CHAPTER 1

INTRODUCTION

1.1 Background study

The piping system is important to all plant/platform operation. Because it looks very simple it is sometimes overlooked. However, if the piping system does not properly operate or failed, a plant/platform will shutdown. Every plant/platform has large and small piping systems. These systems have many different uses in a plant/platform. All fluids and gases in a plant/platform are transferred using piping systems. The piping systems includes pipe, pipe fittings to control the direction of flow and valves to control the amount of flow. The size of the pipe, pipe fittings and valves will vary depending on the different processes. The material used to make up the piping system depends on the type fluids or gases being carried by the system. The piping system in a plant/platform carry hot water and cold water, crude oil, refined products, chemicals, gases and fluids at various temperature, pressure and flow rates. All parts of a piping system must be properly inspected and maintained. The loss of a single piping system in one part of plant/platform may cause the shutdown of the processes. Simply, the main functions of a piping system are:

i. To contain, control, transport and transfer liquid or gas within the plant or platform.

ii. To transport, sales and transfer finished product to the storage facilities.

1.2 Problem Statement

The hot water piping system in Resak LQ consists of copper tubes and brazed type fittings with all the lines are insulated with aluminium cladding. Tubing is a pipe which has thin wall. It is made of metal or plastic. The type of tubing used will depend on the application it is being used for. Tubing is thin walled and is used in various areas in a plant. However, it is mainly used for the following:

- Instrument air lines
- Temporary lines
- Hydraulic lines

Copper tubes are used for plumbing, heating, cooling, gas and steam lines. It can be buried underground as well as in the open air. Thicker walled copper tubing can be used in high temperature application. In the platform the copper tubing is set up above the ceiling and is used for heating purpose. The OD (Outer Diameter) of the copper tubes used is 50mm. Copper tubes are used extensively in hot water distribution due to their corrosion resistance and ease of installation.

Corrosion is the breakdown or deterioration of substances because of a chemical reaction with its environment. The substance does not necessarily have to be a metal to corrode. Weld, ceramic, plastic and other materials also corrode. If a material corrodes its properties will change and the material will fail. All metals corrode in different way and at different rates. Some environment is more corrosive than others. There is always exception but generally true that:

- No corrosion occur in vacuum
- Salt water is more corrosive than fresh water
- Hot water is more corrosive than cold water
- Hot air more corrosive than cold air

For this project, the corrosion occur that lead to the tubes leaking is due to the dezincification effect of the galvanic action on the zinc silver fillers from the brazed fitting against the copper material.

1.3 Objective and Scope of Study

The objective of this project is to do Failure Analysis on the hot water piping system at Resak Living Quarter (LQ). The Failure Analysis processes conducted in this project is the macroscopic examination which involved the surface examination of the sample under optical microscope and the examination of microstructure of the sample under SEM (Scanning Electron Microscope). The XRF Analysis also is conducted to support the result. Data and result will be collected and further analysis will be conducted using these results to find the cause of this failure. The scope of the study focused on the microstructure analysis of the sample and how to interpret data collected from the experiment and analysis. This hot water piping system is made from copper and has been used since year 2000. All the lines are insulated with aluminium cladding to maintain the temperature of the water within the pipe. Due to the long time service, there some leaking occurs at the tube and most of the leaks are located at the distribution line along the corridor. The header and main line is still in good condition. From the survey, the leaks are due to the pitting occurring mainly at the joints.

CHAPTER 2

LITERATURE REVIEW

2.1 Failure Analysis Procedure

Non-Destructive Testing

The primary objective of nondestructive testing is to detect both surface and internal cracks and discontinuities. This NDT involved each one from the process stated:

- Magnetic Particle Inspection Test
- Liquid Dye Penetrant Test
- Eddy Current Test
- Radiography

Mechanical Testing

Various tests have been devised to reveal the mechanical properties of material under two main types of loading conditions, namely,

i. Static Loading (Tension, compression, hardness and creep test)
ii. Dynamic Loading (can be classified into impact load and fatigue load)

Charpy impact test is devised to measure the resistance of materials to such loads.

Macroscopic Examination

Macrostructure characterization at small magnifications, e.g., 10 x, can provide further information about the fracture path and the location from which it was originated, e.g., internal surface or external surface.

Microscopic Examination

Selection of the proper technique for microstructural characterization is dependent upon the type of information required. However, it is always recommended to begin with light optical microscopy or scanning electron microscopy to characterize the overall microstructure features.

In examining the microstructure, particular attention must be given to such features as grain size and shape, secondary precipitates and their distribution, microcracks and their location.

Chemical Analysis

According to the volume of material analyzed, it is possible to classify those techniques into two main types:

- Techniques for bulk chemical analysis, where the entire volume of a bulk specimen is analyzed
- Techniques for microchemical analysis, where a selected micro feature of a specimen is analyzed. These techniques are typically combined with microscopy technique, particularly scanning, transmission, and scanning transmission electron microscopy.

Stress Analysis

From the knowledge of service conditions such as applied loads or pressure, and geometry and size of the component, it is possible to calculate the principal stresses developed in the part. Comparing the maximum principal stress with the strength of the material used in the application provides important information about the suitability of the material for the application and whether the design parameters were strictly followed during service.

Fracture Mechanics

Analysis using the principles of fracture mechanics provides valuable information about the stress developed in the failed component at the time of fracture in relation to the design stress, particularly in the case of crack propagation by a brittle mechanism. The outcome of this analysis determines the next course of action in the investigation.

Failure Analysis Reports

Documentation of a failure analysis study in a detailed report is not only useful in providing a solution to a specific problem, information contained in the report can also be used to settle legal claims. If such information is made available to designers, it can be extremely helpful in selecting proper materials, minimizing or preventing future incidents of failure.

2.2 Copper Tubes in Water Heater Application

2.2.1 Material

The material for this copper tube shall be of such quality and purity that the finished product shall have the properties and characteristics prescribed in ASTM B-88 (Refer Appendix II), and shall be cold drawn to size.

2.2.2 Manufacture

This copper tube shall be finished by such cold-working and annealing operations are necessary to produce the required temper and surface finish. This copper tube which is furnished in straight length shall normally be in the drawn temper. (Refer Appendix II)

2.2.3 Joining Method

The joining method for this copper tube is soldering method. Solders used for joining this copper tube are covered by specification B 32. (Refer Appendix III)

2.3 Typical Corrosion in Copper Tube

2.3.1 Pitting Corrosion

There are many forms of corrosion, but pitting corrosion is most likely to culminate in pinhole leaks in copper plumbing. Pitting corrosion is the non-uniform localized attack of the wall of copper tube, pipe, or fittings initiated on the interior/waterside surface in the domestic water distribution system, in which only small areas of the metal surface are attacked, while the remainder is largely unaffected. Pitting corrosion starts on metal surfaces for unknown reasons, and some combinations of water chemistry factors allow the process to continue while some do not. Pitting corrosion can be classified into three types:

Type I pitting is associated with hard or moderately hard waters with a pH between 7 and 7.8, and it is most likely to occur in cold water. The pitting is deep and narrow, and results in pipe failure.

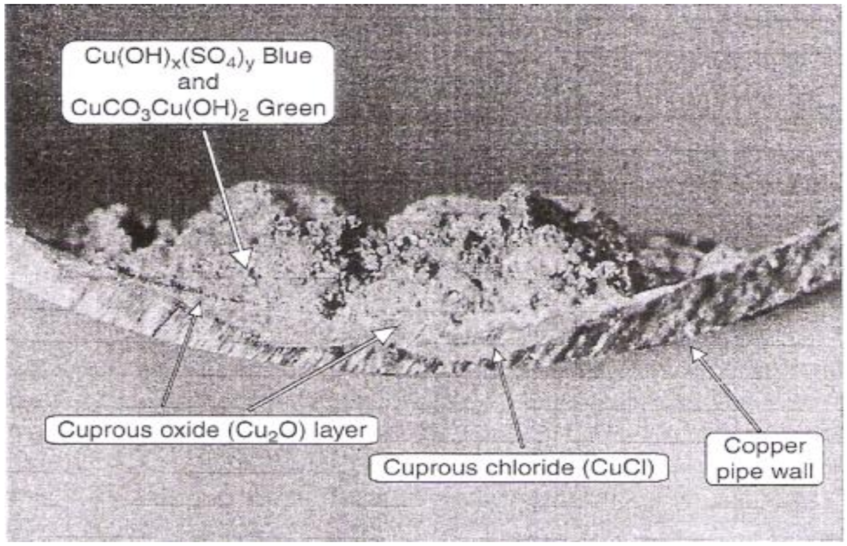


Figure 2.1 Type I copper pitting corrosion[4].

Type II pitting occurs only in certain soft waters, with a pH below 7.2 and occurs rarely in temperatures below 140° F. The pitting that occurs is narrower than in Type I, but still results in pipe failure.

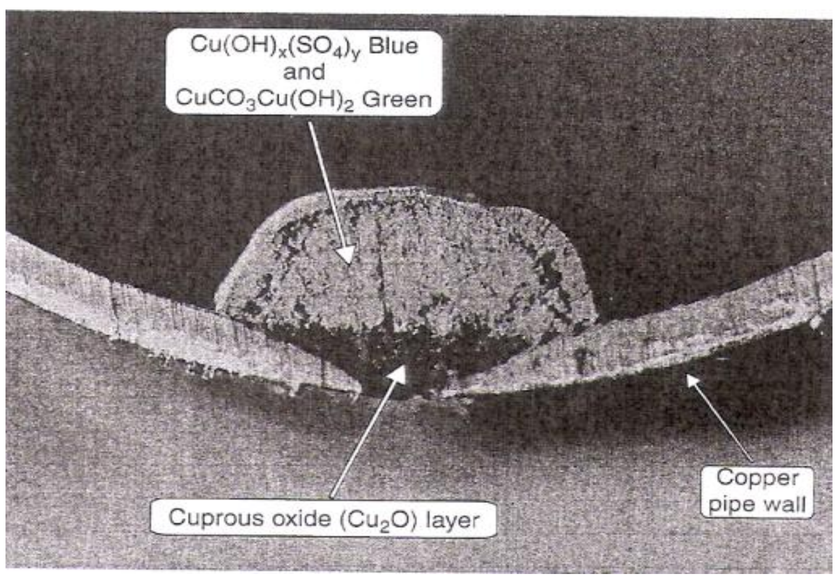


Figure 2.2 Type II copper pitting corrosion[4].

Type III pitting occurs in cold soft waters having a pH above 8.0. It is a more generalized form of pitting, which tends to be wide and shallow and results in blue water, byproduct releases, or pipe blockage.

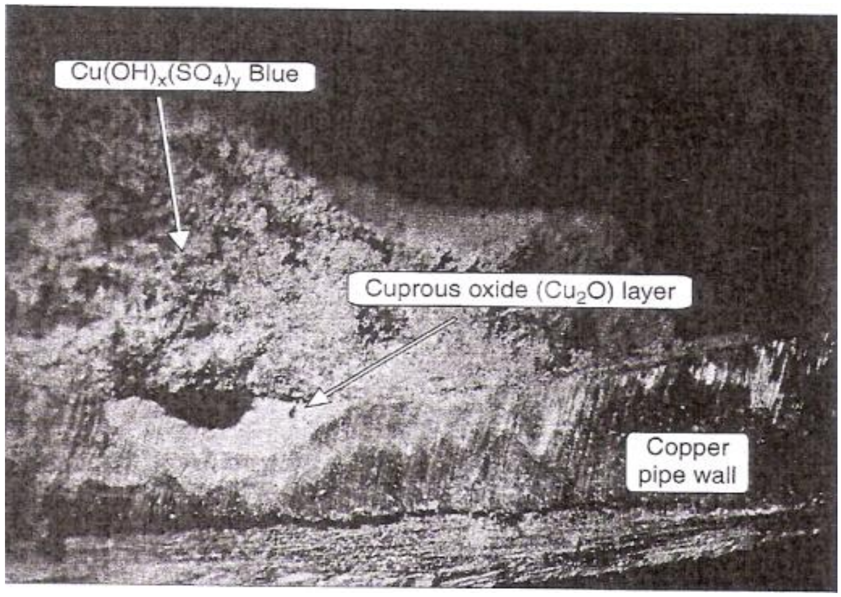


Figure 2.3 Type III copper pitting corrosion[4]

Pitting corrosion is the most common failure mechanism for copper tubes in water distribution systems. Essentially two different types of pitting attack have been identified and these are referred to in the literature as Type I and Type II pitting. Type I pitting is usually encountered in cold water systems carrying borehole or well waters free from organic matter. It occurs sporadically and can result in tube wall penetration within a few months. In some cases, however, penetration occurs only after 15 years or more. The internal surfaces of tubes undergoing Type I pitting are usually covered with a greenish scale of a copper compound called malachite.

Several studies and research projects have been conducted to determine the possible cause of pinhole leaks in copper pipes, but no definitive causes have been established. Some blame it on the chemicals in the water, while others blame it on workmanship and temperature gradients. The list below illustrates the different variables that are thought to cause pinhole leaks. These variables demonstrate the complexity of trying to pinpoint the suspected causes

1. Combination of high pH, low organic matter, aluminum solids, and free chlorine
2. Aggressive water, poor workmanship, and addition of water softeners
3. Workmanship: Excessive use of fluxes; fluxes are corrosive by their nature
4. Aluminum-bearing compounds (from concrete pipes, cement mortar lining of cast iron pipes, aluminum coagulant carryover from treatment plants)
5. Combination of: use of soft waters with low pH; high suspended solids and assimilable organic carbon content; long-term or periodic water stagnation; low or nonexistent chlorine levels; maintenance of water temperatures that promote rapid growth and activity of naturally occurring bacteria; and/or the lack of an adequate monitoring program to periodically evaluate water quality and pipe wall condition
6. Chloramines, which are chemicals caused by combining chlorine and ammonia (NH3)
7. Water velocity in undersized copper tubes. For tubing sizes normally installed in home plumbing, the design water velocity should be targeted toward 4 fps. The greatest effect of velocity occurs where the water is forced to change flow direction, such as at elbows and tees, but excessive water flow rates can be damaging to the entire plumbing system. When copper tubing is installed that is too small in diameter for the pressure and flow available, the resulting high flow rates can erode the protective coating creating areas of bare, unprotected copper. This effect can result in a high rate of corrosion wherever the protective coating is eroded.

CHAPTER 3

METHODOLOGY

It is important to do failure analysis on these copper tubes in order to detect the main cause for the pitting to occur. Meanwhile, the failure analysis involved some process which:

- Background data collection and sample selection
- Preliminary examination
- NDT (Non Destructive Testing)
- Mechanical Testing
- Macroscopic Examination
- Microscopic Examination
- Selection, preparation, examination and analysis of metallographic specimens
- Chemical Analysis
- Stress analysis and fracture mechanics
- Final Analysis, conclusion and report writing.

3.1 Failure Analysis Process

However for this project, Failure Analysis was conducted on the copper tube sample which involved [1]:

Macroscopic Examination

Macrostructure characterization at small magnifications, e.g., 10 x, can provide further information about the fracture path and the location from which it was originated, e.g., internal surface or external surface.

Microscopic Examination

Selection of the proper technique for microstructural characterization is dependent upon the type of information required. However, it is always recommended to begin with light optical microscopy or scanning electron microscopy to characterize the overall microstructure features.

In examining the microstructure, particular attention must be given to such features as grain size and shape, secondary precipitates and their distribution, microcracks and their location.

Selection, preparation, examination and analysis of metallographic specimens

Before doing metallographic, sample is mounted using hot mount and grinding to get the free scratch surface and after that etching with ferric chloride to reveal the microstructure which can be seen through optical microscope. Further analysis will be conducted to see the microstructure under SEM (Scanning Electron Microscope) with the EDS Analysis included.

Failure Analysis Reports

Documentation of a failure analysis study in a detailed report is not only useful in providing a solution to a specific problem, information contained in the report can also be used to settle legal claims. If such information is made available to designers, it can be extremely helpful in selecting proper materials, minimizing or preventing future incidents of failure.

3.2 Metallography

Process of preparing a metal surface for analysis by grinding, polishing, and etching to reveal microstructual constituents [3].

Specimen Preparation:

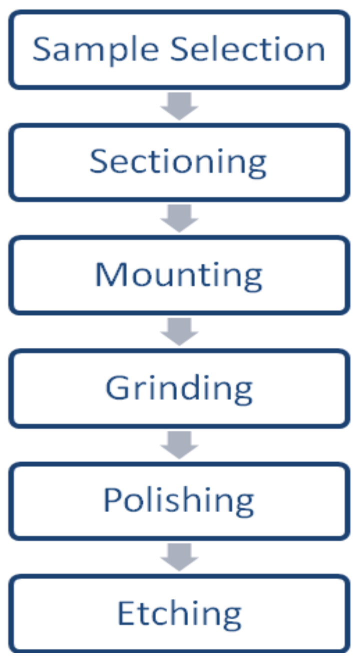


Figure 3.1 Metallography processes

Sample Selection

The location from which the test sample is taken is often chosen on the basis of convenience in sectioning.

Sectioning

Sectioning is required in most metallographic work to produce a sample convenient for further processing In general, abrasive cutoff machines, band saws, and low- speed diamond saw are the most commonly employed devices used.

Mounting

Specimen mounting is frequently necessary in the preparation of metallographic samples. The least expensive material or the quickest technique is usually chosen.

Grinding

Grinding is a very important phase of the sample preparation sequence because damage introduced by sectioning must be removed at this phase. A commonly employed grit sequence uses 120-, 240-, 320-, 400-, and 600-mesh abrasive paper Silicon carbide (SiC) is the most popular abrasive because of its very high hardness, reasonable cost, and excellent cutting characteristics.

Polishing

After being ground to a 1200-grit finish, the sample is polished to produce a flat, reasonably scratch-free surface with high reflectivity Coarse polishing uses abrasives in the range of 30 to 3 μm Fine polishing uses abrasives 1 μm and smaller

Etching

For many materials, the microstructure is revealed only by application of an appropriate etchant. Etchant for this sample is ferric chloride.

3.3 Scanning Electron Microscopic

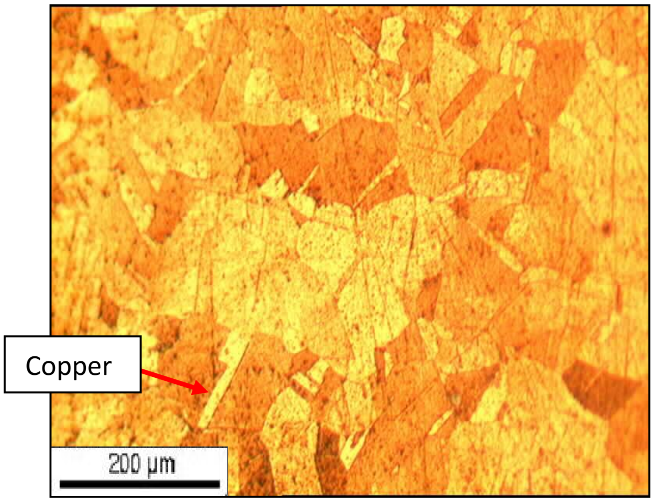
How is the sample prepared

Because the SEM utilizes vacuum conditions and uses electrons to form an image, special preparations must be done to the sample. All water must be removed from the samples because the water would vaporize in the vacuum. All metals are conductive and require no preparation before being used. All non-metals need to be made conductive by covering the sample with a thin layer of conductive material. This is done by using a device called a "sputter coater."

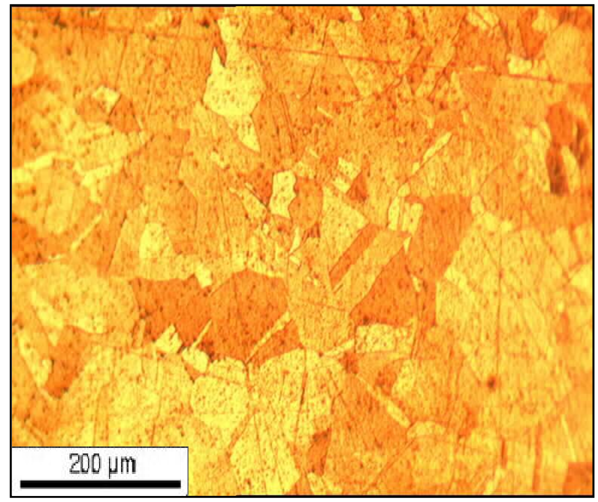
The sputter coater uses an electric field and argon gas. The sample is placed in a small chamber that is at a vacuum. Argon gas and an electric field cause an electron to be removed from the argon, making the atoms positively charged. The argon ions then become attracted to a negatively charged gold foil. The argon ions knock gold atoms from the surface of the gold foil. These gold atoms fall and settle onto the surface of the sample producing a thin gold coating.

CHAPTER 4

RESULTS AND DISCUSSION



(a)



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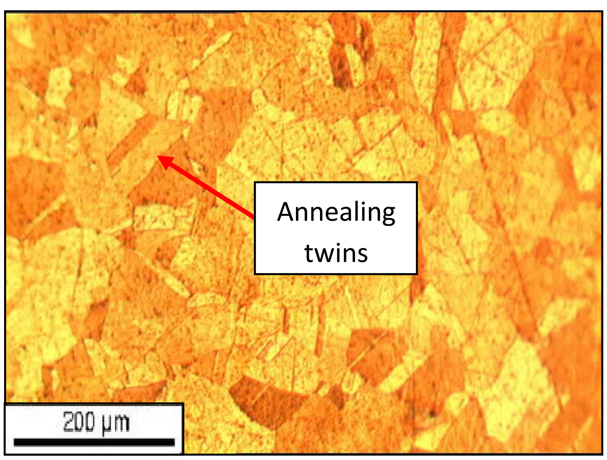
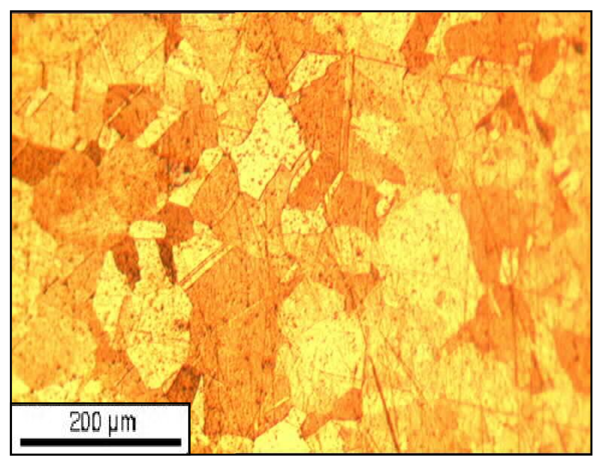


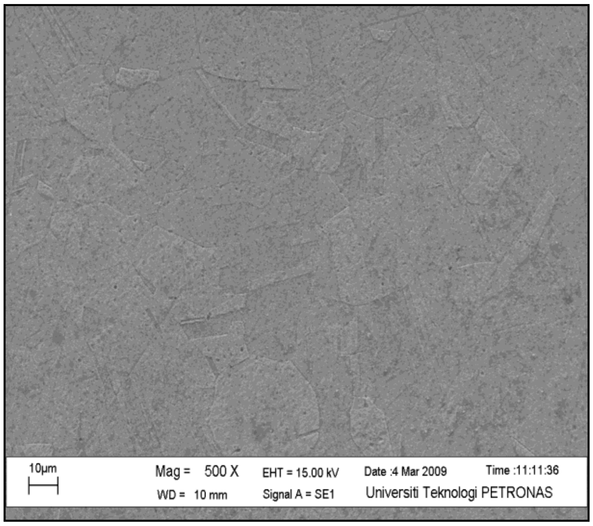
(c)



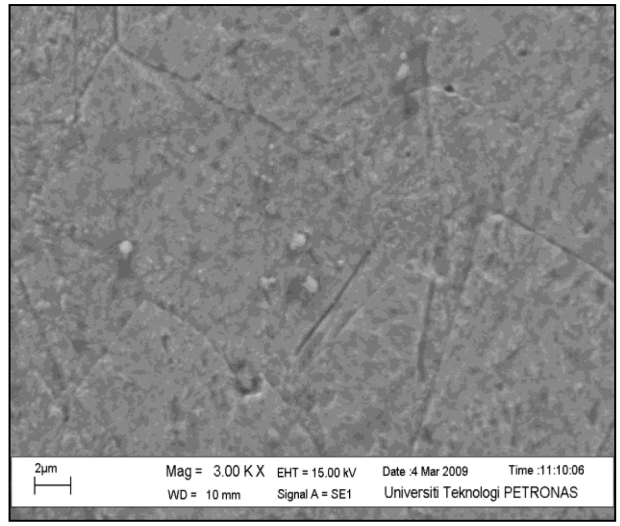
(d)

Figure 4.1 Microstructure of the copper tube at different locations.

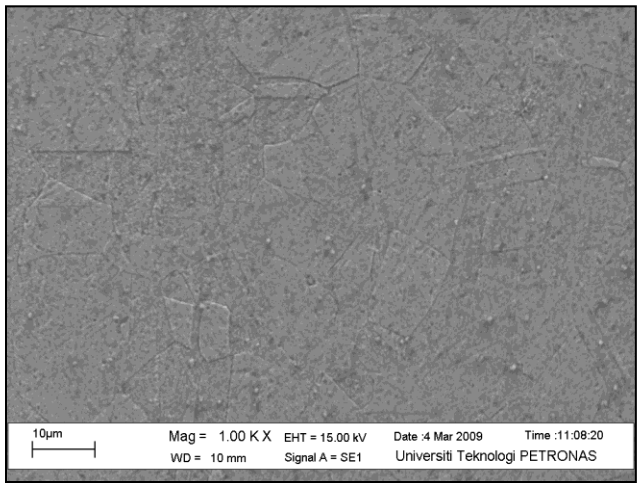
(Magnification 200x)



(a) Magnification 500x



(b) Magnification 3000x



(c) Magnification 1000x

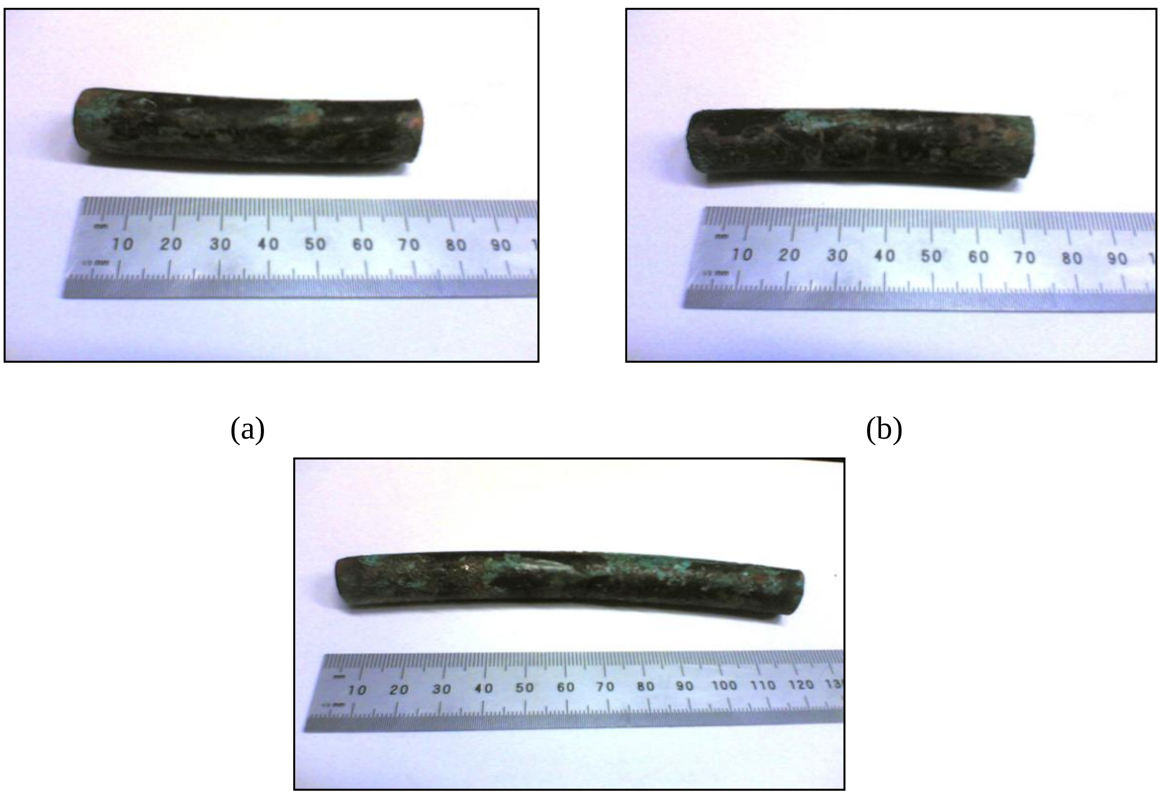
Figure 4.2 Grain Boundary revealed under SEM

Copper alloy are unusual in that they may be selected to produce an appropriate decorative colour. As we can see from Figure 4.1, pure copper is red and the addition of zinc produce a yellow colour.

This copper tube has been cold worked after casting and then annealed at 300°C.The annealing heat treatment has caused recrystallisation of the high energy deformed microstructure. The straight bands crossing each grain are annealing twins and are characteristic of annealed face centered cubic metals. The recrystallised grain size is small due to the high density of nucleation sites in the deformed structure. Compare this microstructure to the cast brass and the cold worked brass [5].Alpha brass has a face centered cubic crystal structure and is a relatively soft alloy which is easily cold worked to increase its strength.

Cold working can increase the strength of the alloy from 300 MPa in the annealed state to 525 MPa in the cold worked state, although the ductility is then reduced from 68% to 7% elongation. Annealing the cold worked structure restores some ductility with a loss of strength, although the refined grain size gives higher strength than the cast microstructure.

Typical applications include electrical components (such as wire), pumps, valves and plumbing par

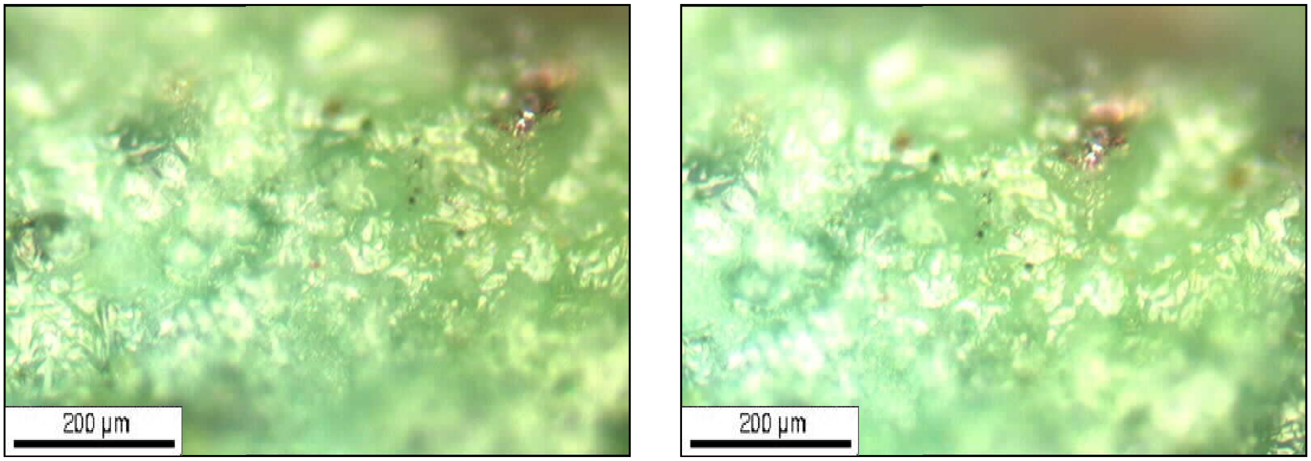


(a) (b)

(c)

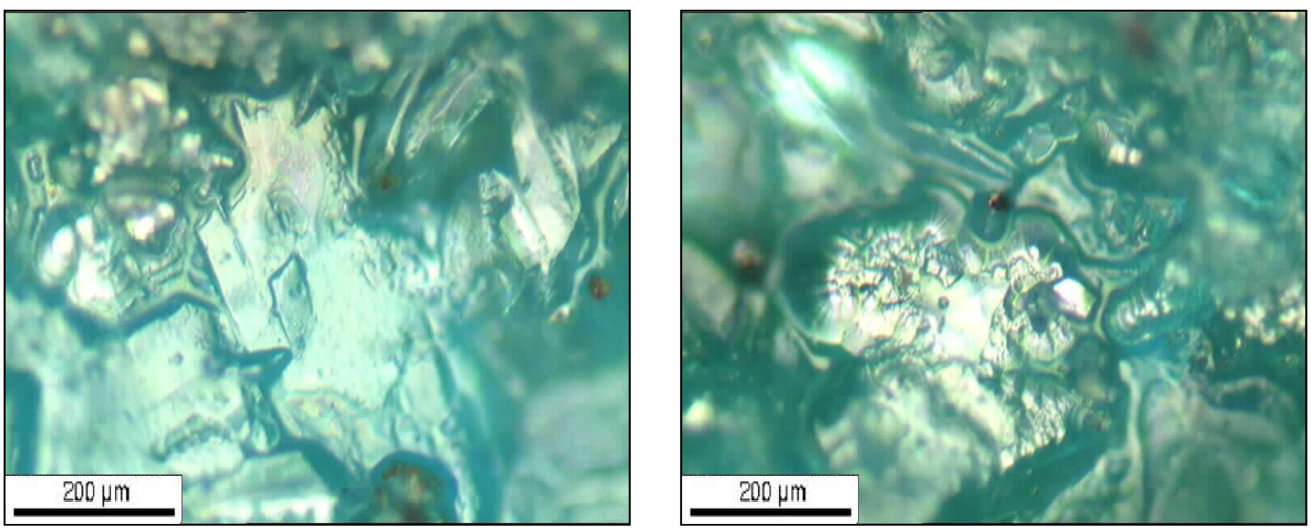
Figure 4.3 The corroded copper tubes

The corroded copper tubes can be divided into three different areas. The blue, green and black areas. These three different areas are specifically viewed under scanning electron microscope to reveal the composition of the area.



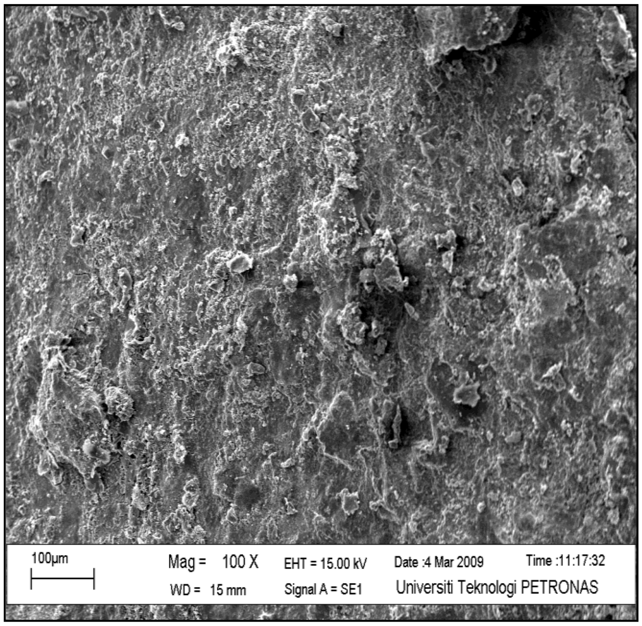
(a) (b)

Figure 4.4 $CuCO_3.Cu(OH)_2$, Malachite, The green area

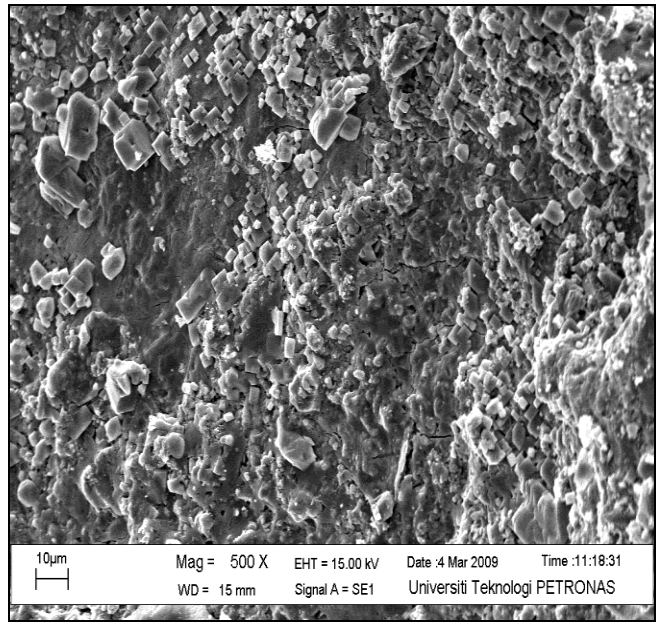


(a) (b)

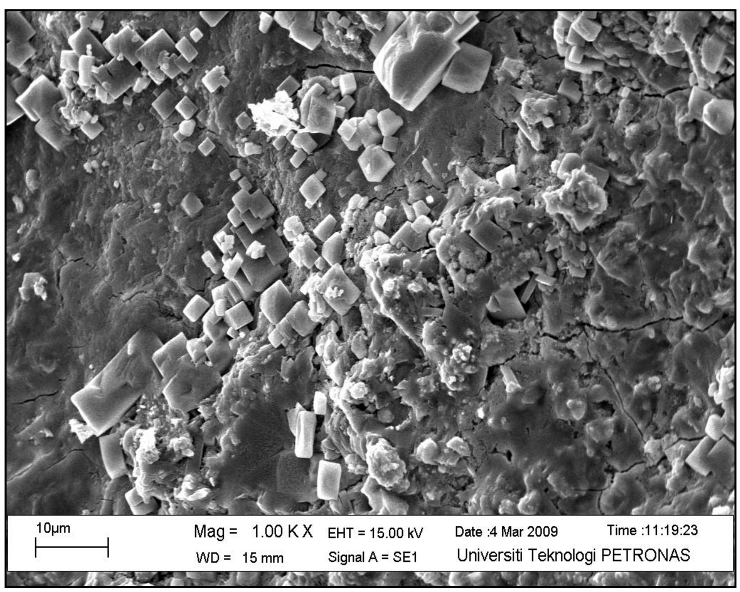
Figure 4.5 $Cu(OH)_x(SO_4)_y$,Copper Sulfate and Cupric Salt, The blue area



(a) Magnification 100x

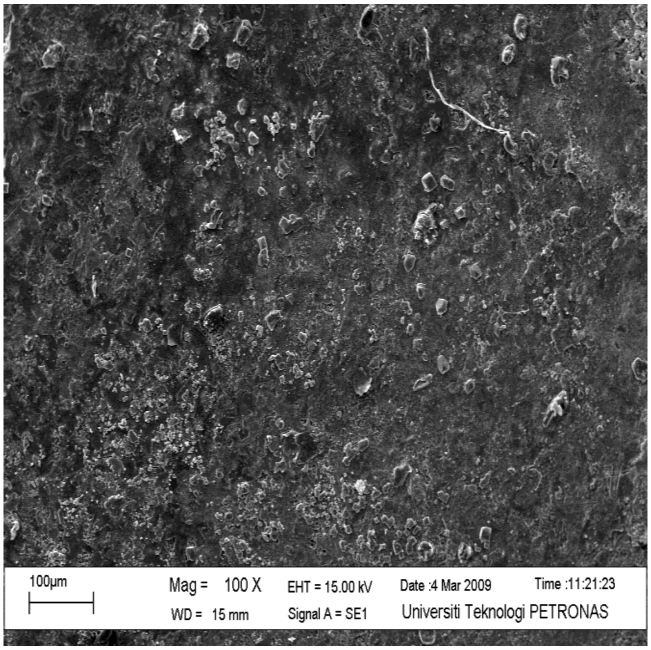


(b) Magnification 500x

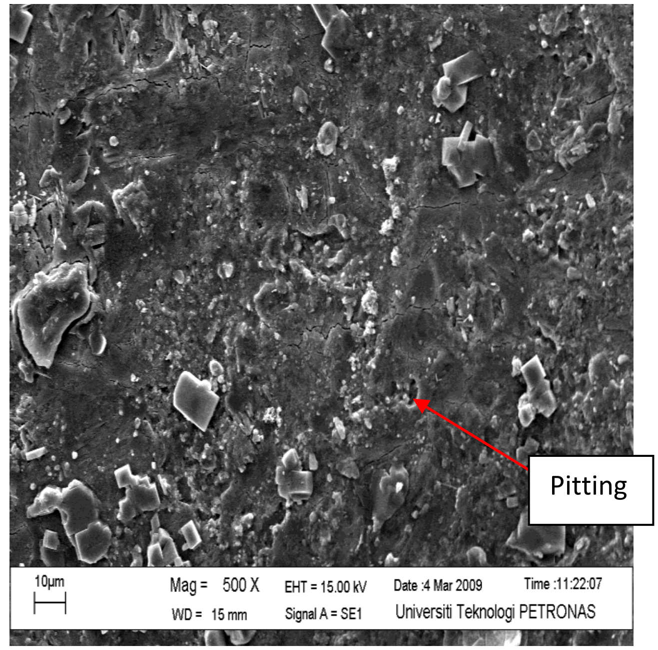


(c) Magnification 1000x

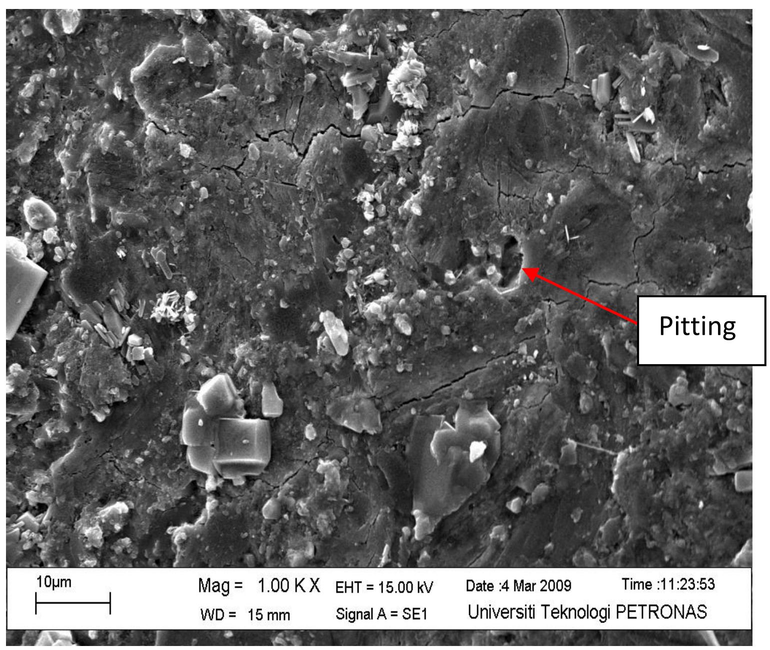
Figure 4.6 The green/blue area of the copper tube under SEM



(a) Magnification 100x



(b) Magnification500x



(c) Magnification 1000x

Figure 4.7 The black area of the copper tube under SEM

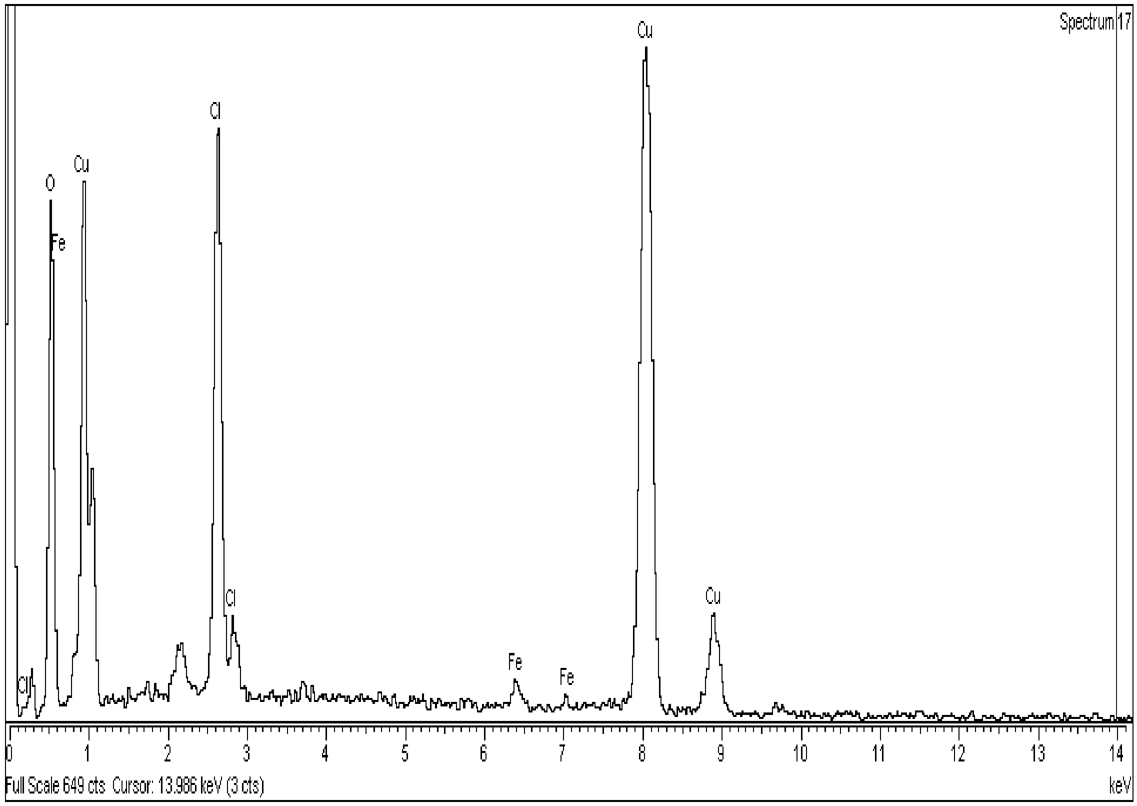


Figure 4.8 The EDS result of the greenish deposits found on the surface of the tubes.

Sample of the tubes were examined in a scanning electron microscope (SEM) equipped with an energy dispersive spectroscopy of X-rays (EDS) facility. The results of the EDS analysis of the greenish scale found on the surface of the copper tubes are shown in figure 4.8. The large copper peak originates from the base metal. The large iron peak is due to the presence of these elements in the scale. This element is readily oxidized and therefore frequently detected in scale deposits. A major chloride peak was also detected. This ion is usually associated with pitting attack.

Type I pitting is usually encountered in cold water systems carrying borehole or well waters free from organic matter It occurs sporadically and can result in tube wall penetration within a few months. In some cases, however, penetration occurs only after 15 years or more. The internal surfaces of tubes undergoing Type I pitting are usually covered with a greenish scale of a copper compound called malachite,$CuCO_3.Cu(OH)_2$ Elements of Malachite: Carbon, Copper, Hydrogen, Oxygen $Cu(OH)_2$ is bright blue. But with the presence of an excess amount of $CuSO_4$, then we will get pale blue basic copper sulfate. Pits develop in the inner wall of copper tube. The pits contain soft crystalline cuprous oxide under a membrane of cuprous oxide crystal. Cuprous chloride also occurs in the pits basic copper carbonate mounds occur over the pits.

The characteristics of Type I pitting are such that many pits at all stages of development can usually be found as in figure 4.7. Larger pits are generally linearly arranged along the bottom half of horizontal water lines. Tubercules can extend over a number of pits to form one long tubercule whenever pits are very close together. Although pitting has been observed in annealed, half hard and hard-drawn tube, susceptibility is generally greatest in annealed condition. The pits formed are relatively wide.

A number of causes of Type I pitting have been identified as below [8]:

1. The occurring of pitting has been associated with the presence of carbonaceous films on the internal surface of the tube. These films are the residues of the lubricant used for the drawing operation and which are carbonized during annealing process. The severity of the pitting occurred depend on the quantity and distribution of these film on the internal surface of the tube. The problems cause by the presence of these carbonaceous films can be prevented by scouring the tubes with water-sand blast or water-air blast.

2. Pitting has been associated with the presence of foreign matter deposits on the bottom half of horizontal tubes [8]. The foreign matter deposits can be introduced into the water lines in a number of different ways. Metal chips and filings and dirt can be allowed to contaminate the system during installation. If

these are not properly removed before service, they may deposit along sections of the water lines where the water velocity is low. Foreign matter deposits may also be introduced into the system in the water or may be due to corrosion products formed during surface corrosion of the tubes during service. The concentration of these deposits, and hence their deleterious effects can be reduced by the installation of filters in the water line.

3. The presence of soldering pastes on the inside of the tubes is another factor to cause pitting attack. This normally caused from bad workmanship and can be avoided by ensuring that adequate quality standards are maintained during installation process. The soldering pastes may act as deposits in the same way as foreign matter. Alternatively, during soldering or brazing these pastes may be converted to oxides which as a thin film on the copper surface. These oxides are generally cathodic to copper and can therefore give rise to pitting corrosion.

4. The effect of water quality on the incidence of Type I pitting are summarized on Table 1[9].

Table 1: The effect of various water constituents and characteristics on Type I pitting

Chemical Species	**Effect**
Sulphate	Assists pit initiation and growth, but its effect depends on the concentration of other chemical species
Chloride	Essential for pitting attack. Assists the breakdown of protective surface films and results in the formation of wide shallow pits
Nitrate	Inhibits pitting
pH	Increase in pH generally decreasing the probability of pitting
Dissolved Oxygen	Increased O_2 content increases the probability of pitting
Carbon Dioxide	Increased CO_2 content increases the probability of pitting due to decreases in pH.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

It was concluded that the failure of the copper tubes was due to the Type I pitting attack. What exactly cause the pitting failure was not clear at this stage since particularly given the fact that pitting only became evident after 12 years service. It is may be due to the presence of foreign matter deposits introduced during installation process of the system. The presence of foreign matter in the water is a possibility if the water is not filtered. Changing in water quality or content for example resulting from mixing of the water with borehole or well waters could also lead to pitting attack.

5.2 Recommendation

It was therefore recommended that the copper tubes be replaced. Full attention should be given to the normal causes of Type I pitting attack. Before the tubes need to be installed, it should be ensured that all tubes be thoroughly cleaned and freed of any carbonaceous deposits. The tubes should also be clean from any foreign matter deposits and solder pastes after installation process. Water filter can be used in order to prevent the introduction of foreign matter in the water. Furthermore, the content and quality of the water should be monitored and its potential to cause pitting attack assessed. The extent of replacement or modifications to the water distribution system should follow the standard and depend on the results of such water analyses.

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APPENDICES

APPENDIX I

GANTT CHART

APPENDIX II

ASTM B-88

APPENDIX III

ASTM B-32