

**DESIGN AND CONSTRUCTION OF AN ELECTROPLATING  
MACHINE**

**BY**

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**2005/21989EE**

**A THESIS SUBMITTED TO THE DEPARTMENT OF  
ELECTRICAL ELECTRONICS ENGINEERING**

**FEDERAL UNIVERSITY OF TECHNOLOGY**

**MINNA**

**NOVEMBER 2010**

## **DEDICATION**

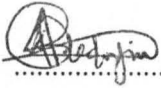
This project work is dedicated to God Almighty, who has brought me up to this point, I'm indeed very grateful.

## DECLARATION

I, Adedoyin Adekunle declare that this work was done by me under the supervision of Prof Oria Usifo and has never been presented elsewhere for the award of a degree and is submitted to Electrical Electronics Engineering Department, Federal university of technology, Minna in partial fulfilment of the requirements for the award of Bachelor of Engineering (B. Eng.) Degree in Electrical and Computer Engineering.

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ADEDOYIN ADEKUNLE O.

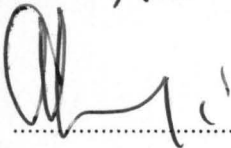
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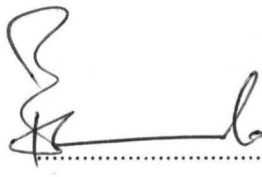
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## ACKNOWLEDGEMENT

My profound appreciation goes to the Almighty God for his continual help and mercies throughout my stay in this institution.

I am grateful to my Parents, Mr and Mrs S.K Adedoyin, and my Siblings for all of their support all these years.

Many thanks to my Supervisor, Prof Oria Usifo for his counsel and patience, and more importantly, his fatherly guidance in the pursuit of this project, Also my Laboratory technologist and guide, Mallam Doko, thank you sir for your advice and constructive criticism.

Mallam Idris of SEDI-M was without a doubt a great help for which I'm eternally grateful.

Finally, may I express my gratitude to my friends, Joshua, Toyin, Sogo, Victoria and Ibukun just to mention a few, thanks for all of your contributions. God bless you all.



## ABSTRACT

This project work deals with the design and construction of an electroplating machine. It shows the use of coating of metals to make them stronger and more appealing to the eyes, lists some of the various systems which can be used and particularly expatiates on one of them, Zinc Plating for which the machine has been constructed.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 WHAT IS ELECTROPLATING?

**Electroplating** (often just called "plating") is the deposition of a metal coating onto an object by putting a negative charge on it and putting it into a solution which contains a metal salt. The metal salt contains positively charged metal ions which are attracted to the negatively charged object and are "reduced" to metallic form upon it. We can also define it as an electrochemical process for depositing a thin layer of metal on, usually, a metallic base. Objects are electroplated to prevent corrosion, to obtain a hard surface and or attractive finish, to purify metals (as in the electro-refining of copper), to separate metals for quantitative analysis, or, as in electrotyping, to reproduce a form from a mould, or provide thickness on undersized parts. Zinc, Cadmium, chromium, copper, gold, nickel, silver, and tin are the metals most often used in plating.

#### 1.2 HISTORY

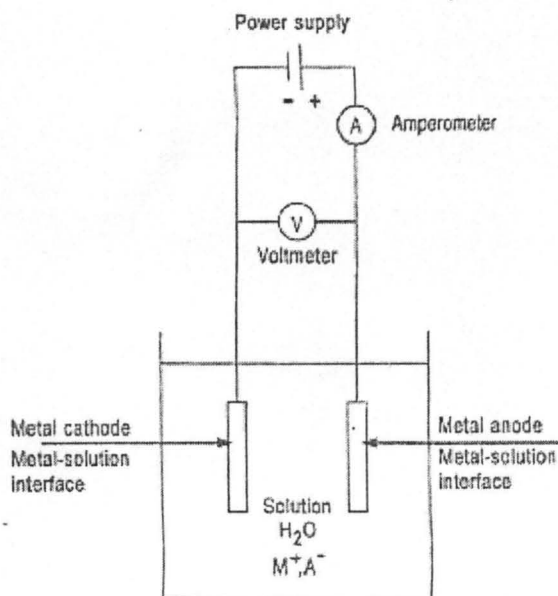
Before continuing with more detailed discussion of the subject at hand, a brief history of electroplating will be presented. The early history of electroplating may be traced back to around 1800. A university professor, or in modern terms: a chemist, Luigi Brugnatelli is considered as the first person to apply electrodeposition process to electroplate gold. Brugnatelli was a friend of Alessandro Volta (after whom the electric unit "volt" has been named) who had just a short time before discovered the chemical principles that would make possible the development of "voltaic" electrical cells. Volta's first actual demonstration of that was called "Voltaic Pile". As a consequence of this development, Brugnatelli's early work using voltaic electricity enabled him to experiment with various plating solutions. By

1805 he had refined his process enough to plate a fine layer of gold over large silver metal objects.

Unfortunately for Brugnatelli, a disagreement or falling out with the French Academy of Sciences, the leading scientific body of Europe at the time, prevented Brugnatelli's work from being published in the scientific journals of his day. His work remained largely unknown outside of his native Italy except for a small group of associates. By 1839, however, scientist in Britain as well as in Russia had independently devised metal deposition processes similar to those of Brugnatelli's for copper electroplating of printing press plates. By 1840, this discovery was adapted and refined by Henry and George Elkington of Birmingham, England for gold and silver plating. Collaborating with their partner John Wright and using formulae developed by the latter for potassium cyanide plating baths, the Elkingtons were able to have the first viable patents for gold and silver electroplating issued on their name. From Great Britain the electroplating process for gold and silver quickly spread throughout the rest of Europe and later to the United States.

Electroplating is often also called "electrodeposition", and the two terms are used interchangeably. As a matter of fact, "electroplating" can be considered to occur by the process of electrodeposition. Electrodeposition is the process of producing a coating, usually metallic, on a surface by the action of electric current. The deposition of a metallic coating onto an object is achieved by putting a negative charge on the object to be coated and immersing it into a solution which contains a salt of the metal to be deposited (in other words, the object to be plated is made the cathode of an electrolytic cell). The metallic ions of the salt carry a positive charge and are thus attracted to the object. When they reach the negatively charged object (that is to be electroplated), it provides electrons to reduce the positively charged ions to metallic form. Figure 1 is a schematic presentation of an

electrolytic cell for electroplating a metal "M" from an aqueous (water) solution of metal salt



"MA".

*Fig 1. Schematics of an electrolytic cell for plating metal "M" from a solution of the metal salt "MA".*

To further illustrate the foregoing, let us assume that we have an object made of one of the common metals, like copper, and that it has been properly pre-cleaned ( to remove impurities which may hamper the electroplating process). We should want to plate it with, say, nickel. A wire will have to be attached to the copper object while the other end of the wire should be attached to the negative pole of a battery (or a power supply). To the positive pole of the battery (or power supply) we connect another wire with its other end connected to a rod made of, as much as possible, pure nickel. Next we fill the cell with a solution of the metal salt to be plated which is Nickel Chloride (NiCl<sub>2</sub>), it is possible to use a molten salt and in some not so common cases, such as the deposition of tungsten, that is what is done. In more common cases though, the salt is simply dissolved in water. In our present example the nickel chloride salt dissociates in water to positively charged nickel cat ions and negatively charged chloride anions. As the object to be plated is negatively charged it attracts the positively charged nickel cations, and electrons flow from the object to the cations to neutralize them (to reduce

them) to metallic form. Meanwhile the negatively charged chloride anions are attracted to the positively charged nickel rod (known as the anode of the electrolytic cell). At the anode electrons are removed from the nickel metal, oxidizing it to the nickel cations. Thus we see that the nickel dissolves as ions into the solution. That is how replacement nickel is supplied to the solution for that which has been plated out and one retains a solution of nickel chloride in the cell.

Electroplating has, over recent decades, evolved from an art to an exact science. This development is seen as responsible for the ever-increasing number and widening types of applications of this branch of practical science and engineering. Some of the technological areas in which means and methods of electroplating constitute an essential component are all aspects of electronics: macro and micro-optics, and sensors of most types, to name only a few. In addition a number of key industries such as the automobile industry (that uses for example chrome plating to enhance the corrosion resistance of metal parts) adopt the methods even where other methods, such as evaporation, sputtering, chemical vapour deposition (CVD) and the like are an option. That is so for reasons of economy and convenience. By way of illustration it should be noted that that modern electroplating equips the practitioner with the ability to pre-design the properties of surfaces and in the case of electroforming those of the whole part. Furthermore, the ability to deposit very thin layers (less than a millionth of a cm) via electroplating represents yet a new avenue of producing new materials. Today, with the impressive progress and deeper understanding of the underlying electrochemical principles of electrodeposition, sophisticated plating baths formulae have been developed and are being routinely employed. Those provide much greater control over the working characteristics of the deposition process than hitherto. Layer thickness, performance of electroplated finishes is among the attributes that have been brought under strict control. New developments enable greater plating speed, better throwing power (the



ability of a plating solution to produce a relatively uniform distribution of metal upon a cathode of irregular shape), as well as reliable plated finishes. In addition, electroplating of materials such as platinum, osmium, and ruthenium are now broadly used in electronics for connectors, circuit boards, contacts etc. It is believed that new and innovative electroplating technology will facilitate the rapid expansion of the telecommunication industry. In general, the growth of the electronics industry as a whole, and the demand to support the expansion of its underlying infrastructure will continue to drive improvements worldwide in the electrodeposition/electroplating industry.

There has been a recent upsurge of interest in electrodeposition due to three main factors/technologies:

1. Metal deposition for the fabrication of integrated circuits: Integrated circuits are quickly forming the 'brain' of most appliances used in homes today. Devices such as rice cooker, air conditioners all make use of microcomputers whose main components are integrated circuits.
2. Deposition of magnetic recording devices (heads, discs): A speedily growing sector (or possibly the fastest growing), the information and telecommunications sector which provide goods and services for all classes of people will be greatly hindered without the use of recording devices. This is another technology that has increased interest in electroplating.
3. Deposition of multilayer structures: In general structure, electroplating also form a major backbone, in fact, from door handles to the staircase handles etc. are all evidence of the value of the electroplating process.

By way of illustration we mention here that electrodeposition of copper for integrated circuit fabrication has been successfully used since 1997 for the production of interconnection lines down to less than 0.02 microns (micron = one millionth of a meter) width.



## 1.1 AIMS AND OBJECTIVES

As a way of continuing the explanations stated above, the primary aim of constructing an electroplating machine for Zinc plating in this particular case (the designs vary depending on the coating material) is to provide a steady and organised structure for the process rather than getting a beaker and a couple of wires every time the process is required. This is in recognition of the fact that electroplating is gaining more popularity as the days go by due to the fact that virtually all equipments for general use have one part or the other that requires electroplating and with the level of demand and its urgency, the electroplating machine is a precise solution.

Another objective of this particular project which comes across as an advantage, is to provide a reasonably smaller version of what is available in the big industries such that it can be used to educational purposes, and furnishing the laboratories with handy utility instead of travelling several miles of distance to coat a small material.

## 1.2 Methodology

The machine structure includes a bath which forms the container of the electrolyte which is the liquid salt of the material which is to be coated, the anode is a pure or almost pure metal of the coating material and the cathode is the metal on which the coating is to be done. The cathode and anode are plugged into an electric source. Several plating methods however, require, accordingly various designs since they have different components that make them up, therefore, the type of electroplating machine for this group is that of Zinc. This choice is inspired by the facts that Zinc is cheaper and more available, making a Zinc plating machine is also easier as it requires less components than others. A major factor that played in this choice is that Zinc plating occurs at room temperature therefore it can be used in almost any

environment. In other electroplating processes such as Nickel plating, there is a heater in the bath and Ions are transferred and deposited on the cathode as the heating continues.

## 2.0 LITERATURE REVIEW

Foray into the manufacture of electroplating machines however have not prospered as much as the chemical process in itself. It would seem that there is so much interest in the product of the process than its schematics and engineering, hence there are very few literature that actually extensively shed light on the production of the machines. The particular machine designed for the purpose of this project is a Zinc Plating bath.

## 2.1 ZINC PLATING

Zinc plating was chosen because it is an industrial process that utilizes either a solely chemical reaction or a combination of a chemical reaction or an electrical current in order to deposit a thin coating of Zinc onto a metal part. As a commonly used metallic element, Zinc (Zn) (also referred to as spelter) is very chemically similar to the element magnesium (Mg). Less dense than iron, Zinc features blue-white colour that is naturally lustrous, but is typically fairly dull in commercial and industrial applications. Zinc is a commonly alloyed metal, specifically with metals such as aluminium, copper, nickel, tin, magnesium, cobalt, gold, iron, lead and many more. Since Zinc can be alloyed with so many different metals, it is able to be used in a diverse range of applications requiring varying characteristics in industries such as: hardware, for the plating of various parts and components such as nuts, bolts and screws; automotive, in the plating of safety features such as fuel caps, seat belt components and brake shoes; construction, to plate small parts such as roofing screws to larger building materials such as storm doors; marine, for the plating of sheet metal used in the construction of carriers and other shipping vessels; and industrial manufacturing, to plate machinery, parts and components in order to increase their life span.

Zinc is typically plated through an electrolytic plating process, but can also be plated using electroless methods such as mechanical plating and galvanization. In an electrolytic plating process, the parts requiring plating are immersed in a bath of chemical solution, typically a zinc-salt solution, and then an electrical current is applied in order to achieve deposition of a thin layer of pure or alloyed zinc (depending on what type of zinc is used in the bath solution) onto the metal part. A cold process i.e. it does not require heating, the mechanical plating of zinc involves placing the components to be plated into a tumbling barrel that also contains zinc dust, which will then adhere to the part during tumbling. However, since the zinc is mechanically-adhered to the part rather than chemically-bonded, there may be some flaking due to the weaker bond.

It is important to state here that Zinc can also be 'electroless' plated using the galvanization process, which is a hot working process. In galvanization, the metal part is immersed, or "dipped" as it is often called industrially, into a molten bath of zinc in order to form a zinc coating onto the part. Stronger than the mechanically-formed bond, this type of coating is the result of a metallurgical bond and is a comparatively much stronger bond but since the project requires the electroplating method.

## **2.2 TYPES OF ZINC PLATING**

However, there are papers and journals which have been presented all around the world concerning some parts of the process concerning the types of Zinc plating. We have

- I. Acid Chloride Zinc plating
- II. Alkaline Cyanide Zinc plating
- III. Alkaline Non-Cyanide Zinc plating

### 2.2.1 Acid Chloride Zinc Plating

According to Erwin and Flannigan (paper presented on products finishing, 2000) Acid chloride zinc plating has a long and varied history. The first zinc electroplating baths were acidic and based upon zinc sulphate. The deposits from these first baths were dull and flat gray. Acid zinc plating technology has come a long way in its almost 200 years of existence.

Acid zinc plating systems have several advantages over alkaline cyanide and alkaline non-cyanide zinc plating systems including:

- Less waste treatment, since no cyanide treatment is required and no chelating agents are used;
- Deposits with outstanding brightness that rival nickel chromium in their lustre;
- High cathode efficiencies, 90 to 95 per cent, at normal operating current densities;
- Plates difficult substrates such as castings and carbo-nitrated pieces, which can be plated directly without any special pre-treatment;
- Excellent levelling;
- Substantially less hydrogen embrittlement than cyanide and non-cyanide processes; and compared to alkaline systems.

Acid zinc plating has some disadvantages however, for example, the electrolyte is extremely corrosive. Any solution that becomes entrapped in crimped or spot-welded areas can eventually bleed out and discolour or corrode the part. Because the plating solution is so corrosive, special tank construction and equipment designed to withstand the corrosive nature of the solution are required.

The surface preparation of parts can cause problems as well. Improper cleaning and/or pickling can lead to serious problems. Other disadvantages include the loss of ductility with thick deposits and the need for continuous filtration to remove iron from the solution.

- **Ammonium Chloride Zinc Plating.**

The ammonium chloride bath is the most forgiving of the three major types of acid zinc plating because of its wide operating parameters. The primary drawback of this system is the high level of ammonia, which can cause problems in wastewater treatment. Ammonia acts as a chelator, and if the rinse waters are not segregated from other waste streams, removal of metals to acceptable levels using standard water treatment practices can be difficult and expensive. Ammonia is also regulated in many communities.

- **Potassium Chloride Zinc Plating.**

Potassium chloride zinc plating solutions are attractive because they contain no ammonia. The disadvantages of this system are a greater tendency to burn on extreme edges and higher operating costs. The potassium bath also requires the use of relatively expensive boric acid to buffer the solution and prevent burning in the high-current-density areas, functions performed by the ammonium chloride in the other systems.

- **Mixed Ammonium Chloride/Potassium Chloride Zinc Plating.**

This bath combines the best of the ammonia and ammonia-free baths. Because potassium chloride is less expensive than ammonium chloride, the maintenance costs of the mixed bath are lower than the ammonia bath, and it does not require boric acid. The ammonia levels in the rinse waters are low enough that it does not significantly interfere with wastewater treatment, even if plating nickel and copper in the same plant with mixed waste streams. If local regulations restrict the level of ammonia discharged, special waste treatment equipment will be required, and the non-ammonia bath is most likely the best choice.

### **2.2.2 Alkaline Cyanide Zinc Plating**

Due to the fact that Alkaline Cyanide plating is quickly becoming an obsolete method, just a brief overview might suffice. The reasons for a change from this method are not farfetched. Cyanide's drawbacks are quite numerous. Waste treatment and cleanup are a constant problem and expenses, dangerous fumes produced also require costly venting. The cyanide



plating lines need close monitoring because their concentration, temperature and current density all operate within a narrow range. Therefore, the industry moved onto a newer method.

### **2.2.3 Alkaline Non-Cyanide (Or Cyanide Free) Zinc Plating**

Holland and Harrick (2003) presenting a paper in Columbia submitted that with the never-ending environmental pressures that are being placed on industry, there is a worldwide push to move away from cyanide zinc and into alkaline cyanide-free zinc plating. Alkaline cyanide-free zinc deposits have very unique characteristics that lend themselves well as a base coating for paint and powder applications.

Work on the first alkaline cyanide-free zinc plating systems began in the early 1960s when waste treatment requirements became stringent. This was the beginning of the push to eliminate cyanide zinc plating. Many processes were introduced into the market but did not prove to be viable plating processes. In the last forty some years, technology has come a long way and alkaline cyanide-free zinc plating has become a very large part of the zinc plating market. There are still some problems with alkaline cyanide-free zinc plating, such as the inability to effectively plate heat-treated fasteners and high-carbon steels. Alkaline cyanide-free processes can plate these types of parts but additional steps in the pre-treatment or cleaning stages of processing need to be taken.

The composition of an alkaline cyanide-free zinc plating bath is very simple. It consists simply of zinc ions and caustic soda. Preparation of steel parts for alkaline cyanide-free zinc plating requires a simple three-stage cleaning cycle prior to entering the plating bath. The first stage is a hot caustic soda soak tank, followed by a caustic electrocleaner.

The final pre-plate process is a hydrochloric or sulphuric pickle. It is important to note that any work entering the alkaline cyanide-free plating tank must be completely free of all oils.

Parts that are not properly cleaned can cause blistering of the zinc plate.

#### **2.2.4 Differences between Alkaline Cyanide-Free Zinc and Acid Chloride Zinc Plating Solutions.**

The most noticeable difference is the chemical makeup costs for the two. An alkaline system is far less costly than acid-based systems. Acquisition and maintenance of equipment are also more economically favourable for an alkaline cyanide-free zinc system. This is due primarily to the fact that an acid chloride solution will readily attack steel tanks and superstructures unless they are lined with a resistant material. The copper bussing can also be susceptible to an attack, which has the potential to cause conductivity issues. Alkaline cyanide-free zinc systems are relatively inert when in contact with tanks or other steel components.

When comparing these two systems we must also consider maintenance of the bath itself. Acid chloride solutions have a tendency to accumulate precipitates of ferrous iron, which must be continuously filtered from the plating bath. It is also possible to build up high levels of soluble ferric iron that must be treated with an oxidizing agent to facilitate its filtration. Alkaline cyanide free zinc solutions do not encounter these problems with iron but the zinc metal content must be monitored continuously to prevent it from falling outside of the limited operational range.

The efficiencies of these two systems can be described as good for alkaline cyanide-free zinc and excellent for chloride zinc. The alkaline cyanide-free zinc solution has an efficiency range of 40%-90% depending greatly on the zinc metal content. The conductivity of the hydroxide electrolyte is considerably less than that of the highly conductive chloride electrolytes. This explains the high cathode efficiency in acid chloride zinc solutions that can range from 95%-98%. This high efficiency can lead to shorter plating times and, in turn, increased productivity.



There are two basic deposit structures formed during zinc electroplating, laminar and columnar. Both the laminar and columnar zinc deposits have different effects on the appearance, physical properties of the chromate such as colour, thickness and adhesion, and on formation and adhesion of topcoats.

The alkaline cyanide-free zinc deposit is columnar in structure with a vertical orientation to the substrate containing a multitude of micro peaks and valleys. This columnar structure increases the overall surface area, lending significantly more area for the paint to collect and adhere. Since the grain refinement of this deposit is porous, it is an ideal finish for paint adhesion. With acid chloride zinc plating, the deposit is laminar in structure with a horizontal orientation to the substrate. This provides a tightly, overlaid electrodeposit with smooth grain refinement. The acid chloride zinc deposit is described as being nickel-chrome like in appearance with extremely deep brightness and having a smooth and level surface. This deposit tends to produce a truer clear, blue chromate finish (less yellowing than alkaline cyanide free) due to chromate film thickness and formation. There is also a greater tendency for chromate rub-off and problems with paint adhesion than with the alkaline cyanide-free deposit.

Although acceptable for paint adhesion, this deposit lacks the porosity of alkaline cyanide-free zinc. The low cost and exceptional corrosion resistance properties of zinc make zinc electrodeposits a very attractive finish for paint and powder coating. Of the three types of zinc plating available, the alkaline cyanide-free zinc deposit —especially the satin finish — provides an ideal base for these applications. Not only is it the most economical, but the columnar structure and porous grain refinement of this deposit provides optimum surface conditions for enhanced adhesion of the paint and powder. The superb plate distribution properties of alkaline cyanide-free zinc plating, allows it to plate deep into low-current density recesses without over plating the outside. In addition, the electrolyte is very simple to make up and operate on a day-to-day basis. Overall, the performance and financial benefits of

alkaline cyanide-free satin zinc make it an ideal base coating deposit for paint and powder coat applications.

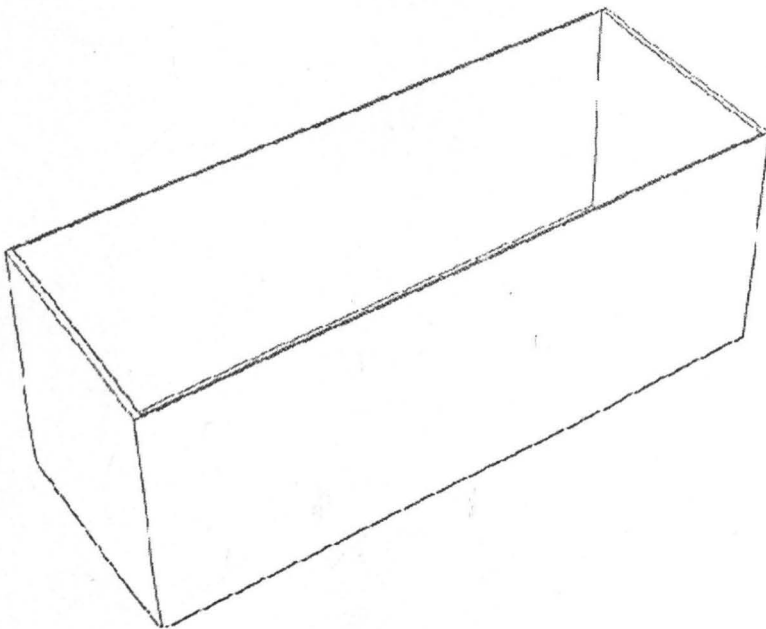
### 2.3 Machine Components

The components of the machine are listed and explained below.

#### 2.3.1 BATH:

The bath for the proposed Zinc plating is to be made of plastic or Pyrex glass of fairly thick surface to prevent as much as possible leak of the electrolyte (Zinc Chloride) from within.

A plastic material is any of a wide range of synthetic or semi-synthetic organic amorphous solids used in the manufacture of industrial products. Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce costs. The word plastic is derived from the Greek plastikos)



*Fig 2. Bath*

meaning capable of being shaped or moulded. It refers to their malleability or plasticity during manufacture, which allows them to be cast, pressed, or extruded into a variety of shapes—such as films, fibres, plates, tubes, bottles, boxes, and much more. The common word plastic should not be confused with the technical adjective plastic, which is applied to any material which undergoes a permanent change of shape (plastic deformation) when strained beyond a certain point. Aluminium which is stamped or forged, for instance, exhibits plasticity in this sense, but is not plastic in the common sense; in contrast, in their finished forms, some plastics will break before deforming and therefore are not plastic in the technical sense. There are two types of plastics: thermoplastics and thermosetting polymers. Thermoplastics will soften and melt if enough heat is applied; examples are polyethylene, polystyrene, polyvinyl chloride and polytetrafluoroethylene (PTFE). Thermosets can melt and take shape once; after they have solidified, they stay solid. Plastics can be also classified based on qualities that are relevant for manufacturing or product design. Examples of such classes are the thermoplastic and thermoset, elastomer, structural, biodegradable, and electrically conductive. Plastics can also be classified by various physical properties, such as density, tensile strength, glass transition temperature, and resistance to various chemical products.

Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships. They have already displaced many traditional materials, such as wood; stone; horn and bone; leather; paper; metal; glass; and ceramic, in most of their former uses. Plastics are durable and degrade very slowly; the molecular bonds that make plastic so durable make it equally resistant to natural processes of degradation which is what particularly makes it relevant to the project as it is highly resistant to action by the electrolyte if any at all unlike metals which could be reduced chemically through contact with the salt. Another suitable

material is Pyrex glass. Pyrex glass is a borosilicate glass. It is made by heating raw materials like silica sand and boric oxide to extremely high temperatures for extended periods of time. The molten material is then processed into different types of glassware. First formulated during the early twentieth century, Pyrex has become an important material for a variety of applications that require heat and chemical resistance.

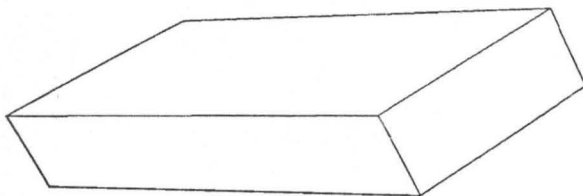
To understand how Pyrex is unique it is important to understand the nature of glass itself. Glass is a state of matter that has characteristics similar to both crystalline solids and liquids. On a macroscopic level glass appears to be like solids. It is rigid and remains in one piece when removed from a container. However, on a molecular level, glasses are more like liquids. In crystalline solids, molecules are arranged in an orderly fashion. In liquids they are randomly arranged. This random arrangement is also a characteristic of glass.

Glass is typically made by heating crystalline compounds to temperatures high enough to melt them. Melting breaks the ordered molecular structure, leaving them in a disordered state. When the melted material is cooled, the molecules become locked in place before they can reform in the ordered crystalline structure. The properties of a specific glass such as hardness, brittleness, clarity, and chemical and thermal resistance are dependent on its chemical composition.

When Pyrex was being developed, scientists were trying to create a glass composition that had a high thermal resistance. At some point it was discovered that glass compositions with boron could be heated to high temperatures without breaking. Boron, which is the fifth element on the periodic chart, has the unique ability to create a variety of chemical bonds. When bonded with oxygen it can create a three dimensional structure that is strong. In a glass composition, this extra strength gives it thermal and chemical resistance that makes it useful for cooking applications, thermometers, and laboratory equipment. Pyrex also has a low alkali content that gives it high corrosion resistance.

The bath shall also be mechanically strong enough for the battery, ammeter and voltmeter to be attached to it without causing imbalance or loss of shape; this is in order to prevent clumsiness when transporting it. Also the shape of the bath shall be one with which easy measurement of the quantity of the electrolyte can be taken, because volume of electrolyte is an important factor in process, thus the use of a cubic bath for which estimating the capacity can be done using the length, breadth and height dimensions. (Cylinders may also be used depending on whichever is more comfortable). If a basin with irregular shape is used, the measurement is difficult and this makes the work more cumbersome.

### 2.3.2 ANODE



*Fig 3. Anode*

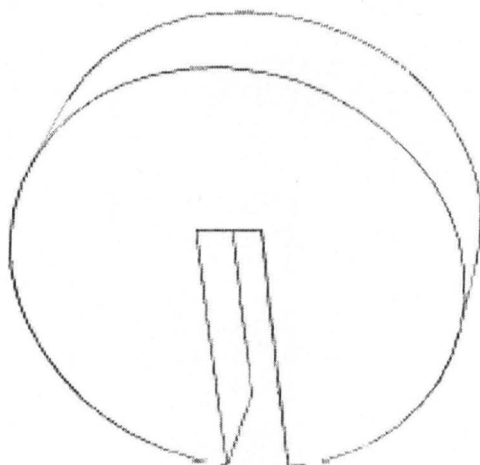
This is the pure or almost pure solid metal of the coating material whose salt is the electrolyte and since the coating material in this context is zinc, a Zinc bar is used and serves as the anode which is the positive electrode of the electrolytic cell and is wholly immersed in the electrolyte to guarantee optimum transfer of ions. Zinc is a bluish-white metal, which, if mechanically polished, or electrodeposited with appropriate brighteners, somewhat resembles chromium in appearance. However, the reflectivity of the polished surface is soon lost in most atmospheres. This quick tarnishing and corroding, is the property that makes zinc

plating work so well in providing "sacrificial" protection for metals. The relatively low cost, protective nature and attractive appearance of zinc plating make it a popular coating for nuts, bolts, washers, metal stampings, and automotive components, fabricated parts for industrial applications, and also serves as an effective undercoat for paints. This concept of sacrificial anode is explained thus. A sacrificial anode, or sacrificial rod, is a metallic anode used in cathodic protection where it is intended to be dissolved to protect other metallic components. The more active metal is more easily oxidized than the protected metal and corrodes first (hence the term "sacrificial"); it generally must oxidize nearly completely before the less active metal will corrode, thus acting as a barrier against corrosion for the protected metal. For example when zinc and iron are electrically connected in the electrolyte, the zinc will lose electrons and go into solution as zinc cations. Electrons released from the zinc atoms flow through metallic conduction to the iron where, on the surface, dissolved oxygen is reduced, by gaining the electrons released by the zinc.

### **2.3.3 CATHODE:**

The cathode is the negative electrode of the electrolytic cell and this is the metallic material to be coated. Copper shall be used here and also totally dipped into the electrolyte for maximum and as much as possible, uniform coating throughout its surface. To obtain uniform plating, it is important to ensure that the geometry of the cathode material, copper in this instance, is uniform as the thickness of the coating is very much dependent on the geometry of the object being plated, and it is preferentially on the external corners and protrusions of the metal body, hence not much of it is deposited on internal corners and recesses. The cathode should also be cleaned of impurities before immersion to prevent reactions. This shall be further treated in the next chapter.





*Fig 4. Cathode*

#### **2.3.4 ELECTROLYTE**

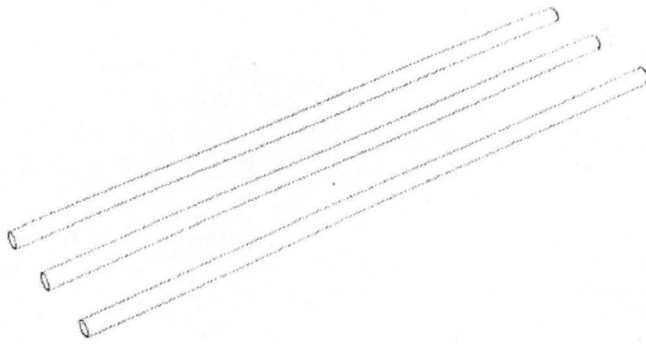
An electrolyte is any substance containing free ions that make the substance electrically conductive. The most typical electrolyte is an ionic solution, but molten electrolytes and solid electrolytes are also possible. Electrolytes commonly exist as solutions of acids, bases or salts. Furthermore, some gases may act as electrolytes under conditions of high temperature or low pressure. Electrolyte solutions can also result from the dissolution of some biological (e.g., DNA, polypeptides) and synthetic polymers (e.g., polystyrene sulfonate), termed polyelectrolytes, which contain charged functional group. Electrolyte solutions are normally formed when a salt is placed into a solvent such as water and the individual components dissociate due to the thermodynamic interactions between solvent and solute molecules, in a process called solvation. An electrolyte in a solution may be described as concentrated if it has a high concentration of ions, or dilute if it has a low concentration. If a high proportion of the solute dissociates to form free ions, the electrolyte is strong; if most of the solute does not

dissociate, the electrolyte is weak. The properties of electrolytes may be exploited using electrolysis to extract constituent elements and compounds contained within the solution. This essentially is the liquid salt of the metal of the anode one of which is Zinc Chloride; there exists several salts of Zinc e.g. Zinc phosphate, Zinc Sulphate, Zinc acetate but Zinc Chloride is easily available, not displaced from its salt by copper and provides desired lustre. It contains metallic salts and additives. Zinc chloride is the name of chemical compound with the formula  $ZnCl_2$  and its hydrates. Zinc chlorides, of which nine crystalline forms are known, are colourless or white and highly soluble in water.  $ZnCl_2$  itself is hygroscopic and even deliquescent. It also should be in a particularly specified and calculated quantity to achieve desired results. Anything below or above prescribed range of values may produce unwanted results causing wastage of efforts and materials. When electrodes are placed in an electrolyte and a voltage is applied, the electrolyte will conduct electricity. Lone electrons normally cannot pass through the electrolyte; instead, a chemical reaction occurs at the cathode consuming electrons from the anode, and another reaction occurs at the anode producing electrons to be taken up by the cathode. As a result, a negative charge cloud develops in the electrolyte around the cathode, and a positive charge develops around the anode. The ions in the electrolyte move to neutralize these charges so that the reactions can continue and the electrons can keep flowing.

### **2.3.5 BUSBARS**

Bus bars are the metal 'transmission' lines onto which the anode and the cathode are connected and linked to the source of power for the machine system called the electrifier. This is because it is not technically correct to attach the anode and cathode directly from inside of the electrolyte to the electrifier's terminals, therefore two metal bars are connected, separately, to the terminals instead. The anode and cathode then draw the current from the bus bars which are passed over the electrolyte and anchored on the bath.



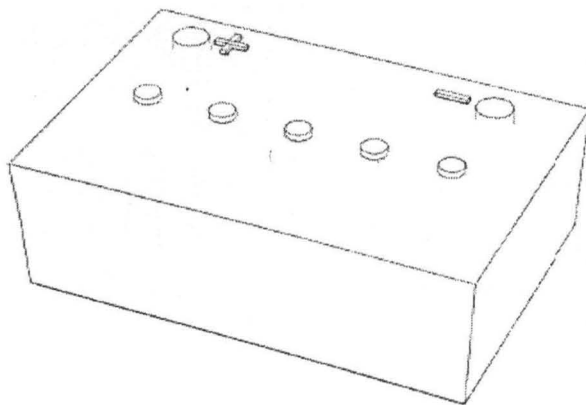


*Fig 5. Busbars*

### **2.3.6 POWER SOURCE**

This is the source of electrical power and a battery is used in the case of this precise project. Without the battery or more accurately put, the power source, there can be no transfer of ions which means no plating can take place since there is nothing that will drive the system( which is basically two half cells consisting of the electrodes and electrolyte) i.e. no current flows, no discharge happens and no coating take place. Each half-cell has a characteristic voltage. Different choices of substances for each half-cell give different potential differences. Each reaction is undergoing an equilibrium reaction between different oxidation states of the ions—when equilibrium is reached the cell cannot provide further voltage. In the half-cell which is undergoing oxidation, the closer the equilibrium lies to the ion/atom with the more positive oxidation state the more potential this reaction will provide. Similarly, in the reduction reaction, the further the equilibrium lies to the ion/atom with the more negative oxidation state the higher the potential. The cell potential can be predicted through the use of electrode potentials (the voltages of each half-cell). The difference in voltage between

electrode potentials gives a prediction for the potential measured. Cell potentials have a possible range of about zero to 6 volts. Cells using water-based electrolytes are usually limited to cell potentials less than about 2.5 volts, because the very powerful oxidizing and reducing agents which would be required to produce a higher cell potential tend to react with



the water

*Fig 6 Power Source*

## CHAPTER 3

### DESIGN AND CONSTRUCTION

#### 3.0 DESIGN

As have been enumerated earlier, the entire machine is contained in the bath made of Pyrex glass with the following dimensions;

Length = 30cm,

Breadth = 20cm

Height = 20cm

Total volume capacity of  $30\text{cm} \times 20\text{cm} \times 20\text{cm} = 12,000\text{cm}^3 = 12$  litres

As shown by the design image below, it will not be filled to capacity so as to allow space, hence, the electrolyte will fill up to 16cm of height. It should be noted that these conductors are ones which have low resistance in order not to distort the calculations required for optimum deposition but before the actual deposition takes place, there are some processes required to obtain desired effect.

Also to note, as stated earlier, low potential is needed for electroplating to take place, and with the low potential is an accordingly low current of about 100milliamps per square inch, therefore, to take for instance, a cathode of surface area 10square inches, 1 amp is what will be required for coating to take place with a corresponding voltage of 1.5v.

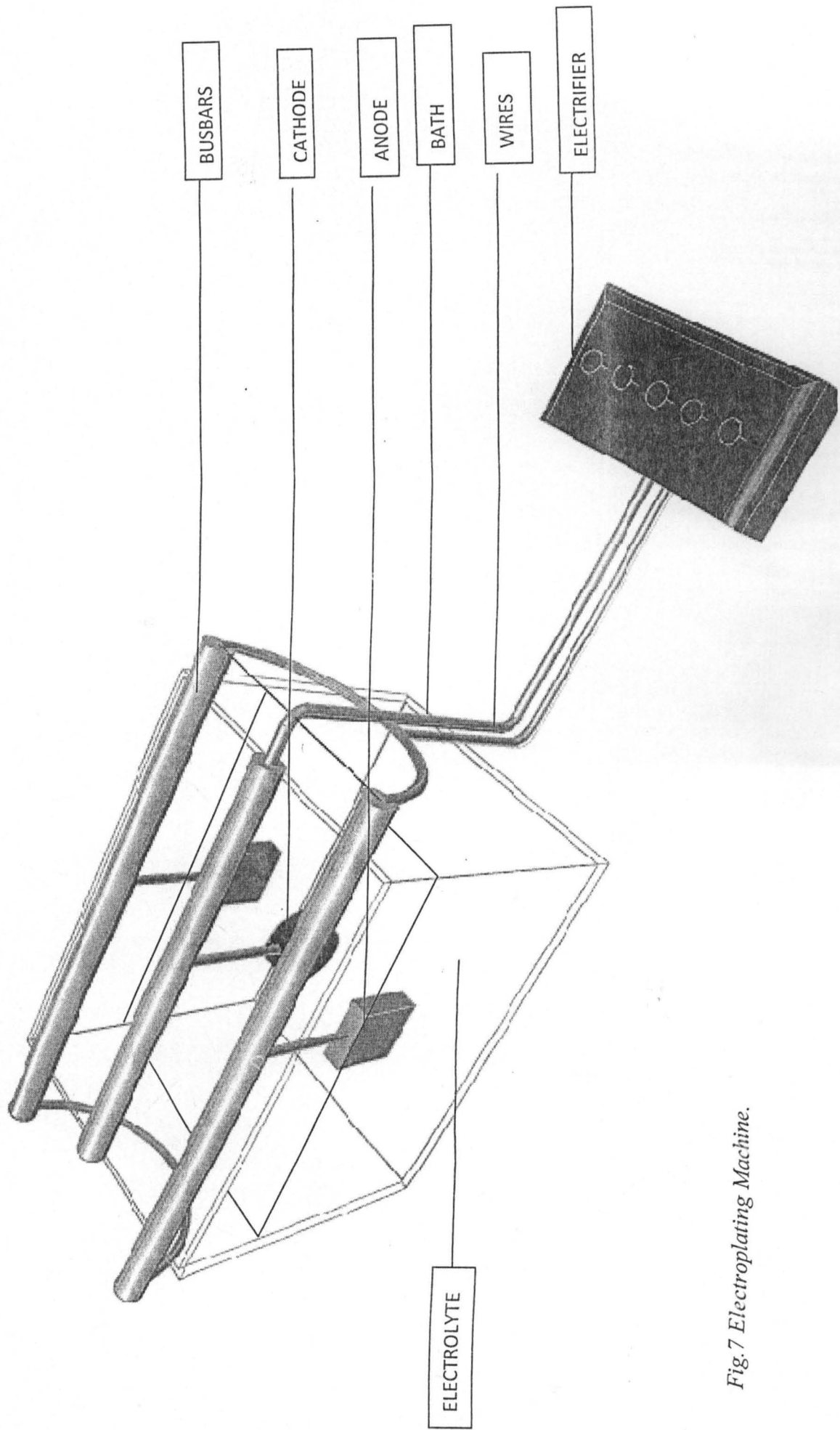
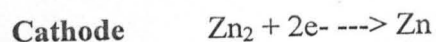
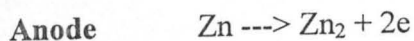


Fig.7 Electroplating Machine.

The equations for the electrochemical reactions at the anode and cathode are as follows:



The principle of operation is explained by Faraday's first law of electrolysis.

**The mass of the substance liberated or deposited on an electrode during electrolysis is directly proportional to the quantity of electric charge passed through the electrolyte.**

If  $m$  is the mass of a substance liberated or deposited at an electrode due to the passage of charge  $q$ , then according to Faraday's law of electrolysis,

$$m \propto q \quad \text{or} \quad m = z \times q$$

Where  $z$  is a constant of proportionality and is called electrochemical equivalent of the substance. It has the same charge which passes is due to a steady current  $I$  flowing for time  $t$ ,

The above equation can be written as;

$$m = z \times I \times t$$

$$= z \times q$$

if  $q = 1C$ , then  $m = z$

where  $m$  = mass deposited

$I$  = Flowing Current ( Amperes)

Hence electrochemical equivalent of a substance is the mass of the substance liberated or deposited in electrolysis by the passage of 1 coulomb of charge.

### 3.1 Surface preparation

It is commonly accepted and often quoted by electroplaters that one can make a poor coating perform with excellent pre-treatment, but one cannot make an excellent coating perform with poor pre-treatment. Surface pre-treatment by chemical and/or mechanical means is important not only in the case of preparations for electroplating but is also required in preparation for painting. In either of these, methods are designed to ensure good adhesion of the coating or paint to the surface. Most (metal) surface treatment and plating operations have three basic steps.

1. Surface cleaning or preparation. Surface of the metal is cleaned in alkaline detergent type solutions (Sodium hydroxide, Caustic Soda may be used), and it is treated with acid (Hydrochloric Acid in this case) in order to remove any rust or surface scales. Cleanliness is essential for successful zinc electroplating, as the molecular layers of oil or rust can prevent adhesion of the coating. Usually this includes employing of solvents, alkaline cleaners, acid cleaners, abrasive materials and/or water.
2. Surface modification. Surface modification is the act of modifying the surface of a material by bringing physical, chemical or biological characteristics different from the ones originally found on the surface of a material. This modification is usually made to solid materials, but it is possible to find examples of the modification to the surface of specific liquids. The modification can be done by different methods with a view to altering a wide range of characteristics of the surface, such as: roughness, hydrophilicity, surface charge, surface energy, biocompatibility and reactivity and this includes change in surface attributes, such as application of (metal) layer(s) and/or hardening.

3. Rinsing or other work-piece finishing operations to produce/obtain the final product.

Surface cleaning or preparation will be discussed in more detail. Success of electroplating or surface conversion depends on removing contaminants and films from the substrate. Organic and non-metallic films interfere with bonding by causing poor adhesion and even preventing deposition. The surface contamination can be extrinsic, comprised of organic debris and mineral dust from the environment or preceding processes. It can also be intrinsic, one example being a native oxide layer. Cleaning methods are designed to minimize substrate damage while removing the film or debris. If a (metal) surface's chemistry and processing history are known, one can anticipate cleaning needs and methods. In practice, extrinsic organic and inorganic soils originate with processing of the substrate before plating, as well as from the environment. Specific residues include lubricants, phosphate coating, quenching oils, rust-proofing oils, drawing compounds, and stamping lubricants. In short, the mixture of potential contaminants to which a part is exposed is typically complex. Again in case of a metal substrate it must be remembered that all metals form oxide and inorganic films to a degree with environmental gases and chemicals. Some of these are protective against continuing attack such as the aluminium oxide formed on aluminium. That phenomenon is the reason of the usefulness of aluminium siding on some homes. On the other hand, some are non-protective, such as iron oxide on steel. Some of these films can even be plated directly with nickel over aluminium oxide over aluminium being an example. The cleaning and activation steps must account for the fact that surface oxide re-forms at different rates on different metals. Specifically, in case of iron or nickel the oxide re-forms slowly enough that the part can be transferred from a cleaning solution to a plating bath at a normal rate. In case of aluminium or magnesium the oxide re-forms very fast such that special processing steps are required to preserve the metal surface while it is being transferred to electroplating. Cleaning processes are based on two approaches. In physical cleaning, mechanical energy is



introduced to release both extrinsic and intrinsic contaminants from the (metal) surface. Examples are ultrasonic agitation and brush abrasion. In chemical cleaning contaminant films are removed by active materials, dissolved or emulsified in the cleaning solution. Extrinsic contaminants are removed with surface-active chemicals while the chemical energies involved are modest. Intrinsic films are removed with aggressive chemicals that dissolve the contaminant and often react with the surface (metal) itself. The energy involved in surface preparation is substantial.

### 3.3 Deposition

By now it should be evident that electrodeposition or electroplating should be defined as the process in which the deposit of a (usually) thin layer (of metal) is formed "electrolytically" upon a substrate (that is often, but not always, also a metal).

From the above it would appear that the thickness of the electroplated layer on the substrate is determined by the time duration of the plating. In other words, the longer time the object remains in the operating plating bath the thicker the resulting electroplated layer will be. Typically, layer thicknesses may vary from 0.1 to 30 microns (micron = one millionth of a meter), though nothing prevents the deposition of thicker or thinner layers, as desired. The geometric shape and contour of an object to be plated affects the thickness of the deposited layer. In general, objects with sharp corners and features will tend to have thicker deposits on the outside corners and thinner ones in the recessed areas. The cause of this difference in the resulting layer thicknesses is that dc current flows more densely to sharp edges than to the less accessible recessed areas, in other words, the current distribution is not uniform. (Another, more accurate, explanation of this phenomenon involves the geometry of the electric field lines that exist between cathode and anode in the solution). In practice, an item such as, say, a watch or similar item with sharp faceted corners are difficult (almost impossible, actually) to plate uniformly. A plating method known as "electroless plating",



assures uniformity of plated thickness even on highly irregular shaped objects. In the case of electroplating, judicious placement of the anode(s) as well as modifications of the current density are required to overcome the thickness irregularity effects. Electroplating processes will not, as a rule, conceal pre-existing surface imperfections such as scratches, dents or pits. Actually, the plating process will more often than not, make most surface blemishes even more pronounced. Thus it is important to remove any undesirable surface marks prior to the plating action.

Now, the electrochemical process which occurs in the deposition of a single metal has been known and utilized empirically for more than a century. In this case, it is not particularly necessary to examine the details of the mechanism and all the different (and numerous) parameters that would affect the process (and are outside the scope of this project) but still a brief intricate description shall be offered.

$ZnCl_2$  salt ionizes in the electrolyte into  $Zn^{++}$  ions and two parts of  $Cl^-$  ions. Because the object to be plated is negatively charged (by being connected to the negative pole of the battery and having electrons pumped to it), it attracts the positively charged  $Zn^{++}$  ions that are floating around in the solution. These  $Zn^{++}$  ions reach the object, and electrons flow from the object to the  $Zn^{++}$  ions. For each ion of  $Zn^{++}$ , 2 electrons are required to neutralize its positive charge and "reduce" it to an atom of  $Zn^0$  metal. Thus, the amount of metal that deposits is directly proportional to the number of electrons that the battery provides which is a demonstration of Faraday's first law of electrolysis which states that **"the quantity of a substance produced by electrolysis is proportional to the quantity of electricity used."**

## CHAPTER 4

### Results and Discussion

#### 4.0 Results

The resulting material coated has a bright finishing throughout its surface after about 25 minutes of immersion and electron transfer. The cathode is retrieved from the bath by unwinding its connecting wires from its bus bars. When this is done, it is immersed in a 'recovery tank'. A recovery tank is a container filled with clean water sufficient enough to submerge the cathode, it acts as a rinser and removes any loose coats, if material has parts which have not been properly coated, it is returned to the bath for more deposition else, the cathode is immersed into a the part is immersed in the final rinse for 30 seconds. The purpose of this rinse is simply to dilute the chemicals from the plating bath. The final rinse is done in distilled water. Distilled water is used to ensure maximum purity.

What is noticed after all these is that as predicted, the cathode has the colour and some of the properties of the Zinc

#### 4.1 Colorants

For industrial/ commercial purposes more lustre may be desired, hence the use of colorants. For Zinc, there are basically two colorants used, the blue and the yellow passivation although the blue is most common and more available. The coated material is immersed in the colorant for 5 minutes and the colour adheres to the material and brings forth a fine glitter.

#### 4.2 Drying

When it is brought out, there is a final process to be done before the material can be put into whatever use it was originally designed for. This process is called drying.

moisture and the separation of pieces prevents spot rusting. Another form of drying is to put the coated material in an industrial drier which blows air against it to remove the moisture.

As the zinc dries, it will form a bond with the steel so that there is actually a transition point between the two materials. This means that the zinc cannot be peeled off. It is integrated right into the part. After a couple of days, the zinc will change into zinc oxide, this is good because it gives extra protection, about twice as much, to the part. After even more time, this will change into zinc carbonate, which adds even more protection, so the part will stay in good shape for a long time.

## **CHAPTER 5**

### **Conclusion**

#### **5.0 Conclusion**

Someone was remarked that 'All that Glitters is not Gold', a saying which is often interpreted as a metaphor, however technology available shows today that the same saying could be interpreted literally. Some of the things that glitter can be Zinc or better still, Zinc plated.

At the risk of placing excessive emphasis, I wish to state that Zinc plating and Electroplating in general remains a viable yet uncultivated industry and means of mass employment if properly exploited. I hereby want to submit that in light of the aforementioned points, electroplating methods represent a very attractive alternative to the hitherto conventional fabrication methods.

#### **5.2 Recommendations**

I would also like to recommend that a proposal be made to all levels of government in Nigeria to seek skilled professionals in this field and invest money and resources into it.

The fact remains that most of what is imported to the country can be produced by the country, just a little skill building and application is required.

#### **5.3 Anticipated Areas of Advancement**

It is naturally expected that as time passes, the design of this particular machine may become obsolete or inadequate for the purposes for which it is required therefore I anticipate and hope that very soon, there will be replacement for liquid salts and other substances which are

sometimes dangerous for human contact to bring about quicker and manufacturing methods and processes to help in wastewater recycling reduction and work place exposure to dangerous chemicals and waste by-products.. To illustrate the possible directions of progress, I will like to mention the need for further refinement and control of dc power supplies. Such progress should lead to further achievements in the electroplating and metal finishing industry.

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