reduction (redox) reactions.

## **1.2 Aim and Objectives**

The major objective of the project (zinc plating using alkaline bath) :

- 1) To get improve surface appearance on the basic metal
- 2) To obtain improved resistance to corrosion, tarnish, chemical and wear.
- 3) To increase hardness of metal
- 4) To increase electrical conductivity.
- 5) To change the surface properties of the metal
- 6) To beautify the surface or appearance of the metal.

## **1.3 Scope of Work**

In theory at least to every metal, electroplating can occur and their electro-deposition can theoretically carried out. In practice however, there are chemical, electrochemical and metallurgical consideration, which considerably limit the number of metals with which the present state of knowledge can be difficult to electroplate, even impossible to plate.

The process is based on the fact that when a direct current of electricity is passed between electrodes immersed in solution containing metallic salts, electrolysis will occur. This will result in metal ion migrating to the cathode.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 An Overview of Electroplating

Electroplating is a process of electro deposition by which a thin smooth sound metallic deposit is produced over a basic metal. Electroplating protects, beautifies, insulates or increases the corrosion resistance, conductivity or solderability of metal objects, generally of iron or copper alloys, but sometime other metals as well. The process involves dissolving metal at the anode and depositing it at the cathode. Direct current applied between the electrodes is conducted through the solution containing metallic salts. Because the ions depleted by the plating process at the cathode are replenished at the anode, the process is essentially self-maintaining. (J. J. Moore)

Modern electroplating is as skilled as an operation of any other manufacturing endeavour. Plating baths, load size and current density are carefully controlled. Platers immerse objects into a series of chemical baths in order to change their surface conditions. The number of tanks and their chemical make-up differs based on the desired result and every plating plant is different.

Designers of goods to be finished need broader understanding of the processes used. Platers must know what kind of metal they are finishing. Every metal requires a somewhat different pre-treatment. Aluminium, for example, may dissolve in a solution designed for clearing steel. Even variation between alloys will require modification of the pre-treatment process. An incorrect identification may result in damage or even the destruction of the parts.

Metals pre-treatment or preparation is crucial because it affects adhesion and appearance, as well as, composition and properties of the final deposit. Platters need accurate information about pre-existing contamination, such as, inclusion, in the base metal, cutting oils used and any organic or inorganic surface films. Environmental regulations have severely restricted clearing options. While the choices are limited, most soils can be safely removed if the platters know what they are dealing with. Information supplied by the customers is the key to successful metal finishing. (Raymond Chang)

## 1. 1 Principle of Electrolysis

Electrolysis is defined as gradual decomposition of a metal in an electrochemical cell when an electric current is passed through it. Electrolysis was found by Michael Faraday, who in the 1830s and 1840s was the first person to investigate electrolysis systematically.

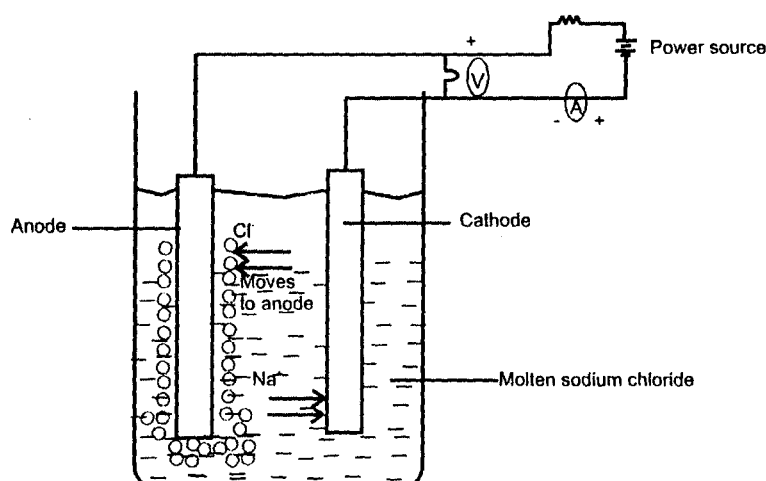
Often the Faraday constant is written as a round number, perhaps  $96500\text{Cmol}^{-1}$ , which is not accurate but handy in calculation. (Philip Matthews)

Here are many uses of electrolysis namely:

- 1) It is used in extraction of very reactive metal such as sodium
- 2) It is used in purification of metals containing impurities.
- 3) Electrolysis is also used to decompose compounds, and to convert them into more useful and valuable chemicals.
- 4) It can also be used in electroplating of metals to prevent wearing away of the metal which is mainly emphasized in this research.

In electrolysis, current is passed through a solution containing ions, or a molten salt, called the electrolyte. The negative electrode called the cathode is coated with electrons, some of which can be stolen by the positive ions that come close to the electrode.

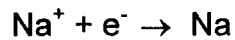
A typical example of the reaction. (W. Kann et al)



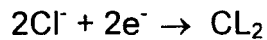


## 2.2.0 Electrolysis of Molten Sodium Chloride

In the electrolysis of molten sodium chloride, sodium ions travel to the cathode and the sodium metal is liberated.



Chloride ion moves to the anode and chlorine is given off

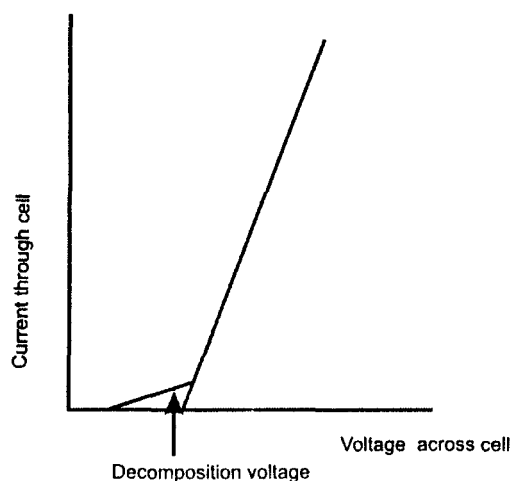


Reduction takes place at the negative electrode ie. There is electron gain while oxidation always takes place at the positive electrode ie there is electron loss.

In an electrochemical cell, if the voltage across the cell is increased gradually and the current passing through the electrolyte is measured. It was found that current remains very small until a certain voltage, it rises very quickly then the electrolysis starts. The minimum voltage causing electrolysis to take place is called the decomposition voltage.

Electrodes placed into a solution will set up an electrode potential. The decomposition voltage is at least equal to the combination of the two electrode potentials at the anode and cathode.

Once electrolysis is under way, there are significant changes in the concentration of the ions near the electrode. This effect increases the decomposition voltage, so that it is larger than that which might be calculated from electrode potential. The ions discharged during electrolysis, you need to know their over voltage. (Phili Mathew, et'al)



The graph shows how the current through an electrochemical cell varies with voltage

## 1.1 Fundamental Laws of Electrolysis

Product of electrolysis only appear on the surface of electrode and no where else in solution, because the electrolysis's the result of electron acceptance electron shedding phenomena, and this can occur only at electrode surface.

The fundamental of electrolysis were investigated by MICHEAL FARADAY, the English physicist and chemist, discovered the two laws that bear his name, who laid down two important principles, which adapted to electrode position or electroplating, these are;

The amount of chemical substance (w) deposited at or dissolved from an electrode during electrolysis is directly proportional to the quantity of electricity (Q) that passes through the circuit.

$$\text{i.e. } M \propto Q$$

$$\text{But } Q = It$$

the quantity of electricity (Q) is measured in coulomb and current flow ( I ) measured in ampere and time(t) in seconds.

$$\text{Weight of deposition on electrode (W) } = Z, I. t$$

Where z is the constant of proportionality and depends upon the characteristic of the species discharged at the electrodes. The constant is called the electrochemical equivalent of the ionic species and its unit is gram per coulomb.

The electrochemical equivalent of an ionic species is its quantity in grammes, which is deposited from an electrode, passing one coulomb of electricity through the electrolyte.

That when equal quantities of electricity (Q) pass through solutions of different electrolytes, the amount of the substance (W) deposited or dissolved at the electrodes is directly proportional to the equivalent weight of the substance. (Assuming current efficiency of 100 percent).

The equivalent weight of a substance is its atomic weight divided by its oxidation number or valence.

$$\text{Chemical equivalent} = \text{atomic weight/valence.}$$

By second law of faraday; when a current is passed through two electrolytes, if the deposits in two different electrolytes, electrode is  $W_1$  and  $W_2$  gm, and their equivalent weight is  $M_1$  and  $M_2$ , then.

$$W_1/W_2 = M_1/M_2$$

### 2.2.2 Rate of Deposition

The minimum quantity of electricity required to deposit the equivalent weight in grammes of metal is 96500 will discharge 1 mole of hydrogen; this quantity of electricity is called faraday. One faraday is equal to one mole of electron since, the discharge of one mole of single charge ions involves the transfer of one mole of electron, which contains Avogadro's number i.e.  $6.02 \times 10^{23}$  of electrons.

Thus  $W = ItA/ZF$

Where A is the atomic weight of metal deposited of valence, Z, F, is a constant called the faraday. The relation between atomic weight and chemical equivalent is; atomic weight = equivalent weight x valence.

The valence may be defined as being the number of atoms of hydrogen with which one atom of the element combines, or which it replaces. The figure is always a whole number, for example; silver is monovalent and cadmium divalent, or in other words, have valences of one and two respectively.

The faradays law of electrolysis can also be explained in terms of discharge of ion at the electrodes in electroplating, since electrons are involved in the discharge of an element.

### 2.3 Chemistry of Electroplating.

The quantity of products liberated at the electrodes during electroplating depends on three factors, which are the magnitude of the steady current, the time of flow of the steady current and the charge, of the liberated element. These quantitative aspects of electrolysis or electroplating were first investigated by faraday that later put forward two laws in 1833 to describe these quantitative relationships, these laws are called faraday laws of electrolysis.

Electroplating which involves electrolysis is guided by theories and laws. These are ionic theory, which was first presented by Arrhenius in 1887. Another law guiding electrolysis is the Faraday's law of electrolysis as earlier stated.

### 3.1 The Ionic Theory:

The ionic theory was first presented by Arrhenius in 1887 to explain electrolysis. The theory stated that when an electrolyte is melted or dissolved in water, some, if not all, of the molecules of the substance dissociate (break up) into freely moving charged particles called ions. The process of dissociation into ions is known as ionization e.g.



The metallic ions, like hydrogen and copper ion are positively charged. The number of electrical charges carried by an ion is equal to the valence of the corresponding atom or group. Due to electrical charges carried by these ions, their properties are quite different from those of their corresponding atoms, which are electrically neutral. A metallic ion is formed from the corresponding atom by the gain of a number of electrons equal to the valence of the atom.

When an electrolyte is dissolved in water or is melted, its molecules dissociate, or separate into freely moving ions. These free ions can exist independently of one another in solution, but must of course always balance out electrically in other words, the numbers of positive and negative charges must always be equal. Under the influence of a potential applied between two electrodes immersed in the solution. (Cell voltage or cell potential) the ions will migrate, the positively charged ions towards the cathode or negative electrodes. The positive ions are specifically known as cations i.e. cathode ions, at the cathode the cations gain electrons and become uncharged atoms. Simultaneously, the negatively charged ions called anions, travel to anode. Where they give up electrons and also become uncharged atoms.

As a result of this transfer of electrons, uncharged atoms of the elements of which electrolyte is composed gather at the electrodes. Elements possessing positive oxidation number (metals) accumulate at the cathode, element with negative oxidation number (non-metals) gather at the anode.

In a deposition, although it is continuously removed from the layer of electrolyte next to the cathode, the concentration of metal ions at the interfaces does not continuously decrease. A steady or equilibrium state is quickly reached because a number of natural agencies transport metal ions from the body of the bath to the cathode, to replace the ions deposited. These agencies are diffusion, convection and electrical migration. Electrical migration is the transport of ions under an applied electrical field (positive ion being attracted to the negative electrode and vice versa), contributes little to the transport of ions, as the speed of the ions is very small. The other two agencies, convection and diffusion transport most ions. These agencies do not rely upon an electrical field in order to operate. Convection is due to density gradients with the solution temperature.

Diffusion is the natural movement of ions from higher concentration to less concentrated regions of the electrolyte. Its effect is most pronounced in the regions of the electrolyte next to the cathodes (diffusion layer) from which the ions are continuously removed by deposition and replaced by transport from bulk of the bath. Both diffusion and convection play a major role in the transport of complex ions from body of bath to the cathode.

### **2.3.2. Electroforming**

Electroforming is a variety of electro-deposition (deposition by electrolysis) in which an article to be reproduced is made conductive by spraying it with a metallic coating, then electroplated with a metallic deposit in the normal way. The metallic deposit forms a mold, which is removed from its base and filled into, reproduce the original article.

### **2.4. Preparation of the Object**

The object to be plated must be thoroughly or surgically cleaned and rinsed before being placed in the plating bath. The surface must be free of dirt, rust, oil and any oxides or other chemical impurities.

If such substances are not removed, the coating may not adhere well to the surfaces. Grease and dirt are removed by organic solvent or alkaline solutions. Oxides are removed by organic solvent or alkaline solutions. Oxides are removed by organic solvent or alkaline solution.

Oxides are removed by immersing the object in acid, the process is called pickling. In some cases the object is cleaned by making it the anode in an electrolytic process. This process is called electroplating.

## **2.5. Electrical Conductance of a Solution**

Solution of sodium chloride, lime in water is good conduction of electricity, while solutions of sugar, urea are bad conductor. To understand the difference in electrical conductance capacities for solutions, it is essential to know what was difference in conducting solutions as compared to a non-conducting one.

### **2.5.1 Presence of Ion and Electrical Conductance**

Ordinarily metal wires are good conductors of electricity. This is due to easy availability of electrons in a metal and they have free electron. When an electric field is applied to a metal, according to the directions of applied field electrons starts moving from negative charged end of metal to its positive one, this is the way current flow in metal. In actual practice, it happens that only electrons can move in a metal, larger particles (i.e. atomic nuclei or non metallic ions) cannot move through a metal. Thus, a substance conducts electricity when an electron or some other electrical charged particles like ion have to move through two types of electrically charged particles or ions. One type of ions negatively is called anions and other is positively charged and is called cations.

### **2.5.2. Cathode and Anode**

The metal plates dipped in a solution through which this electrons are liberated or absorbed, are called electrodes. The electrode which liberates electrons from the solution after acquiring them from negatively charged ions in the solution is positively charged and called the ANODE but the electrode which gives electrons to the solution (negatively charged is called CATHODE) of nickel plating. This double plating gives better production and the chromium adheres more strongly to the nickel than it does to most base metals. Zinc is the most reactive of all common metals it may however, be attached or dissolved by ordinary liquids

such are soft drinks and vinegar. Therefore, materials that are plated with zinc are usually passivated with blue or yellow solution, that is finely covered with a solution that makes the surfaces passive to attack like oxidation, which can bring about tarnishing, in this project zinc (metal) was used for electroplating of basis metal.

### **2.6.1 General Application of Electroplating**

For decorative plating metals used are Gold, Nickel, Chromium, Brass, Rhodium and Copper. For special decorative effect Tin, Zinc, Lead, Cadmium, Palladium and Platinum etc. are used. One metal may be plated over the basis metal or several metal may be plated one over the other on the basis metal. Metal, which forms basis metals, are steel, Brass, Copper, Nickel, Silver white metals alloys of lead or Tin base and Aluminum alloys.

### **2.6.2. Plating for Protection**

Steel must be protected from rusting and chemical attack and so it is electroplated. Protective metals applied are Zinc, Cadmium and tin e.t.c. where both protection and good appearance. Nickel dulls by tarnish when exposed to atmosphere and chromium does not.

### **2.6.3. Plating for Special Surface and Engineering Effects**

A part of a plant can be fabricated of an alloy, which is easy to fabricate and has got the required mechanical properties but is widely corroded when subjected to atmosphere of working. In such a case electroplating of the part with corrosion resisting metal serves their purpose very well.

Electroplating in engineering is employed for temporary use in metal treatment. For examples steel are parts before carbonizing are copper plated to prevent carbonization of undesired portions.

In hardening process, portion of steel are protected from nitrified by electroplating tin or copper-tin alloys on such portions

## **2.7 Electric Current**

The electric current that is used in electroplating must be very carefully controlled in order to produce a smooth, even, non-porous coating of metal. The weight of metal deposited on the object and its average thickness deposited depends on the amount of electricity used and the time for which it flows.

### **2.7.1. Electrical Conductance of a Solution and Concentration of Ions in it.**

When an electric current is passed through a metallic conductor, according to the direction of the applied of the applied electrons flow as a stream in a single direction. This flow of current in an electrolyte (solution), have two streams of cations and anions flowing in mutually opposite directions. But the total current strength is the sum of current strength due to the streams of cations and anions.

### **2.7.2 Electrolytes**

This kind of electrolyte that is used for electroplating and its concentration has an important effect on the quality of coating. The electrolyte solution must be a good conductor of electricity and should not oxidize when exposed to air. It should also have a good throwing power, the measure of its ability to coat all parts of the object close to the anodes. Even when the throwing power of the electrolyte is good the object is sometimes rotated during electroplating to make the coating more uniform. In many cases certain chemicals, called brighteners, are added to the electrolyte to help make the coating brighter.

### **2.7.3 Metals Used in Electroplating**

Nearly all metals can be used for electroplating. The most important are gold, silver, chromium, nickel tin, copper, cadmium lead and zinc (which this project really based on). Certain alloys, such as brass, nickel, cobalt and speculum, an alloy of tin and copper are also



used for plating. The most commonly used plating metal is nickel, because it is more resistant to corrosion than most of the other metals. Chromium plating, which is also very common, is usually applied on top of a layer.

## 2.8 Properties of Zinc

Zinc is a bluish-white lustrous metal, which is hard, crystalline and brittle. The metal is electronegative to ion and gives excellent corrosion resistances, particularly in industrial and urban environments. Zinc readily alloys with many other metals and one of the primary uses is in an alloy form for "zinc base die casting" which are of importance in the metal finishing trade. The "super plastic" alloys are also zinc based and can be blow-moulded.

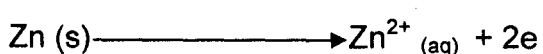
Zinc is almost always deposited in the fully bright condition where an attractive and corrosion resistant finish is required; this can be subsequently passivated or dyed, dissolving readily in dilute acids and alkalis therefore it is an unsuitable material for electroplating onto articles that are liable to come into contact with foodstuffs.

### 2.8.1 How a Layer of Zinc Prevent Iron Rusting

Iron is dipped into molten zinc (at about 450°C) it gains a layer of zinc over its surfaces. Iron with its layer of zinc is said to be galvanized. There are two reasons why the zinc prevents iron rusting.

The first, most obvious, reason is that it prevents water and oxygen reaching the iron. The second, more interesting, reasons are that even if the zinc becomes partially worn away, it will still prevent rusting. Diagram below gives an idea of why this happens.

A somewhat similar situation arises to the zinc and copper in that case the copper was not worn; rather, it provided a path for this reaction of zinc with hydrogen ions to give off hydrogen successfully. So it is with zinc and iron. Zinc has more electrode potential than iron (the values are  $E^{\theta}_{\text{Zn}^{2+}/\text{Zn}} = -0.76\text{V}$ ,  $E^{\theta}_{\text{Fe}^{2+}/\text{Fe}} = -0.44\text{V}$ ) therefore zinc will react according to the equation.



Zinc is the anode. Zinc ions are converted into zinc hydroxide by hydroxide ions in the water. The electrons directly between the zinc and the iron, which in this case is the cathodes. Where the iron is exposed to the surrounding water, hydrogen ions picks up the electrons.



The point is that the iron remains unaffected; it is protect from the corrosion. A layer of zinc prevents iron from rusting. Instead of the  $\text{Fe}^{2r}$  ion going into solution,  $\text{Zn}^{z+}$  ions are lost from the zinc. The electrons release into the lattice joins with hydrogen ion in the water to make hydrogen. The hydrogen is produced at the iron surfaces. (J. J. Moore et'al)

## CHAPTER THREE

### 3.0 METHODOLOGY

#### 3.1. Equipment Used

- Electroplating bath
- Rectifier consisting of both voltmeter and Ammeter
- Beaker
- Oven (dryer)
- Digital weighing balance
- stop watch

#### 3.2. Materials Used

- Alkaline solution
- zinc cyanide
- Sodium cyanide
- HcL for pickling
- Distilled water
- Zinc anode
- Ferrous metal (cathode)
- Sodium chromate
- H<sub>2</sub>S<sub>04</sub>

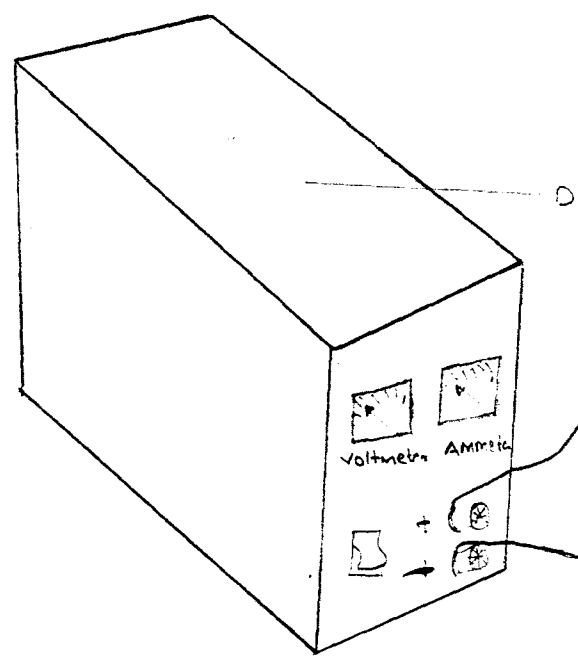
Trioxonitrate acid

Brightener

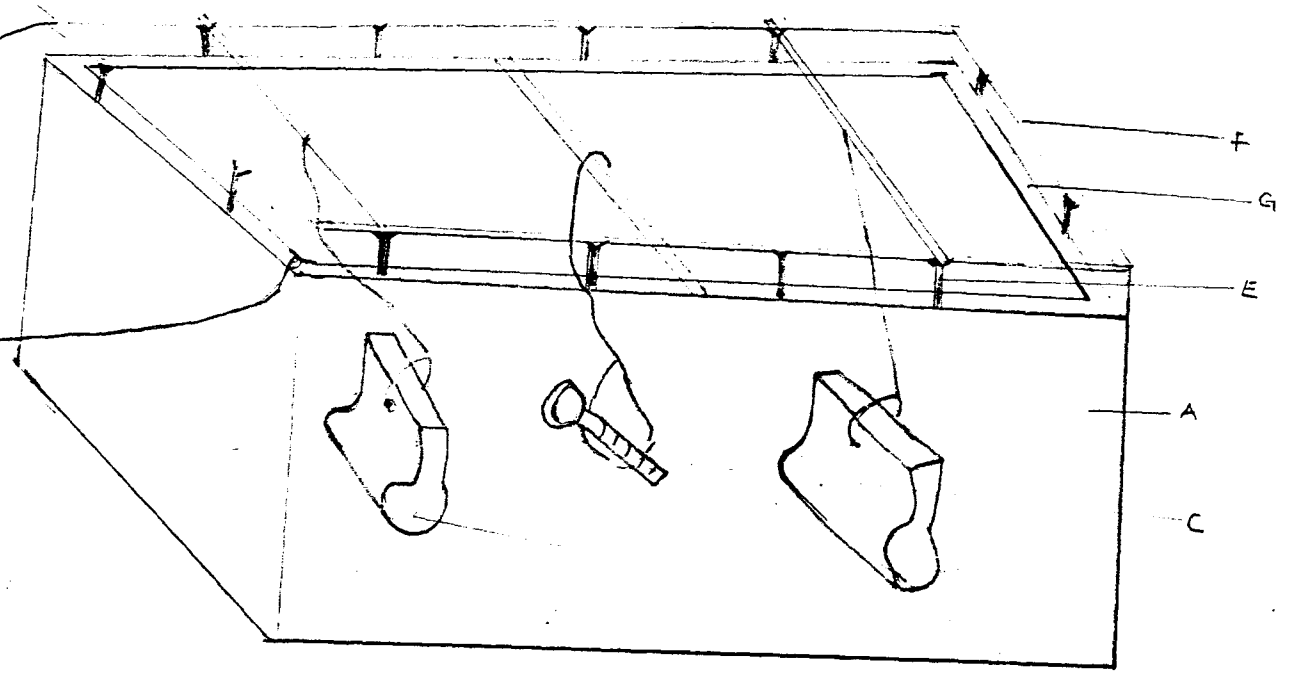
#### 3.2 Design of the Bath

The bath is made of thermoplastic cooler which will not react with the electrolyte and capable of containing 4 litres of electrolyte. The cathode wire is made of flat copper bored at interval, which was flitted on the thermoplastic cooler with the aid of glue and plastic insulating material. The plastic insulator aids in separating the cathode wire from the anode. The zinc

- A — plastic bath
- B — Zinc anode
- C — Bolt (Cathode)
- D — Rectifier (Containing both voltmeter and ammeter)
- E — Plastic insulator
- F — Positive copper wire
- G — Negative copper wire



RECTIFIER



ELECTROPLATING BATH

was connected to the positive copper wire while metal was connected to the negative copper wire.

### **3. Preparation of the Bath**

The electrolyte is a mixture of 500g of sodium cyanide, 1kg of zinc cyanide, and 500g of sodium hydroxide, 0.5 litre of zinc brightener and 2 litres of distilled water.

After the solution (electrolyte) was made, it was left to stay for 24 hours so that the chemicals will normalize.

The second step is the activation of carbon, which is for removing organic compounds in the baths. The bath is allowed to stay for another 24 hours before it is free of organic materials hence the bath is ready for use.

### **4. Plating Procedure**

Plating procedure can be divided into three processing units

1. Pre-treatment
2. Electroplating
3. Post treatment

#### **4.1. Pre-Treatment (Cleaning of Base Metal)**

Different materials had different pre-treatment procedures, which depend on the nature of the material. The nature of the base metal is very important for its pre-treatment. The nature of contamination or the exposure is also important for efficient pre-treatment, pre-treatment or cleaning of the base metal increases adhesion of the deposited metal. These are the following types of cleanliness.

- a. Physical cleanliness. If the surface of the metal is oily, greasy and rusty. It must be degreased at first. Grease greatly affects efficiency in mechanical cleaning, therefore metals were freed from oil, grease and superficial dirt. This is done by using organic solvents such as tetrachloroethylene.
- b. Chemical cleanliness; the metal should be free from oxides or other compounds formed on the surface of the base metal. This was achieved by dipping in acid solution

of 10-30% by volume, this is also known as "Acid Picking". The acid used is hydrochloric acid (HCL)

- c. Mechanical cleanliness; the metal surface defects such as scratches, and scans are removed by polishing. The metal should have no damaged surface, which is caused by mechanical operation. Sand paper was used so as to achieve better surface polishing the base metal improves adherence of electro-deposition.

### 3.5 Electroplating

After pre-treatment and water break on the basis metal, it was transferred to the racks into the electrolyte. The cathode is the ferrous metal, which is to be coated, zinc anode is the plating metal and the electrolyte is a zinc salt. Electroplating was carried out in a vessel, called the plating bath that contains the electrolyte.

The electrolyte is the zinc salt of the metal that is to form the coating. The base metal and zinc electrode are immersed in the electrolyte. The base metal is used as the cathode while the zinc metal is used as the anode. The base metal that is well cleaned was connected to the current source (rectifier) and is therefore "cathode". The zinc anode was connected to positive terminal and is therefore positive terminal and is therefore "zinc anode"

The positively charged metal ions, that is zinc ions from the zinc electrolyte are then moved and deposited on the basis metal (negative cathode) and are reduced to a metal atoms. The metal from the electrolyte is replaced by metal dissolved from the rod (zinc anode).

According to the theory of electrolysis; the amount deposited on the basis metal equals the amount dissolved from the zinc anode. After the required plating, the work piece was removed from the electrolyte and rinsed with distilled water and transferred to a well diluted trioxonitrate solution, which presents the plated metal from wearing out easily and finally the work piece was passivated and dry with a temperature rang of 40-50<sup>0</sup>c in a dryer.

### 3.6 Composition of the Electrolyte

Zinc cyanide	-----	1kg
Sodium cyanide	-----	500g
Sodium hydroxide	-----	500g
0.5 litre of zinc brighter	-----	0.5 litres
Distilled water	-----	2litres

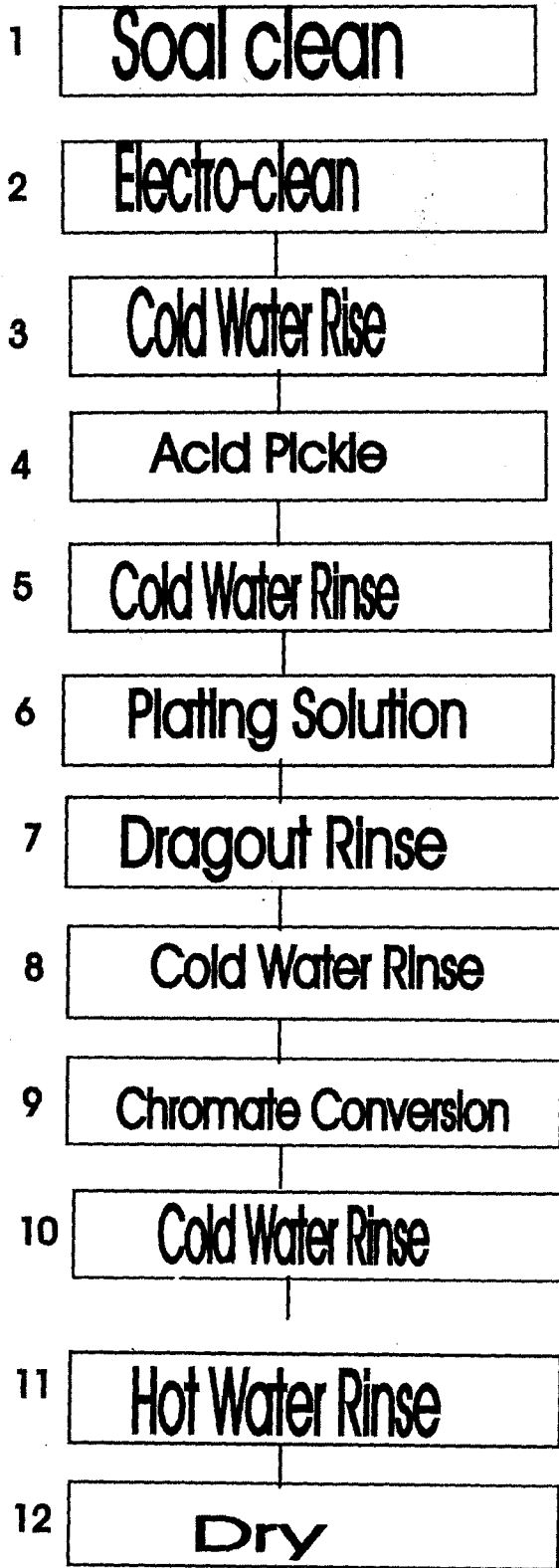
### 3.7 Post Treatment

The plated metal is passed through a clean water to remove some of the ions attached to the work piece, and their pass through mild solution of trioxonitrate acid. Thus helps the plated surfaces from wearing out easily. It finally pass through a yellow passivation mixed a few drops of tetraoxosulphate (vi) acid. The metal is then ready for drying in a dryer with a temperature range of 40-60<sup>0</sup>c for about 5 to 7 minutes.

Passivation concentration

Potassium chromate	-----	300g
H <sub>2</sub> SO <sub>4</sub>	-----	5.0ML
Distilled water	-----	1Litre

# ELECTROPLATING PROCESS FLOW SHEET





## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

The results obtained are tabulated, the voltage, time of plating and current are recorded. Also current density and physical appearances were obtained. Different in weight of the metals with there corresponding thickness were also recorded. The temperature is at room temperature and the P<sup>H</sup> of electrolyte is 9.0.

4.1.0, Table Values of y at 1.1V and 1.0A with different time interval

S/NO	Voltage x <sub>1</sub>	Time(mins)	Current AMP	Coloumb It x <sub>2</sub>	ACM <sup>-2</sup> Electric density	Initial wt (g)	Final wt (g)	Increase in wt (g)	Thickness Y (cm)	observation
1	1.1	5	1.0	5	0.53	11.5	11.60	0.100	7.32X10 <sup>-4</sup>	Yellow
2	1.1	7	1.0	7	0.53	11.4	11.54	0.140	9.50X10 <sup>-4</sup>	Brownish yellow
3	1.1	9	1.0	9	0.53	11.6	11.78	0.180	1.20X10 <sup>-3</sup>	Bright yellow

#### 4.1.1, Table Values of y at 1.2V and 1.3A with different time interval

S/NO	Voltage x <sub>1</sub>	Time(mins)	Current AMP	Coloumb It x <sub>2</sub>	ACM <sup>-2</sup> Electric density	Initial wt (g)	Final wt (g)	Increase in wt (g)	Thickness Y (cm)	observation
4	1.2	5	1.3	6.5	0.68	11.6	11.73	0.130	8.87x10 <sup>-4</sup>	Yellow
5	1.2	7	1.3	9.1	0.68	13.90	13.28	0.180	1.20x10 <sup>-3</sup>	Brownish yellow
6	1.2	9	1.3	11.7	0.68	11.5	11.75	0.230	1.57x10 <sup>-3</sup>	Bright yellow

#### 4.1.2, Table Values of y at 1.4V and 1.5A with different time interval

S/NO	Voltage x <sub>1</sub>	Time(mins)	Current AMP	Coloumb It x <sub>2</sub>	ACM <sup>-2</sup> Electric density	Initial lwt (g)	Final wt (g)	Increase in wt (g)	Thickness Y (cm)	observation
7	1.4	5	1.5	7.5	0.79	11.4	11.55	0.150	1.02x10 <sup>-3</sup>	Yellow
8	1.4	7	1.5	10.5	0.79	11.5	11.71	0.210	1.43x10 <sup>-3</sup>	Brownish yellow
9	1.4	9	1.5	13.5	0.79	13.10	13.37	0.270	1.84x10 <sup>-3</sup>	Bright yellow

4.1.3, Table Values of  $y$  at 1.8V and 2.0A with different time interval

S/NO	Voltage $x_1$	Time(mins)	Current AMP	Coloumb It $x_2$	ACM <sup>2</sup> Electric density	Initial wt (g)	Final wt (g)	Increase in wt (g)	Thickness Y (cm)	observation
10	1.8	5.0	2.0	16.0	1.10	11.14	11.60	0.200	$1.30 \times 10^{-3}$	Bright
11	1.8	7.0	2.0	14.0	1.10	11.4	11.68	0.280	$1.90 \times 10^{-3}$	Bright
12	1.8	9.0	2.0	18.0	1.10	11.4	11.76	0.360	$2.46 \times 10^{-3}$	Bright

4.1.4, Table Values of  $y$  at 2.0V and 2.3A with different time interval

S/NO	Voltage $x_1$	Time(mins)	Current AMP	Coloumb It $x_2$	ACM <sup>2</sup> Electric density	Initial wt (g)	Final wt (g)	Increase in wt (g)	Thickness Y (cm)	observation
13	2.0	5.0	2.3	11.5	1.20	11.5	11.73	0.230	$1.57 \times 10^{-3}$	Bright
14	2.0	7.0	2.3	16.1	1.20	11.6	11.92	0.320	$2.18 \times 10^{-3}$	Bright
15	2.0	9.0	2.3	20.7	1.20	11.5	11.92	0.420	$2.46 \times 10^{-3}$	Bright

4.1.5, Table Values of y at 2.2V and 2.5A with different time interval

S/NO	Voltage $x_1$	Time(mins)	Current AMP	Coloumb It $x_2$	ACM <sup>-2</sup> Electric density	Initial wt (g)	Final wt (g)	Increase in wt (g)	Thickness Y (cm)	Observation
16	2.2	5	2.5	12.5	1.30	11.4	11.65	0.250	$1.70 \times 10^{-3}$	Bright
17	2.2	7	2.5	17.5	1.30	11.5	11.85	0.350	$2.38 \times 10^{-3}$	Bright
18	2.2	9	2.5	22.5	1.30	11.5	11.95	0.450	$3.10 \times 10^{-3}$	Bright

4.1.6, Table Values of y at 3.0V and 2.8A with different time interval

S/NO	Voltage $x_1$	Time(mins)	Current AMP	Coloumb It= $x_2$	ACM <sup>-2</sup> Electric density	Initial wt (g)	Final wt (g)	Increas e in wt (g)	Thickness Y (cm)	Observati on
22	3.0	5.0	2.8	14.0	1.50	11.6	11.88	0.280	$1.91 \times 10^{-3}$	Yellow
23	3.0	7.0	2.8	19.6	1.50	11.5	11.90	0.400	$2.73 \times 10^{-3}$	Yellow
24	3.0	9.0	2.8	25.2	1.50	11.5	12.01	0.510	$3.49 \times 10^{-3}$	Yellow

4.1.7, Table Values of y at 3.5V and 3.0A with different time interval

S/NO	Voltage $x_1$	Time(m ins)	Curre nt AMP	Coloumb It= $x_2$	ACM <sup>-2</sup> Electric density	Initial wt (g)	Final wt (g)	Increas e in wt (g)	Thickness Y (cm)	Observati on
25	3.5	5.0	3.0	15	1.60	11.6	11.80	0.300	$2.91 \times 10^{-3}$	Yellow
26	3.5	7.0	3.0	21	1.60	11.6	12.02	0.420	$2.73 \times 10^{-3}$	Yellow
27	3.5	9.0	3.0	27	1.60	11.6	12.15	0.550	$3.49 \times 10^{-3}$	Yellow

## 4.2 Discussion of Results

In the experiment, the actual mass deposited or discharged at the cathodes are 0.100g, 0.140g, 0.108g, 0.130g, 0.180g, 0.230g, 0.150g, 0.210g, 0.270g, 0.200g, 0.280g, 0.360g, 0.230g, 0.320g, 0.420g, 0.250g, 0.350g, 0.450g, 0.270g, 0.380g, 0.490, 0.280, 0.400g, 0.510g, 0.300g, 0.420g, 0.550g, while the theoretical mass discharged are 0.1018g, 0.143g, 0.138g, 0.132g, 0.185g, 0.238g, 0.153g, 0.214g, 0.275g, 0.204, 0.285, 0.367g, 0.234 g, 0.328g, 0.422g 0.255g, 0.357 g, 0.458 g, 0.275g, 0.385g, 0.495g, 0.285g, 0.399g, 0.513g, 0.310g, 0.428 g, and 0.580g. These differences are the effect experimental such as inaccurate timing, improper agitation, etc. The mass of the deposited metal is directly proportional to the electricity supplied. The higher the quantity of the electricity the higher the deposited mass, for example, in table 4:1:0 the quantity of the electricity of 5, 7, and 9 coulomb has corresponding deposited mass of 0.100g, 0.140g and 0.180g respectively.

The thickness of the plated metal is also directly proportional to the deposited mass of the metal. The deposited masses of 0.100g, 0.140g, 0.108g, 0.130g, 0.180g, 0.230g, 0.150g, 0.210g, 0.270g, 0.200g, 0.280g, 0.360g, 0.230g, 0.320g, 0.420g, 0.250g, 0.350g, 0.450g, 0.270g, 0.380g, 0.490, 0.280, 0.400g, 0.510g, 0.300g, 0.420g, 0.550g, and its corresponding thickness of  $7.32 \times 10^{-4}$  cm,  $9.50 \times 10^{-4}$  cm,  $1.20 \times 10^{-3}$  cm,  $8.87 \times 10^{-4}$  cm,  $1.20 \times 10^{-3}$  cm,  $1.57 \times 10^{-3}$  cm,  $1.02 \times 10^{-3}$  cm,  $1.43 \times 10^{-3}$  cm,  $1.84 \times 10^{-3}$  cm,  $1.30 \times 10^{-3}$  cm,  $1.90 \times 10^{-3}$  cm,  $2.46 \times 10^{-3}$  cm,  $1.57 \times 10^{-3}$  cm,  $2.18 \times 10^{-3}$  cm,  $2.46 \times 10^{-3}$  cm,  $1.70 \times 10^{-3}$  cm,  $2.38 \times 10^{-3}$  cm,  $3.10 \times 10^{-3}$  cm,  $1.91 \times 10^{-3}$  cm,  $2.73 \times 10^{-3}$  cm,  $3.49 \times 10^{-3}$  cm,  $2.71 \times 10^{-3}$  cm,  $2.93 \times 10^{-3}$  cm, and  $3.49 \times 10^{-3}$  cm.

From the experiment, it is observed that the thickness of the plated metal increases, the appearance of the finished material becomes less brighter.

### **4.3 Effect of Electric Density in the Experiment**

In the experiment, rough surface of the base metal greatly reduced the expected current density. Activation and concentration polarization effect were observed to be directly dependent on the current density.

#### **4.3.1 Effect of impurities in the experiment**

Due to inaccurate information of pre-existing contamination such as inclusion in the base metal, cutting oils used and any organic or inorganic surface films, inadequate pre-treatment was given to the base metal which has effect on the metal finishing

#### **4.3.2 Effect of improper agitation in the experiment**

As a result of improper agitation of the electrolyte, there was excessive sludge built up, which affects the rate deposition to the base metal

#### **4.3.3 Effect of voltage in the experiment**

High voltage causes damage (burning) to the surface of the base metal; at voltage of 3.5volts, it was observed that coating of the base metal was not uniform, there was dark coloration at the surface of the metal. It was also observed as the voltage increases held constant, the thickness of the base metal decreases.

#### 4 Predicted Values of Y

S/NO	Voltage $eX_1$	Time (mins.)(t)	Current(AM P)T	Coloubr $It=X_2$	Electr ic Densi ty	Change In wt(g)	Thickness $Y_1$ (cm)	Observation
1	1.1	5	1.0	5	0.53	0.100	$7.80 \times 10^{-4}$	Yellow
2	1.1	7	1.0	7	0.53	0.140	$9.60 \times 10^{-4}$	Brownish yellow
3	1.1	9	1.0	9	0.53	0.180	$1.14 \times 10^{-3}$	Brownish yellow
4	1.2	5	1.3	6.5	0.68	0.130	$9.50 \times 10^{-4}$	Brownish yellow
5	1.2	7	1.3	9.7	0.65	0.180	$1.20 \times 10^{-3}$	Brownish yellow
6	1.2	9	1.3	11.7	0.68	0.230	$1.40 \times 10^{-3}$	Brownish yellow
7	1.4	5	1.5	7.5	0.79	0.150	$1.10 \times 10^{-3}$	Yellow
8	1.4	7	1.5	10.5	0.79	0.210	$1.40 \times 10^{-3}$	Yellow
9	1.4	9	1.5	13.5	0.79	0.270	$1.7 \times 10^{-3}$	Yellow
S/NO	Voltage $eX_1$	Time (mins.)(t)	Current(AM P)T	Coloubr $It=X_2$	Electr ic Densi ty	Change In wt(g)	Thickness $Y_1$ (cm)	Observation

					ty			
10	1.8	5	2.0	10.0	0.75	0.200	$1.50 \times 10^{-3}$	Bright
11	1.8	7	2.0	14.0	1.10	0.280	$1.80 \times 10^{-3}$	Brighter
12	1.8	9	2.0	18.0	1.10	0.360	$2.2 \times 10^{-3}$	Brighter
13	2.0	5	2.5	11.5	1.10	0.250	$1.70 \times 10^{-3}$	Brighter
14	2.0	7	2.5	16.1	1.30	0.350	$2.10 \times 10^{-3}$	Brightest
15	2.0	9	2.5	20.7	1.30	0.450	$2.51 \times 10^{-3}$	Brighter
16	2.2	5	2.7	12.5	1.30	0.270	$1.84 \times 10^{-3}$	Bright
17	2.2	7	2.7	17.5	1.40	0.380	$2.3 \times 10^{-3}$	Bright
18	2.2	9	2.7	22.5	1.40	0.490	$2.70 \times 10^{-3}$	Bright
19	2.6	5	2.8	13.5	1.40	0.280	$2.0 \times 10^{-3}$	Bright
20	2.6	7	2.7	18.9	1.40	0.300	$2.6 \times 10^{-3}$	Bright
<b>S/NO</b>	<b>Voltag eX<sub>1</sub></b>	<b>Time (mins.)(t)</b>	<b>Current(AM P)T</b>	<b>Coloum b It=X<sub>2</sub></b>	<b>Electr ic Densi ty</b>	<b>Change In wt(g)</b>	<b>Thickness Y<sub>1</sub> (cm)</b>	<b>Observation</b>
22	3.0	5	2.8	14.0	1.50	0.280	$2.2 \times 10^{-3}$	Yellow



23	3.0	7	2.8	19.6	1.50	0.400	$2.8 \times 10^{-3}$	Yellow
24	3.0	9	2.8	25.2	1.50	0.510	$3.3 \times 10^{-3}$	Yellow
25	3.5	5	3.0	15	1.60	0.300	$2.50 \times 10^{-3}$	Yellow
26	3.5	7	3.0	21	1.60	0.420	$3.0 \times 10^{-3}$	Yellow
27	3.5	9	3.0	27	1.60	0.550	$3.6 \times 10^{-3}$	Yellow

#### 4.5 Discussion of Predicting Equation

Polymath 5:1 is a chemical engineering software use for general statistical analysis, using the software a response linear equation was derived for the experimental results. This is achieved by using general procedure with the aid of computer and making  $X_1$  and  $X_2$  independent variables and  $Y_1$  the dependent variables, which gives a linear regression equation show below:

$$Y_1 = -4.754E-05 + 3.452E-04X_1 + 9.01E-05X_2$$

Substitution of  $X_1$  and  $X_2$  into the above linear equation will bring corresponding values of  $Y_1$  as shown in the table below

Comparing the two process equation, there is a high degree of consistency with their corresponding values and the experimental values of  $Y$ . It was observed that their differences were within acceptable limit with the variance is calculated to be  $1.055 E-04$ . This means that variance is close to zero. The correlation co-efficient is calculated to 0.95, which is very close to 1, thus this simply means that the mathematics model best represents the experimental data.

## CHAPTER FIVE

### 5.0 CONCLUSIONS AND RECOMMENDATION

#### 5.1 CONCLUSION

The aim of this project is to zinc plate metals so as to increase harden ability and prevent them against corrosion, wear and tarnishing, which will serves as a decorative and protective functions. Metals were plated at various time and voltage and thickness was obtained.

Unlike most other commonly plated metals, zinc protects the substrate by sacrificing itself and thus corrodes before the base metal; this means that zinc will protect even if the zinc coating sustains minor damage; hence it was concluded that zinc coating with bright appearance which was yellow or blue passivated is good for engineering applications and of great importance in chemical process industries.

Electroplating process can be well understood with good knowledge of electrolysis as presented in this project with emphasis on the laws and theories that govern electrolysis.

#### 5.2 RECOMMENDATION

Zinc is the most reactive of all common metals, it, may however be attacked or dissolved by ordinary liquids such as soft drinks or vinegar. The ultimate corrosion resistance of zinc is a function of the plating thickness. To increase the corrosion resistance of zinc plating, a conversion coating is usually added, hence yellow or blue passivation. Therefore this project can be recommended for industries where corrosion resistance is needed so as to reduce the cost of preventing corrosion, also is good for decoration of the products in an industries, this will make it more attractive and generally accepted.

## APPENDIX

1. Electric Density  $\Rightarrow \frac{\text{Current}}{\text{Geometric Area of the Electrode}}$
2. Current Efficiency  $\Rightarrow \frac{\text{Actual mass deposited}}{\text{Theoretical mass discharge}} \times 100\%$
3. Theoretical mass Discharge  $\Rightarrow M = \frac{Wit}{nf}$

Where w = molecular weight of element

I = current used

t = time of plating

n = valence of the atom

f = faraday.

### Thickness of the plated metal.

$$\text{Weight} = mg \Rightarrow PVg \Rightarrow \int Ahg$$

$$\Delta \text{weight} = \int_{fe} A.h.g$$

$$h = \frac{\Delta \text{weight}}{\int_{fe} A_{fe} g}$$

Where h = thickness

$\int_{fe}$  = Density of iron

$A_{fe}$  = Cross-sectional area of the base metal

g = Gravitational force

The multiple regression equation for predicting Y values from X and x<sub>2</sub> values is

$$= a + b_1 x_1 + b_2 x_2$$

$$\text{where } a = \bar{y} - b_1 \bar{x}_1 - b_2 \bar{x}_2$$

$$= y + b_1 (x_1 - \bar{x}_1) + b_2 (x_2 - \bar{x}_2)$$

$$= y + b_1 x_1 + b_2 x_2$$

then

$$b_1 = \frac{\Sigma (x_1 y) (\Sigma x_2^2) - \Sigma (x_2 y) (\Sigma x_1 x_2)}{(\Sigma x_1^2) (\Sigma x_2^2) - (\Sigma x_1 x_2)^2}$$

$$b_2 = \frac{\Sigma (x_2 y) (\Sigma x_1 y) (\Sigma x_1 x_2)}{(\Sigma x_1 x_2) (\Sigma x_2^2) - (\Sigma x_1 x_2)^2}$$

$$b_1 = \frac{(126.81 \times 10^{-3}) (6914.51) - (930 \times 10^{-3}) (876.76)}{(134.1) (6914.51) - (876.76)^2}$$

$$b_1 = 3.452 \times 10^{-4}$$

$$b_2 = \frac{(930 \times 10^{-3}) (134.1) - (126.81 \times 10^{-3}) (876.96)}{(134.1) (6914.51) - (876.76)^2}$$

$$b_1 = 3.452 \times 10^{-4}$$

$$b_2 = \frac{(930 \times 10^{-3}) (134.1) - (126.81 \times 10^{-3}) (876.96)}{(134.1) (6914.51) - (876.76)^2}$$

$$b_2 = 9.018 \times 10^{-5}$$

$$\text{Where } a = \bar{y} - b_1 \bar{x}_1 - b_2 \bar{x}_2$$

$$= 2.014 \times 10^{-3} - 3.452 \times 10^{-5} \times 2.09 - 9.018 \times 10^{-5} \times 14.86$$

$$a = -4.754$$

Valuable	X1	X2	Y	Mean
X1	134.1	876.76	$126.81 \times 10^{-3}$	2.09
X2		6914.59	$930 \times 10^{-3}$	14.86
Y			$1237 \times 10^{-4}$	$2.014 \times 10^{-3}$

S/N	X <sub>1</sub>	X <sub>1</sub>	X <sub>1</sub> <sup>2</sup>	X <sub>2</sub> <sup>2</sup>	X <sub>1</sub> X <sub>2</sub>	Xy	X <sub>2</sub> y	Y <sup>2</sup>
	1.1	5.0	1.21	25.00	5.50	$7.50 \times 10^{-4}$	$3.41 \times 10^{-3}$	$4.65 \times 10^{-7}$
	1.1	7.0	1.21	49.00	7.70	$1.05 \times 10^{-3}$	$6.65 \times 10^{-3}$	$9.03 \times 10^{-7}$
	1.1	9.0	1.21	81.00	9.90	$1.32 \times 10^{-3}$	$10.8 \times 10^{-3}$	$1.44 \times 10^{-6}$
	1.2	6.5	1.44	42.25	7.80	$1.06 \times 10^{-3}$	$5.77 \times 10^{-3}$	$7.87 \times 10^{-7}$
	1.2	9.1	1.44	82.81	10.92	$1.44 \times 10^{-3}$	$10.92 \times 10^{-3}$	$1.44 \times 10^{-6}$
	1.2	11.7	1.44	136.89	14.02	$1.88 \times 10^{-3}$	$18.37 \times 10^{-3}$	$2.47 \times 10^{-6}$
	1.4	7.5	1.96	56.25	10.50	$1.48 \times 10^{-3}$	$7.65 \times 10^{-3}$	$1.04 \times 10^{-6}$
	1.4	10.5	1.96	110.25	14.70	$2.00 \times 10^{-3}$	$15.02 \times 10^{-3}$	$2.05 \times 10^{-6}$
	1.4	13.5	1.96	182.25	18.90	$2.58 \times 10^{-3}$	$24.84 \times 10^{-3}$	$3.39 \times 10^{-6}$
0	1.8	10.0	3.24	100.00	18.00	$2.34 \times 10^{-3}$	$13.00 \times 10^{-3}$	$1.69 \times 10^{-6}$
1	1.8	14.0	3.24	196.00	25.00	$3.42 \times 10^{-3}$	$26.60 \times 10^{-3}$	$3.61 \times 10^{-6}$
2	1.8	18.0	3.24	324.00	32.40	$4.43 \times 10^{-3}$	$44.28 \times 10^{-3}$	$6.05 \times 10^{-6}$
3	2.0	11.5	4.00	132.25	23.00	$3.14 \times 10^{-3}$	$18.06 \times 10^{-3}$	$2.43 \times 10^{-6}$
4	2.0	16.1	4.00	259.21	32.20	$4.36 \times 10^{-3}$	$35.10 \times 10^{-3}$	$4.75 \times 10^{-6}$
5	2.0	20.7	4.00	428.49	41.40	$4.92 \times 10^{-3}$	$50.92 \times 10^{-3}$	$6.05 \times 10^{-6}$
6	2.2	12.5	4.84	156.25	27.50	$3.74 \times 10^{-3}$	$21.52 \times 10^{-3}$	$2.89 \times 10^{-6}$
7	2.2	17.5	4.84	306.25	38.50	$5.23 \times 10^{-3}$	$41.65 \times 10^{-3}$	$5.66 \times 10^{-6}$

18	2.2	22.5	4.84	506.25	49.50	$6.82 \times 10^{-3}$	$69.75 \times 10^{-3}$	$9.61 \times 10^{-6}$
19	2.6	13.5	6.74	182.25	35.00	$4.78 \times 10^{-3}$	$24.84 \times 10^{-3}$	$3.39 \times 10^{-6}$
20	2.6	18.5	6.74	357.27	49.14	$6.73 \times 10^{-3}$	$48.95 \times 10^{-3}$	$6.71 \times 10^{-6}$
21	2.6	24.3	6.74	590.49	63.18	$8.68 \times 10^{-3}$	$81.16 \times 10^{-3}$	$1.12 \times 10^{-6}$
22	3.0	14.0	9.00	196.00	42.00	$5.73 \times 10^{-3}$	$26.74 \times 10^{-3}$	$3.65 \times 10^{-6}$
23	3.0	19.6	9.00	384.16	58.80	$8.19 \times 10^{-3}$	$53.51 \times 10^{-3}$	$7.45 \times 10^{-6}$
24	3.0	25.2	9.00	635.04	75.60	$10.47 \times 10^{-3}$	$87.95 \times 10^{-3}$	$12.18 \times 10^{-6}$
25	3.5	15.0	12.25	225.00	52.50	$7.18 \times 10^{-3}$	$30.75 \times 10^{-3}$	$4.20 \times 10^{-6}$
26	3.5	21.0	12.25	441.00	73.50	$10.01 \times 10^{-3}$	$60.05 \times 10^{-3}$	$8.18 \times 10^{-6}$
27	3.5	27.0	12.25	729.00	93.50	$13.13 \times 10^{-3}$	$10.25 \times 10^{-3}$	$14.06 \times 10^{-6}$
$\Sigma$	56.4	401.1	134.10	6914.59	876.76	$126.81 \times 10^{-3}$	$130.10^{-3}$	$1.237 \times 10^{-4}$

## REFERENCES

- American Society of Quality Control (1990) "Metal Handbook" volume 2, Heat Treating, Cleaning and Finishing McGraw-Hill book company, New York, USA 6<sup>th</sup> Edition.
- Ankerem E. N. (1993) "Introduction to Electroplating and Quality Control" Pg 1-3 Third edition.
- Encarta M. A. (1998) "Electroplating and Allied products" McGraw-Hill book company, New York, USA 2nd edition. Pg 17, 24-28.
- Graham (A. Kenneth Graham) (1978) "Electroplating Engineering Handbook" Third Edition, Van Nostrand Reinhold (VNR) production London Pg 66-68, 190-191.
- J.J Moore Chemical Metallurgy Reed educational and professional publishing limited. Melbourne Newelh Singapore. 2<sup>nd</sup> Edition Pg 221-224.
- Leslie W. Flott "Quality Control in Electroplating" Pg 55 and 57.6<sup>th</sup> edition.
- M. M. Uppal A (1988) "Textbook for Engineering Chemistry". For engineering student KHANNA Publishers, India (pg. 558 and 564)
- Philip Matthews Advanced Chemistry Cambridge University press London low priced edition. Pg 408-410.
- Raymond Chang: Physical chemistry and its application, Macmillan publishing Co. Inc. New York second edition. Pp 214 - 278
- Sedick Folashade Medinat (Dec. 2000) "Nickel Plating of Metals". Department of Chemical Engineering, FUT Minna.
- W. Kann & F. N. Spon "The Canning Handbook, Surface Finishing Technology Chemical Metals Electronic". 23<sup>rd</sup> edition. London Macmillan publishing co., Inc. New York. Pg 272 – 273, 293-320, 661-320 and 707-708.

## GLOSSARY OF ELECTROPLATING

Activation: Elimination of a passive condition on a surface.

Adhesion: (1) the attractive force that exists between an electrodeposits and its substrate.

(2) The force required separating electrodeposits from its substrate.

Alloy: A substance having metallic properties composed of two or more elements of which at least one is a metal

Anion: Anion, which is negatively charged.

Anode: The electrode at which current enters or electrons leaves the solution; the positive electrode in electrolysis, the electrode at which negative ions are discharged, positive ions are formed, or at which other oxidizing reactions occur.

Anodizing: Anodic treatment of metals, particularly aluminium to form an oxide film of controlled properties.

Brightener: An addition agent, which leads to the formation of a bright plate; or which improves the brightness of the deposit over that which is obtained without its use.

Cathode: The electrode through which current leaves, or electrode in electrolysis. The electrodes at which positive ions are discharged, negative ions are formed, or other reducing reactions occur. In electroplating, the electrode which receives the deposit.

Chemical pickling: The surface layer is removed from metal by chemical pickling.

Cleaning: The removal of grease in which a current is passed through the solution, the work being one other electrode.

Solvent; Cleaning by means of organic solvents.

Coating: A protective layers.

Corrosion: (1) Gradual destruction of a material usually by solution. Oxidation or other means attributable to a chemical process.

(2)(Of anodes in plating) solution of anode metal by the electrochemical action in the plating cell.

Degreasing: The removal of grease and oils from a surface by using solvent.

Drag-In: The water of solution that adheres to the objects introduced into a bath. Drag-out: The solution that adheres to the objects removed from a bath.

Electrode: A conductor of the metallic class through which a current enters or leaves arm

electrolytic cell; at which there is a change from conduction by electrons to conduction by particles of matter, or vice versa