Report of Cooperative Education

Proposed Solutions to Solve Corrosion Problems of Chilled Water System

Rungnapa Wattanapant

A Report Submitted in Partial Fulfillment of the Requirements

for the Degree of Bachelor of Engineering (Petrochemical Engineering),

Department of Chemical Engineering, Faculty of Engineering,

King Mongkut's Institute of Technology Ladkrabang

Academic Year 2019

รายงานสหกิจศึกษาฉบับสมบูรณ์

แนวทางการแก้ไขปัญหาการกัดกร่อนในระบบน้ำหล่อเย็น

นางสาวรุ่งนภา วัฒนาพันธุ์

รายงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรบัณฑิต

หลักสูตรวิศวกรรมปิโตรเคมี ภาควิชา วิศวกรรมเคมี คณะวิศวกรรมศาสตร์

สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

ปีการศึกษา 2562

Cooperative Title: Proposed Solutions to Solve Corrosion Problems of Chilled Water System

By: Miss Rungnapa Wattanapant

Field of Study: Petrochemical Engineering

Advisor: Asst. Prof. Dr. Apinan Namkanisorn

Co-Advisor: Assoc. Prof. Dr. Anchaleeporn Waritswat Lothongkum

Affiliation: Department of Chemical Engineering, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang

Mentors (Position): 1) Ms. Alisa Puttharak (Production Manager-Compounding Manufacturing)
2) Mr. Sutham Chuanchom (Production Engineer-Compounding Manufacturing)

Company: Momentive Performance Materials (Thailand) Limited

Abstract

Corrosion is an extremely perilous problem in petrochemical and refinery industries. Corrosion in chilled water system can damage piping system and the equipment. In addition, corrosion may produce large amounts of corrosion products in terms of scale and rust that can lower the performance of the equipment in chilled water system, e.g., heat exchangers, chilled water tank, cooling jackets, etc. The target of this study is to propose the solutions to solve the corrosion problems of chilled water system. After the survey, this study came up with two methods: 1) chemical cleaning and passivation and 2) changing new pipeline. For chemical cleaning and passivation, three acid solutions including sulfuric acid, hydrochloric acid and rydlyme were considered appropriate to use in the chilled water system. Based on their properties, sulfuric acid is the best in chemical cleaning and passivation of the chilled water system. In the case of changing new pipeline, of the three materials, i.e., carbon steel, stainless steel and PE-lined steel, the PE-lined steel is recommended. PE-lined steel is a good corrosion resistant material that helps reduce using additional corrosion protection such as corrosion inhibitors. In conclusion, the proposed two solutions can be used to solve the corrosion problems of the chilled water system in this case study depending on their advantages and disadvantages herein.

Keywords: Corrosion, Chilled water system, Chemical cleaning, Passivation, Corrosion resistant materials

Acknowledgements

Foremost, I would like to express my sincere gratitude to my advisor, Asst. Prof. Dr. Apinan Namkanisorn, and my co-advisor, Assoc. Prof. Dr. Anchaleeporn Waritswat Lothongkum, for their continuous support and guidance throughout the project. This project would not have been possible without their timely suggestions.

I also would like to thank the production team of Momentive Performance Materials (Thailand) Limited: Ms. Alisa Puttharak (Production Manager-Compounding Manufacturing), Mr. Sutham Chuanchom (Production Engineering-Compounding Manufacturing), Mr. Kawin Soontorkiti (Production Engineering-Compounding Manufacturing), and others, for offering and leading me to work on diverse exciting co-operative education project.

My sincere thanks go to Nalco Industrial Service (Thailand) Co., Ltd., CHC Chemical Co., Ltd. and Relate Intertrade Co., Ltd. for supporting necessary information regarding this project.

Last but not least, I would like to thank my family and beloved friends who always encourage and support me for all.

Table of Contents

Table of Contents (Cont.)

List of Figures

List of Figures (Cont.)

List of Tables

CHAPTER I

INTRODUCTION

1.1 Background

Momentive Performance Materials (Thailand) Limited (MPM) produces silicone fluids by polymerization unit; and silicone sealants and silicone elastomers by compounding unit. Silicone fluids are used in many industries such as cosmetics and pharmaceuticals, paint and coating additives, food packaging and processing, and rubber and plastic additives. Silicone sealants are commonly used in commercial and home construction as an adhesive on materials. Silicone elastomers include a wide variety of products, e.g., automotive applications, cooking, baking, food storage products and medical devices. The MPM has encountered serious corrosion problems with carbon steel pipe and the equipment in chilled water system for long time. The chilled water system is used for both polymerization and compounding units. From the beginning, the MPM used demineralized water in chilled water system without chemical treatment. Normally, demineralized water is corrosive to carbon steel. Rust and corrosion were found randomly inside the pipeline and the equipment of chilled water system, e.g., heat exchangers, chilled water tank, cooling jackets, etc leading to low equipment performance. At turnaround in February 2019, the MPM team found that heat exchangers and cooling jackets (Figs.1.1 and 1.2) were clogged with rust and could not clean out even by using the high-pressure steam.

Figure 1.1 Rust clogged at the heat exchanger in the chilled water system

(Momentive Performance Materials (Thailand) Limited. 2019)

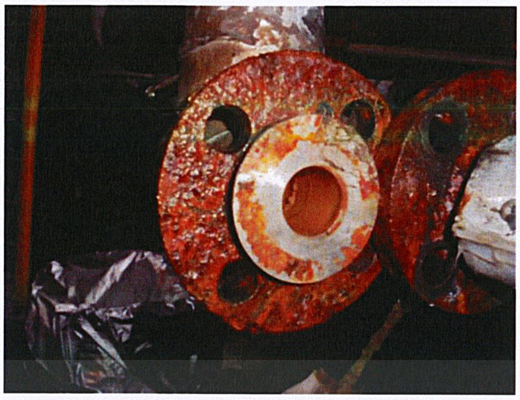


Figure 1.2 Rust clogged at the cooling jacket in the compounding unit

(Momentive Performance Materials (Thailand) Limited. 2019)

High priority to solve the problem was set and the company consulted with Nalco Industrial Service (Thailand) Co., Ltd., a water treatment company. Chemical treatment was adopted in demineralized water to solve the problem. Weekly monitoring of chilled water quality having ferric ions (Fe^{3+}) less than 3 ppm was targetted. Fig. 1.3 shows the results of ferric ions monitoring in chilled water system. The ferric ions were still higher than 3 ppm, so the MPM team decided to install the filters to filtrate rust from chilled water system. However, after filter installation, it was still unsatisfactory.

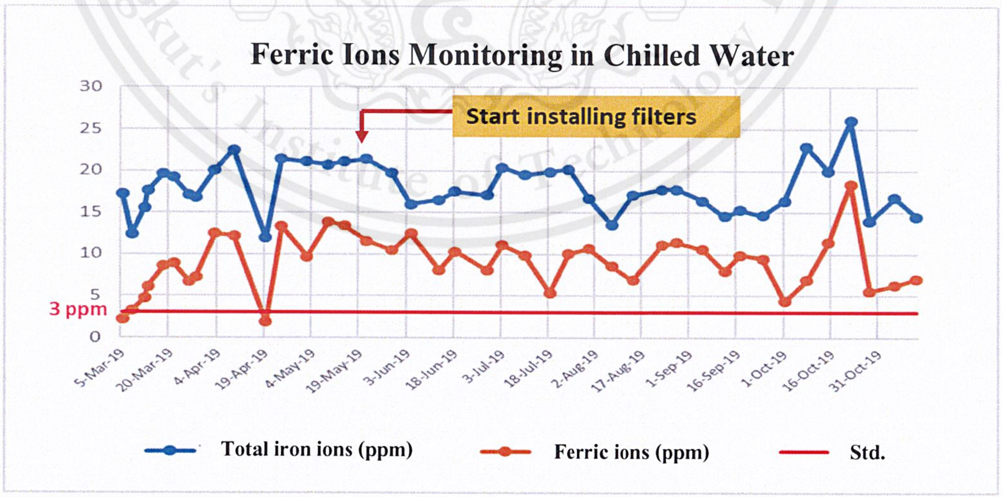


Figure 1.3 Ferric ions monitoring in chilled water system

(Nalco Industrial Service (Thailand) Co., Ltd. 2019)

Remark: Total iron ions = Ferric ions (Filtered iron ions) + Ferrous ions (Unfiltered iron ions)

Moreover, in June 2019, the MPM team and outside corrosion specialists inspected chilled water pipeline and the inside surface of the chilled water tank. Severe under deposit corrosion (Levels 1-4) were found, as shown in Fig. 1.4.

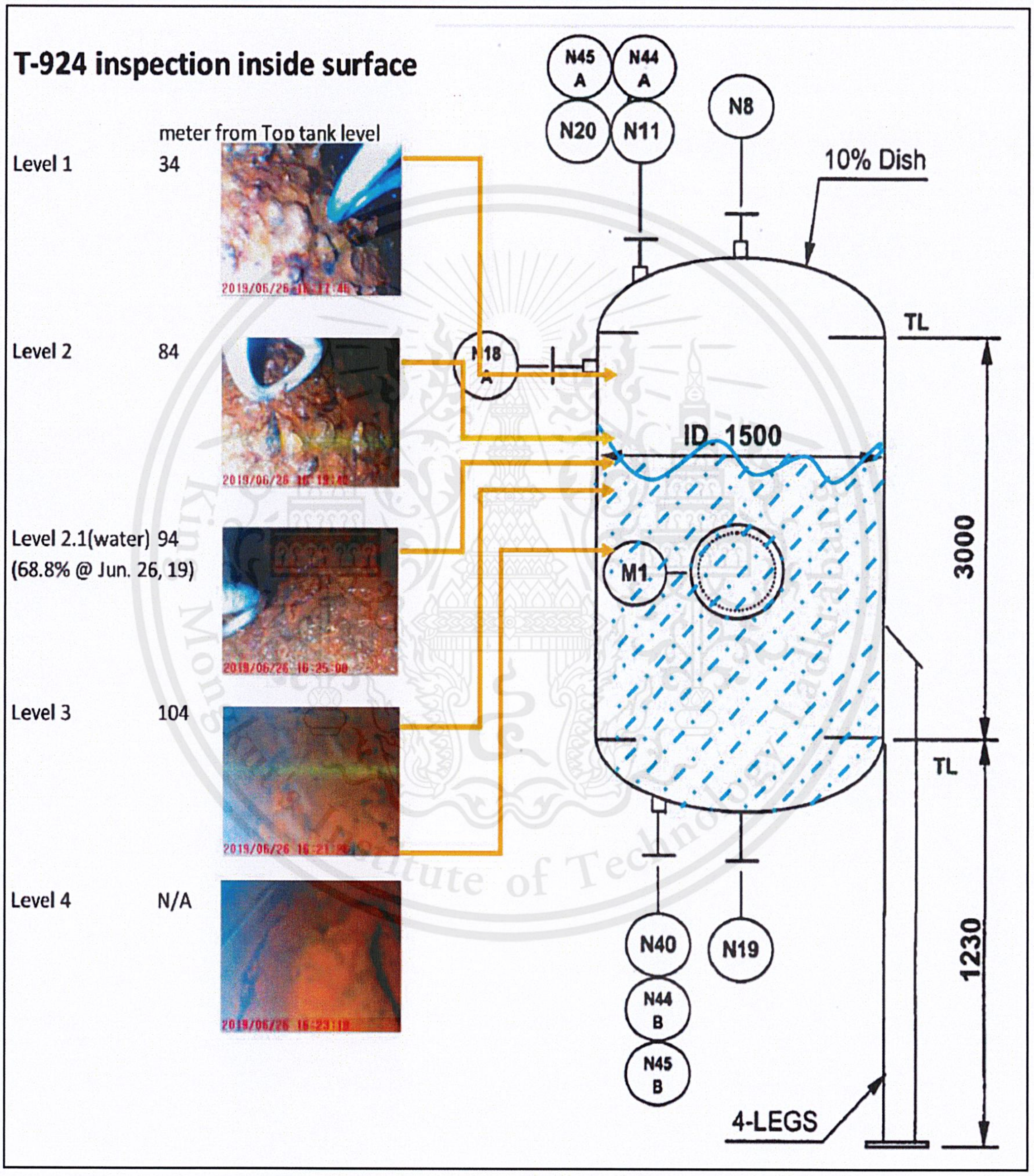


Figure 1.4 Under deposit corrosion at chilled water tank

(Momentive Performance Materials (Thailand) Limited. 2019)

Therefore, this project aims to study the corrosion in chilled water system and then propose the solutions to solve the corrosion problems.

1.2 Objective

To propose the solutions to solve corrosion problems of chilled water system

1.3 Scope of Work

1.3.1 Study chilled water system of the MPM

1.3.2 Study fundamentals of corrosion and corrosion issues in chilled water system

1.3.3 Propose the methods to solve corrosion problems of chilled water system

1.4 Outputs

1.4.1 Understand the corrosion issues in chilled water system

1.4.2 Proposed solutions to solve corrosion problems of chilled water system

1.4.3 Recommend the acid solution used in chemical cleaning and passivation

1.4.4 Recommend material selection for changing new pipeline

CHAPTER II

LITERATURE REVIEW

2.1 Cooling Systems

Cooling systems can be divided into three classifications: 1) once-thru, 2) open recirculating (evaporative), and 3) closed recirculating (non-evaporative) cooling systems.

1) Once-thru Cooling System

Cooling systems in many plants are once-thru cooling system. Water from a nearby source is pumped through the heat exchanger of the cooling system to absorb process heat. Heated water is then returned to the original source as shown in Fig. 2.1. The original source may be a lake, river, ocean, or well.

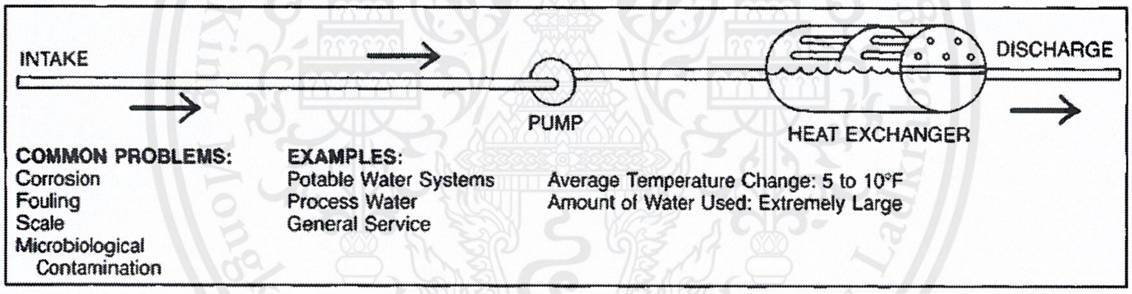


Figure 2.1 Schematic of once-thru cooling system

(Herro, H.M. and Port, R.D, 1993)

2) Open Recirculating Cooling System

Open recirculating cooling system is the most widely used cooling system in many industries. The open system uses the same water repeatedly to cool the process equipment. Heat absorbed from the process must be dissipated to allow reuse of the water. Open recirculating cooling system (Fig 2.2) consists of three main equipment, i.e., cooling tower, recirculating water pump and heat exchanger.

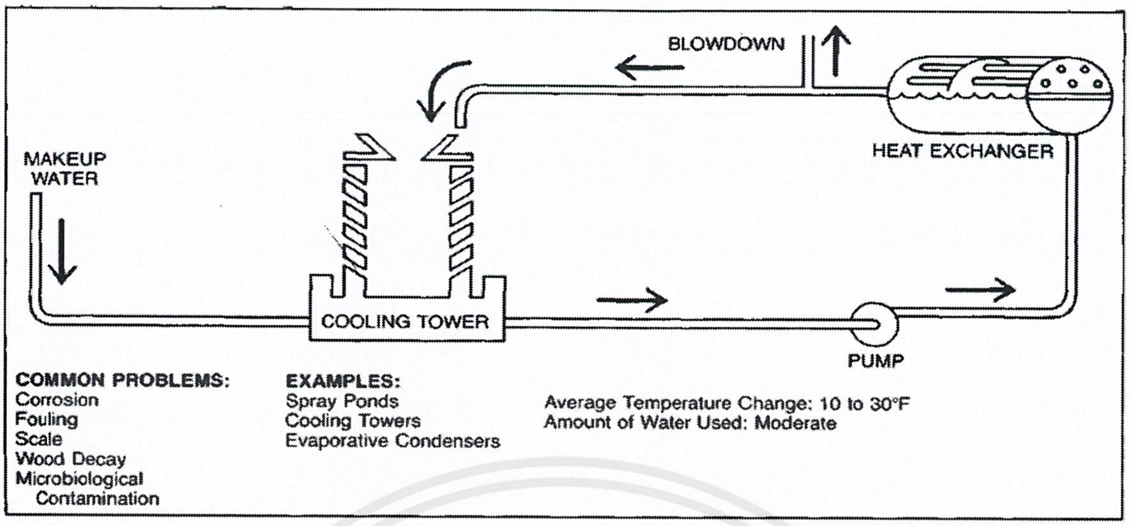


Figure 2.2 Schematic of open recirculating cooling system

(Herro, H.M. and Port, R.D, 1993)

3) Closed Recirculating Cooling System

This type of cooling system, water circulates in a closed cycle and there is a little loss of water from the system. Heat is normally transferred from the water in closed system to the coolant or released into the atmosphere through a heat exchanger. The coolant will return to the engine. Fig. 2.3 shows a schematic of closed recirculating cooling system. Chilled water system is one of the closed recirculating cooling systems.

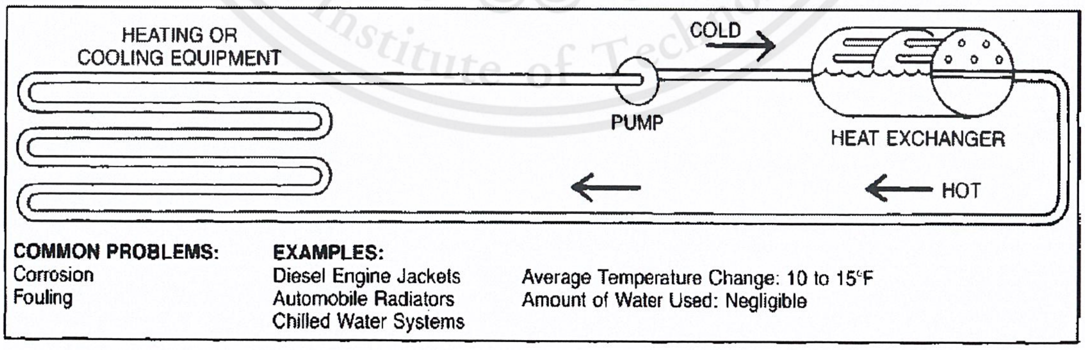


Figure 2.3 Schematic of closed recirculating cooling system

(Herro, H.M. and Port, R.D, 1993)

2.1.1 Chilled Water System of Momentive Performance Materials (Thailand) Limited (MPM)

Chilled water system of the MPM in Fig. 2.4 has the same fundamental steps and equipment as the closed recirculating cooling system.

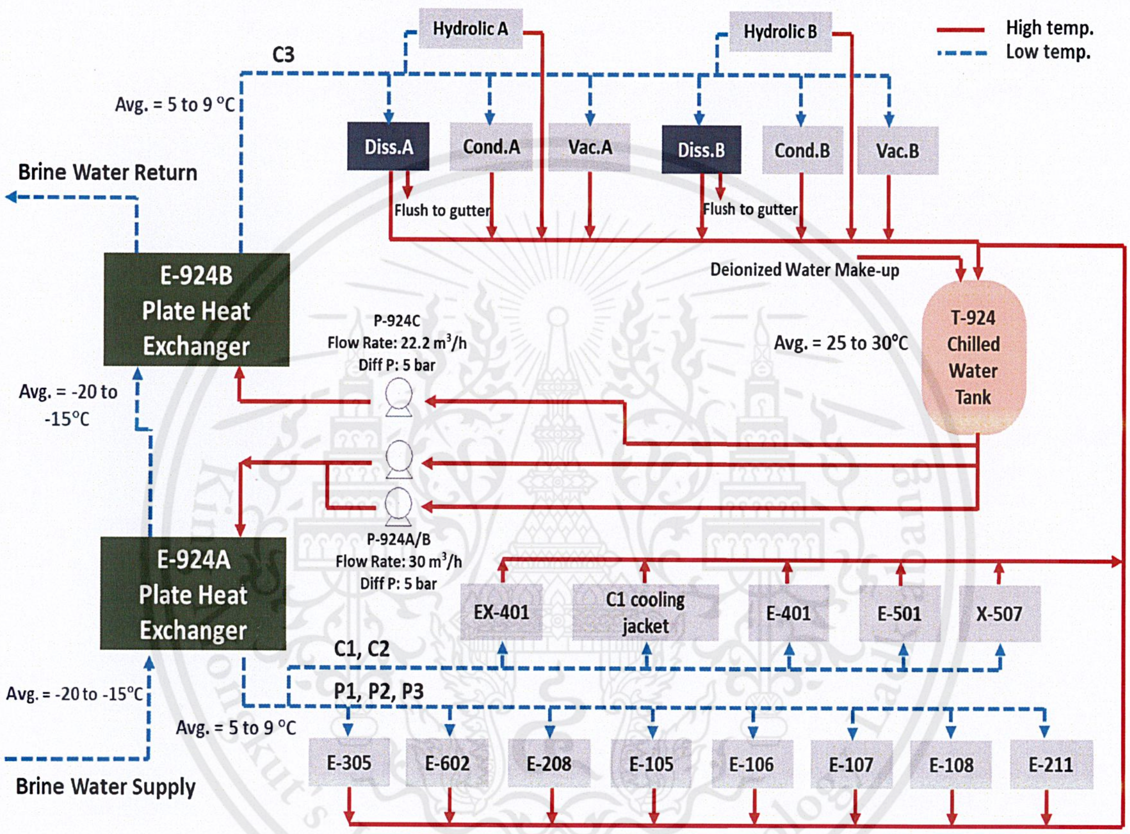


Figure 2.4 Chilled water system of Momentive Performance Materials (Thailand) Limited (Momentive Performance Materials (Thailand) Limited, 2019)

From Fig. 2.4, the demineralized water in chilled water tank (T-924) flows through the pumps. The two demineralized water lines pass through P-924A/B pumps and to a plate heat exchanger (E-924A). They are used in the polymerization units (P1, P2 and P3) and compounding units (C1 and C2). The other demineralized water line passes through P-924C pump and to plate heat exchanger (E-924B). It is used in the compounding unit 3 (C3). Demineralized water in plate heat exchanger at ambient temperature of 25°C to 30°C is heat exchanged with brine water (temp -20°C to -15°C) containing ethylene glycol. Therefore, chilled water at 5°C to 9°C to control the temperature in the production units is obtained.

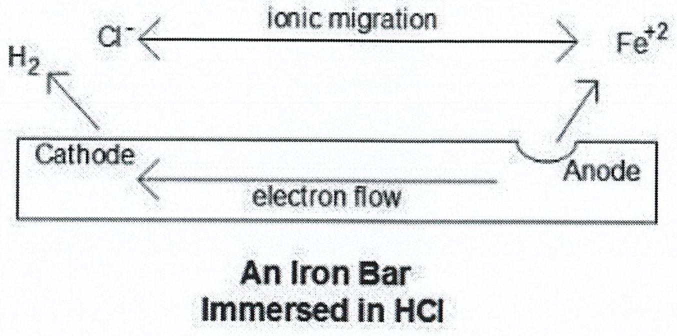
2.2 Corrosion in Chilled Water System

Corrosion is a severe problem in petrochemical and refinery industries. Corrosion is a deterioration of a material by electrochemical reaction with the environment in presence of water and oxygen. Oxidation reaction is one of electrochemical reactions. Corrosion problem can damage the construction, pipeline and equipment. Most metals are easily oxidized or tend to lose electrons to oxygen (and other substances) in the air or water resulting in metal oxide layers (Schweitzer, P.A, 1994).

2.2.1 Corrosion Fundamentals

Corrosion is defined as the process of a metal returning to natural state. Metal, an anode in oxidation reaction, loses electron and becomes metal ion. The electron is consumed by cathodic reaction (e.g., oxygen reduction). The less corrosion-resistant metal becomes the anode, and the more corrosion-resistant metal becomes the cathode. The common metal corrosions are metal oxidation in aqueous solutions, such as water, seawater, various industrial process streams or aqueous strong acid. A familiar case is pure metal iron encountering with hydrochloric acid (Schweitzer, P.A, 2010).

Fig. 2.5 shows the corrosion mechanisms of a simple laboratory experiment by immersing an iron bar in a hydrochloric acid solution. It can be observed that hydrochloric acid solution bubbled violently (Buecker, B, 2016)



Anodic Reaction: $Fe \rightarrow Fe^{+2} + 2e^-$

Cathodic Reaction: $2H^+ + 2e^- \rightarrow H_2$

Figure 2.5 Corrosion mechanisms of immersing an iron bar in hydrochloric acid solution (Buecker, B, 2016)

Three main components of corrosion are anode, cathode and electrolyte. The following examples are iron corrosion in aqueous acid and in water.

For iron corrosion in aqueous acid, iron (Fe^0) or anode loses two electrons becomes iron with +2 oxidation state or ferrous ion (Fe^{2+}), and thus the corrosion occurs, as shown in Eq. 2-1 which is the anodic reaction.

$$Fe^0\ (s) \rightarrow Fe^{2+}\ (aq) + 2e^- \qquad (2\text{-}1)$$

The electrons flow through the metal to another site or cathode, and react with the hydrogen ions to produce hydrogen gas, which is called reduction reaction or cathodic reaction, as shown in Eq. 2-2.

$$2H^+\ (aq) + 2e^- \rightarrow H_2\ (g) \qquad (2\text{-}2)$$

The ferrous ions migrate in the solution to react with chloride ions (Cl^-) from hydrochloric acid to form ferrous chloride ($FeCl_2$).

In case of iron corrosion in water containing dissolved oxygen, the mechanisms are as follows:

$$Fe\ (s) \longrightarrow Fe^{2+}\ (aq) + 2e^{-} \tag{2-3}$$

$$\tfrac{1}{2}\ O_2\ (g) + H_2O\ (l) + 2e^{-} \longrightarrow 2\ OH^{-}\ (aq) \tag{2-4}$$

$$Fe^{2+}\ (aq) + 2\ OH^{-}\ (aq) \longrightarrow Fe(OH)_2\ (aq) \tag{2-5}$$

$$4\ Fe(OH)_2\ (aq) + O_2\ (g) \longrightarrow 2\ Fe_2O_3 \cdot 2H_2O\ (s) + 2\ H_2O\ (l) \tag{2-6}$$

The hydroxyl ions (OH^{-}) combine with ferrous ion (Fe^{2+}) to form ferrous hydroxide, $Fe(OH)_2$, which further reacts with oxygen to produce $Fe_2O_3 \cdot 2H_2O$, known as rust.

'Rusting' refers to the corrosion products of metal iron or its alloy, which mainly consist of hydrous ferric oxides. Nonferrous metals can be corroded but do not produce rust. If rusting starts at one location of iron, it will wholly spread. Finally, metal iron will eventually be broken down. (Schweitzer, P.A, 1994)

2.2.2 Concentration Cell Corrosion

Concentration cell corrosion is one type of cells that take part in corrosion reactions. A difference in the concentration of electrolyte in contact with the metals leads to differ in solution potential and concentration cell corrosion. If the difference in potential is great enough, the more anodic area will be corroded by concentration cell corrosion. Two kinds of concentration cell corrosions are considered. Differential aeration cell corrosion is practically more important than salt concentration cell corrosion. It can cause pitting damage under rust or pitting corrosion. The amount of oxygen contacts the metal, which is covered by rust, is less than the amount of oxygen that contacts other locations where the permeable coating is thinner or nonexistent (Revie, R.W and Uhlig, H.H, 2008).

2.2.3 Types of Corrosion (Schweitzer, P.A, 1994)

Nine basic types of corrosion in a piping system and equipment are shown in Table 2.1.

Table 2.1 Types of corrosion in a piping system and equipment

Types of Corrosion	Description
General or Uniform Corrosion	- The most common form of corrosion. - Occur when a metal is attacked uniformly by a corrosive substance.
Galvanic Corrosion	- Occur when two different metals are coupled in a corrosive electrolyte due to the potential difference between metals.
Pitting Corrosion	- It is a localized form of corrosive attack that produces holes or small pits in the metal. - Difficult to predict and measure because there are a number of pits with different depths under identical conditions.
Crevice Corrosion	- It is a localized form of corrosion occurring in crevices (shielded areas) on metal surfaces in contact with a corrosive substance.
Stress Corrosion Cracking (SCC)	- Stress corrosion cracking is a result of the combination of a specific corrosive environment, a tensile stress and a sensitive metal.
Intergranular Corrosion	- Refer to a localized corrosion along grain boundaries. - Occur during welding when chromium in austenitic stainless steel reacts with carbon and forms chromium carbide causing chromium deficient and passive oxide layer.
Erosion Corrosion	- The result of relative movement between the corrosive fluid and metal surfaces. - All types of equipment exposed to moving fluids are subjected to erosion corrosion.
Dezincification	- A type of attack occurs with zinc alloys, in which zinc is corroded preferentially and left a porous residue of copper and corrosion products.
Microbiological Corrosion	- Caused by micro-organisms both aerobic (presence of oxygen) and anaerobic (absence of oxygen).

The corrosion founded in the chilled water system of this case study is under deposit corrosion, one type of pitting corrosion. So, this project will focus on pitting corrosion and under deposit corrosion.

2.2.4 Pitting Corrosion

Pitting is a localized form of corrosive attack, in which both local anodic and cathodic points form small concentration cell corrosion with the surrounding surface of the metal. Once a 'pit' has introduced, it grows into a 'hole' or 'cavity' in a variety of different shapes, as shown in Fig. 2.6 (Gibson Stainless & Specialty Inc, 2016).

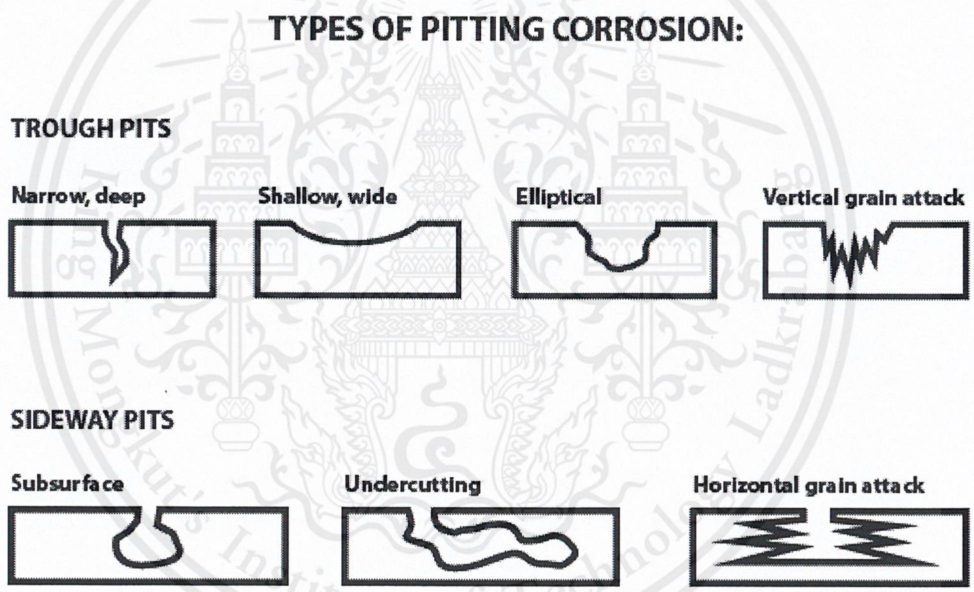


Figure 2.6 Types of pitting corrosion

(Gibson Stainless & Specialty Inc, 2016)

Pits can be wide and shallow or narrow and deep. If the pit attack is restricted in a small area of metal acting as an anode, the pits are described as deep. On the other hand, if the pit attack is in a relatively large area, the pits are described as shallow. These pits can rapidly pierce the wall thickness of the metal leading to the structure failure and metal loss (Schweitzer, P.A, 2010).

One of the most common types of pitting corrosion is under deposit corrosion. Under the deposit, a little amount of or no oxygen is observed while the bulk solution contains higher amount of oxygen, so pitting corrosion occurs under the deposit (Schroeder, C.D, 1991).

2.2.4.1 Under Deposit Corrosion (Herro, H.M. and Port, R.D, 1993)

Under deposit corrosion is a phenomenon that occurs mostly in boilers and cooling water systems. Deposits cause directly and indirectly corrosion. Direct corrosion occurs in case the deposits contain corrosive substances. Indirect corrosion is the result of surface shielding below the deposits. Direct and indirect attacks relate to the concentration cell corrosion.

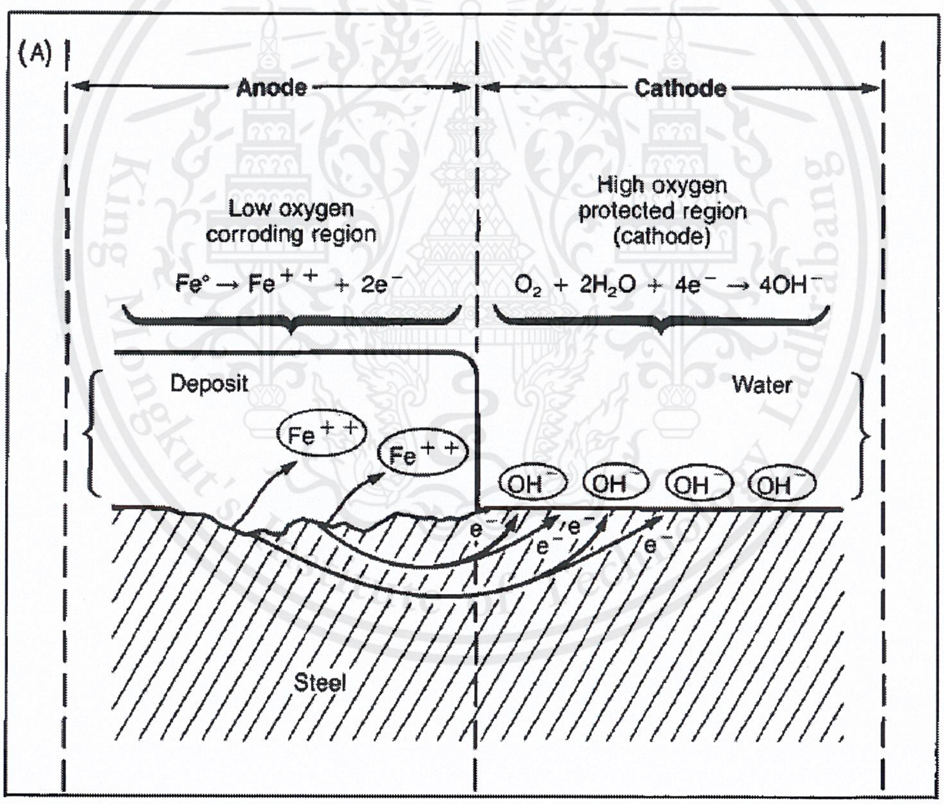


Figure 2.7 Oxygen concentration cell corrosion beneath a deposit

(Herro, H.M. and Port, R.D, 1993)

Deposits in the cooling systems produce oxygen differential cells associated with differential aeration, in which the environment beneath the deposits becomes oxygen deficient in comparison to the bulk solution, as shown in Fig. 2.7. The deposit retards oxygen diffusion to regions near the corroding surface causing the tube metal below the deposit to become anodic and corroded. Deposits can be generated internally as precipitates, laid down as transported corrosion products, or brought into the system from external sources. Heat exchangers, in which water temperature changes suddenly with distance, tend to accumulate precipitates and deposits. Equipment, in which water flow is slow or irregular, is subjected to under deposit corrosion. Deposits usually accumulate in narrow orifices, screens, long horizontal pipe runs, or at regions of constricted flow. The under deposit corrosion, therefore, can be found in any locations of the cooling systems, especially the troubled systems contain large amounts of silt, sand, grease, oil, precipitates, corrosion products, and other debris.

2.2.5 Corrosion Related Factors in Chilled Water System (Schroeder, C.D, 1991)

The related factors causing the corrosion in chilled water system are as follows:

1) Corrosion Related to Inhibitor Employed

Corrosion inhibitors in chilled water system prevent corrosion, but in many cases they fail to achieve their intended result and cause the problems. These corrosion inhibitor problems usually arise from incorrect applications, for example, high and low dosages, incompatibility with other water treatment chemicals, and scale formation.

2) Corrosion Related to Material Construction of Chilled Water Pipe

In plant construction, the material selection is very important. Improper materials can cause corrosion and additionally affect the performance of pipeline and equipment in the system.

Chilled water pipe of the MPM uses carbon steel same as any other usual cases. The corrosion resistance of carbon steel to pitting corrosion is relatively poor. Therefore, pits can be easily developed under the deposits in carbon steel pipe.

3) Corrosion Related to Water Quality

Besides all other corrosion related factors in chilled water system, water quality is another important factor to be considered. The quality of chilled water with high oxygen content, bacteria, suspended solids, etc can lead to corrosion.

Oxygen

Oxygen involves in many types of corrosion. Conversely, many metals depend on oxide films for their corrosion resistance. The oxygen content in daily operating cooling water is virtually no control. Therefore, if the oxygen content is known, it will make the selection of the proper inhibitor and material construction easier.

Bacteria

Bacteria can cause direct and indirect corrosion. The best prevention solution is by using the biocides to maintain the control.

Suspended solids

Suspended solids may also deposit in low-velocity or stagnant areas and create differential aeration cells, which cause pitting corrosion.

Demineralized water

Using demineralized water as chilled water without chemical treatment can cause problem. Demineralized water is completely free (or almost free) of dissolved minerals. Thus, it is more aggressive in terms of corrosion to carbon steel because it contains almost no calcium or magnesium ions. Calcium or magnesium ions existing in the water tend to form suspended compounds onto the metal surfaces, which can subsequently protect the metal surfaces from corrosion. In short, using demineralized water without chemical treatment or inhibitors in chilled water system can corrode pipeline.

Fig. 2.8 shows the immersing of coupon strip into demineralized water. The corrosion spots were observed on the coupon strip.

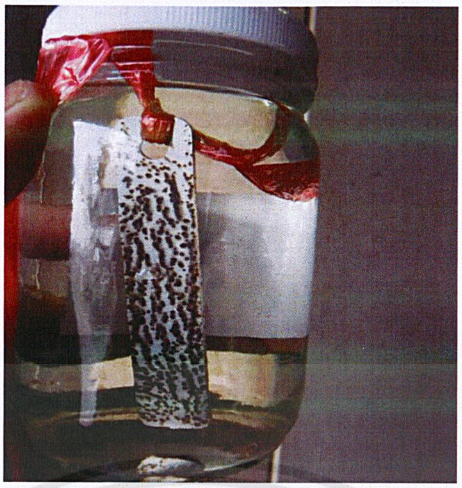


Figure 2.8 Coupon strip immersed in demineralized water from chilled water tank

(Momentive Performance Materials (Thailand) Limited, 2019)

2.2.6 Effects of Corrosion in Chilled Water System (Schweitzer, P.A, 2010)

Corrosion may affect direct and indirect losses. Direct losses involve the direct replacement of corroded equipment, components, structures including necessary labor cost and so on. For example, the additional costs from the use of corrosion-resistant metals or alloys instead of less-expensive carbon steel; from the applications of corrosion-resistant coatings to carbon steel; or from the addition of corrosion inhibitors.

In case of indirect losses, they involve:

1) Efficiency loss. Corrosion in the piping system and equipment can result in the buildup of a scale. This scale leads to poor heat transfer and needs more power consumption to pump the fluid through the system.
2) Downtime and shutdown. Downtime and unplanned shutdown due to the equipment failure from corrosion lead to production loss and consequently profit loss.
3) Loss of product. Many times, severe corrosion causes leakage and loss of product. If the leaking material itself is a corrosive material, it spreads adverse effects to the surroundings, and thus causes the additional losses.

2.3 Chemical Cleaning and Passivation

2.3.1 Chemical Cleaning

The pickling treatment is a chemical cleaning used in many industries to remove scale, rust and deposits from the metal surfaces. Pickling treatments can be divided into two processes: chemical and electrolytic cleaning processes. Chemical cleaning is used for the treatment of carbon steel, non-ferrous and light metals, and less frequently to alloy steels. This project considers chemical cleaning and passivation to solve the corrosion problems in chilled water system. The suitable chemical solutions used in chemical cleaning are success factors to remove fouling from the equipment prior to the passivation (Dibble, K, 2017). Two kinds of chemical cleanings are considered.

- Pre-operational cleaning is the preparation of the metal surfaces for chemical treatment, which can protect the metal surfaces from scale, corrosion products, and microbiological growth. It can be applied in the new systems or the equipment installed in any existing systems to remove the contaminated materials such as mill scale, rust, oil and grease resulting from fabrication or installation of the equipment (Guyer, J.P, 2011).

- Remedial cleaning is applied to improve the operating units that are fouled from scale, corrosion products and microbiological growth due to insufficient water treatment. The chemicals used for remedial cleaning usually consist of acids, chelating agents, neutralizing agents and specialty chemicals. Remedial cleaning is frequently done by outside vendors that are familiar with cleaning procedures, techniques and safety (Guyer, J.P, 2011).

In chemical cleaning mechanisms, the H^+ ions from the selected acid are used to remove rust (Fe_2O_3) on the metal surfaces. This reaction results in the conversion of iron oxide to soluble ferric ions and water, as shown in Eq. 2-7 (Technical Bulletin, 2004).

$$Fe_2O_3\ (s) + 6\ H^+\ (aq) \longrightarrow 2\ Fe^{3+}\ (aq) + 3\ H_2O\ (aq) \tag{2-7}$$

The other reactions occurring in chemical cleaning is shown in Fig. 2.9.

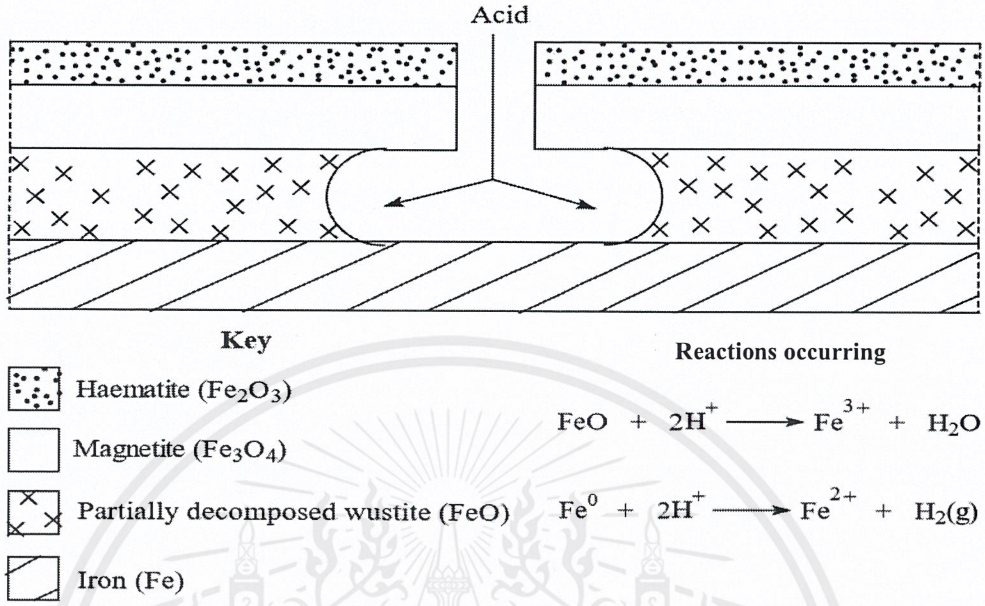


Figure 2.9 Reactions occurring in chemical cleaning

(Dibble, K, 2017)

However, the reaction between the acid and the metal iron produces hydrogen gas, of which the gas bubbles on the metal surfaces are visible. The hydrogen gas may also react with the metal, and this process is referred to hydrogen embrittlement. This undesired side-reaction can be reduced by adding the corrosion inhibitors to the acid solution. Each type of acid requires a specific inhibitor, so it is important to use the appropriate inhibitor to the specific acid (Technical Bulletin, 2004).

2.3.1.1 Chemical Cleaning Methods (Burt, V, 2015)

The chemical cleaning methods are circulation, fill and soak, cascade, foam, vapor phase organic, and steam-injected cleanings.

1) Circulation cleaning: the most common method used to clean columns, heat exchangers, cooling water jackets. The equipment is prepared until it can be filled with the chemical cleaning solutions and circulated by a pump to maintain flow to

the system. Flow of the solutions through the equipment helps the cleaning action in the system. During chemical cleaning, temperature and concentration are measured to monitor the progress, and a coupon strip is used to determine the effect of the chemicals on the equipment materials.

2) Fill and soak cleaning: a method involved the filling of chemical cleaning solutions into the equipment, and draining it after finishing. This method may be done repeatedly. The equipment is then flushed with water to remove loose particles and residual chemicals.

3) Cascade cleaning: a modification of the circulation cleaning method. This method is primarily used in large columns, and is suitable for several types of columns, except for packed columns. The chemical cleaning solution is filled in the column, and continuously drawn from the reservoir and pumped to the top of column. The solution then cascades down through the column and cleans the surfaces as it passes over them.

4) Foam cleaning: a static foam generator is used in the method to produce a foamed solvent from air or nitrogen gas. Foam cleaning is used on the equipment that cannot support full or partial filling with liquid solution. Foam cleaning results in significantly less solution volume for disposal compared with other methods.

5) Vapor phase organic cleaning: a method used in the equipment that is difficult to clean with liquids. For example, vaporized organic solvents are used to remove organic deposits from the columns. The organic solvent is vaporized, injected into the top of column, then condensed, collected in a circulation tank, and revaporized. The recirculation tank should be purged and blanketed with nitrogen gas, fitted with adequate venting and condensing system, and grounded to prevent an electrical charge accumulation inside the tank.

6) Steam-injected cleaning: by using this method, the concentrated mixture solution of chemical cleaning is injected into a stream of fast-moving steam. The steam is injected at one end of the system and condensed at the other end.

2.3.2 Passivation

Passivation is a process that makes steels more rust resistance. The two-step process of passivation is considered. In the first step, acid is used to remove any free iron ions or iron compounds on the metal surfaces, otherwise these free iron ions will generate a localized site where corrosion can continue. In the second step, the oxidizer is selected to form the uniform chromium oxide protective layer on the metal surfaces, as shown in Eq. 2-8 (Hunt, H, 2000).

$$4Cr\ (s) + 3O_2\ (g) \longrightarrow 2Cr_2O_3\ (s) \qquad (2\text{-}8)$$

This chromium oxide layer is invisible and only a few molecules thick, but it provides a barrier that will not let oxygen and moisture attack the metal surfaces, and will prevent rust.

A schematic structure of the first-formed adsorbed passive films is shown in Fig. 2.10. The initial passive films contain less or more than monolayer amounts of adsorbed oxygen molecules. After that the initial passive films grow into a multilayer adsorbed passive film of M•O•H structure (Revie, R.W and Uhlig, H.H, 2008).

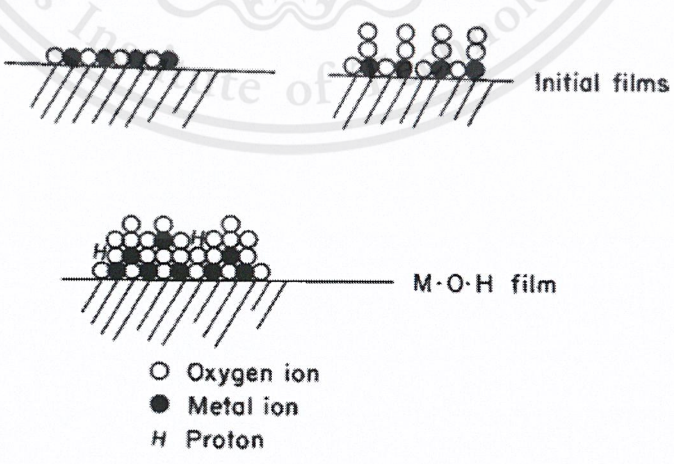


Figure 2.10 Schematic structure of initial passive films and a thicker passive film (Revie, R.W and Uhlig, H.H, 2008)

The most common acid used in passivation is nitric acid, which is a strong mineral acid. It can quickly dissolve free iron ions or iron compounds on the metal surfaces, and is also a strong oxidizer which can generate the chromium oxide protective layer at the same time (Hunt, H, 2000).

The other chemical is citric acid. It can effectively remove free iron ions from the metal surfaces, and it is safer to use than nitric acid. However, citric acid is not an oxidizer so it cannot generate chromium oxide protective layer which is the second step of passivation. If citric acid is used in passivation, the oxidizer, such as $NaNO_2$, will be added to form chromium oxide protective layer instead (Hunt, H, 2000).

The more common oxidizers used in passivation are sodium nitrite, hydrogen peroxide, air, and sodium bromate. A selection of passivating solution is also important, as some oxidant reaction by-products can obstruct uniformity of the new protective layer. For example, halides are known to strongly adsorb onto the metal surfaces so ClO_3^-, BrO_3^-, OCl^- are not good passivating agents (Dibble, K, 2017).

CHAPTER III

RESEARCH METHODOLOGY

The practical methods to solve the corrosion problems of chilled water system are, for example, metal selection and surface conditions control, environmental modification, cathodic protection and corrosion inhibitors. This project proposed two solutions 1) chemical cleaning and passivation, and 2) changing new pipeline by using good corrosion resistant material. The details are described below.

3.1 Methodology of Chemical Cleaning and Passivation

The methodology of the chemical cleaning and passivation is shown in Fig 3.1.

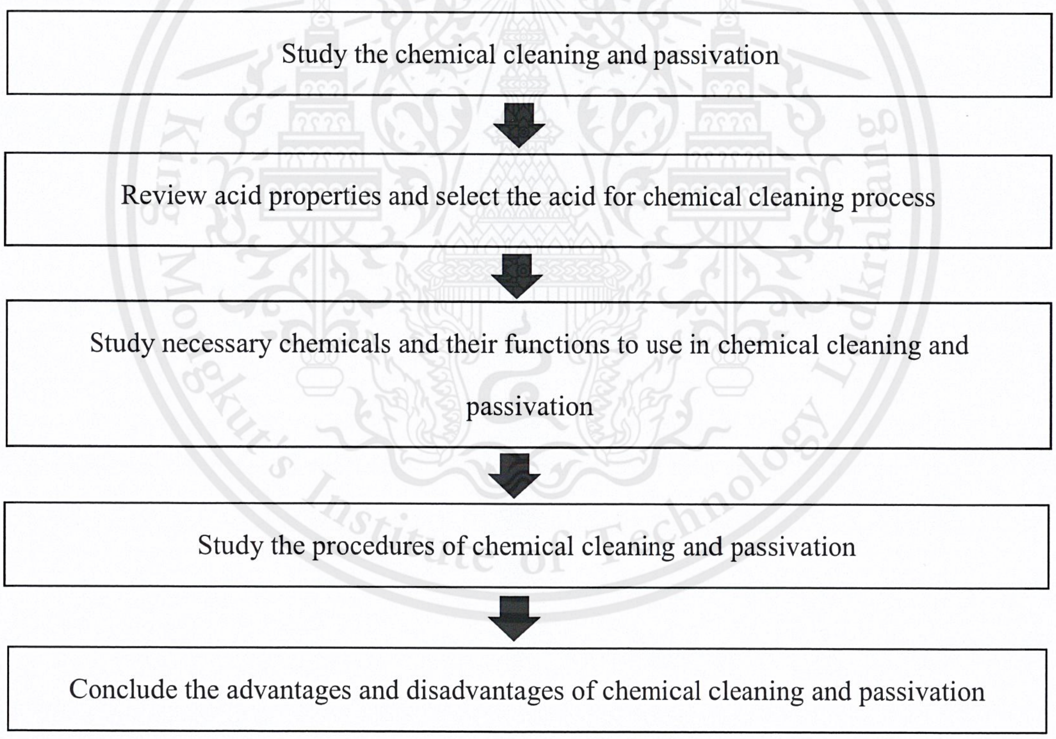


Figure 3.1 Simplified methodology of chemical cleaning and passivation

3.1.1 Procedure of Chemical Cleaning and Passivation

The procedure of chemical cleaning and passivation is divided into 4 parts.

Part 1: Preparation of Temporary Piping and Equipment

1. Fabricate all the temporary piping.
2. Provide temporary equipment and test-run.
3. Install the flow counters on the water supply line.
4. Flush the temporary system with clean water.
5. Leak test the temporary system at the maximum discharge pressure of the chemical circulating pump.

Part 2: Preparation of the Existing System for Chemical Cleaning and Passivation

1. Pre-inspection of rust and thickness of mill scale at the internal surface of the existing system (i.e., the existing piping and equipment of the chilled water system) to determine strength of acid used.
2. Confirm if the materials of all parts of the existing system are compatible with the selected acid solution.
3. Isolate the existing system to be ready for chemical cleaning and passivation.
4. Provide the circulating loop.
5. Mark all venting systems and drainage in the existing system. Fabricate the additional venting systems and drainage, if necessary.
6. Take out the removal coating on the surface of the existing system, if necessary, before chemical cleaning and passivation.

Part 3: Tie-in

Tie-in the temporary piping and equipment with the existing system.

Part 4: Chemical Cleaning and Passivation (CHC Chemical Co., Ltd, 2019. a)

1. **Flushing Step**

   Flush the existing system using clean water by the chemical circulating pump. Open all venting systems and drainage to remove loose particles, dirt and deposits.

2. **Leak Test**

Leak test the existing system before acid cleaning step at the maximum pump discharge pressure of the chemical circulating pump.

3. **Filling and Heating up**

If select sulfuric acid in chemical cleaning, it is necessary to fill up clean water in the existing system up to the maximum volume, and heat up the existing system to 45-50°C.

4. **Cleaning with Acid**

Add the appropriate inhibitor and acid into the circulating loop. Time to circulate depends on acid type and volume of the existing system. Keep the circulating loop until end of passivation. Sample the solution inside the chilled water system to check the total iron ions and percent acid concentration changed to monitor the cleaning process efficiency. Stop the circulation when the analysis results show that the total iron ions and percent acid concentration changed are constant three times consecutively.

5. **Draining and Rinsing**

Drain the solution inside the chilled water system under nitrogen gas atmosphere. Rinse the circulating loop with clean water until the pH of its effluent is higher than 5 to ensure any loose particles or deposits are removed.

6. **Iron Complexing**

After finishing the acid cleaning, the metal surfaces are active and easily corrodible. Add the iron complexing chemical (e.g., another acid solution different from cleaning acid) in the circulating loop to remove any free iron ions or its compounds from the metal surfaces. Keep the circulating loop for 1-2 hours.

7. **Neutralization**

Add neutralizing agent in the circulating loop (e.g., NH_4OH in case using sulfuric acid or NaOH in case using hydrochloric acid as the cleaning acid) to adjust the pH of the solution inside the chilled water system to 9-10. Keep the circulating loop for 1 hour.

8. **Passivation**

Add an oxidizer (e.g., $NaNO_2$ in case using sulfuric acid or Na_3PO_4 in case using hydrochloric acid as the cleaning acid) to create iron oxide protective layers or passive films on the metal surfaces. Keep the circulating loop for 2-4 hours. Drain the solution to the waste storage tank under nitrogen gas atmosphere.

9. **Treated Rinsing Water**

Fill up treated rinsing water in the chilled water system to eliminate oxygen gas and protect the passive films. Keep the circulating loop for 1 hour. Drain treated rinsing water to the waste storage tank.

10. **Inspection**

Select visual inspection of smooth passive films by one of two methods. The first method is immersing the coupon strip, which is the representative metal of the system in the chilled water system before chemical cleaning and passivation. After finishing the process, observe the passive films on the surface of coupon strip. The second method is random inspection of the pipeline and equipment to check the passive films on the metal surfaces.

3.2 Methodology of Changing New Pipeline By Using Good Corrosion Resistant Material

The methodology to study on changing new pipeline is shown in Fig 3.2.

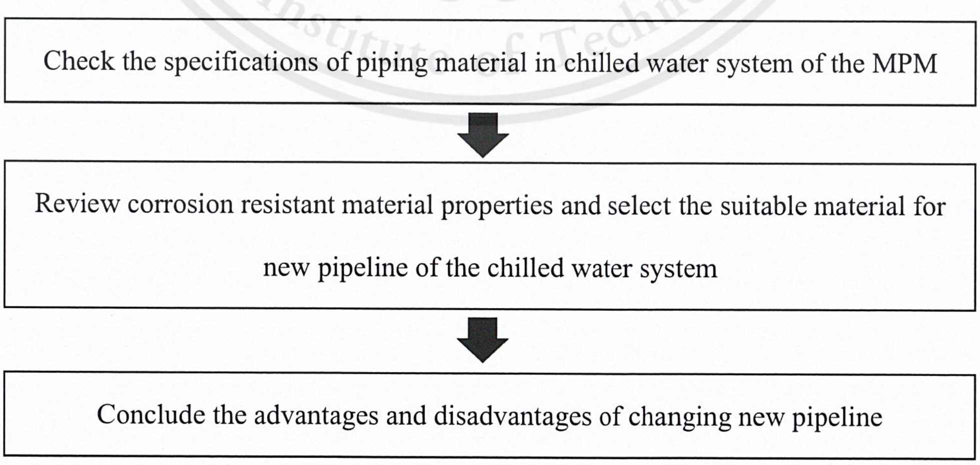


Figure 3.2 Simplified methodology of changing new pipeline

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Chemical Cleaning and Passivation

4.1.1 Acid Selection for Chemical Cleaning and Passivation

Acids can be divided into organic and inorganic acids. The common acids used in chemical cleaning and passivation are given in Table 4.1.

Table 4.1 Acids used in chemical cleaning and passivation

Inorganic Acids	Organic Acids
Sulfuric Acid (H_2SO_4)	Formic Acid (HCOOH)
Nitric Acid (HNO_3)	Citric Acid
Hydrochloric Acid (HCl)	Oxalic Acid
Hydrofluoric Acid (HF)	EDTA

Acid selection is primarily considered from the scale (deposit) types, the physical and chemical properties of acids, the acid solution temperature, and the material of piping and equipment. In addition, price is also important to consider. To compare with organic acids, inorganic acids are cheaper. Most of inorganic acids can be used at room temperature because of their high ionization while organic acids, which are less ionization, are used at the temperature around 90°C.

Nitric acid is a strong inorganic acid so it can quickly dissolve all iron compounds on the metal surfaces. It is usually used in chemical cleaning of stainless steel because it does not damage the protective chromium oxide layer on stainless steel. Conversely, dilute nitric acid will rapidly corrode copper alloys and carbon steel so it cannot use to clean the chilled water system of the MPM.

Sulfuric acid, hydrochloric acid, and rydlyme are considered an appropriate acid to use in chemical cleaning and passivation of the chilled water system.

4.1.1.1 Sulfuric Acid

Sulfuric acid is one of the most important inorganic acids with a wide range of applications. The physical properties of sulfuric acid are given in Table 4.2.

Table 4.2 Physical properties of sulfuric acid

Molecular Formula	H_2SO_4
Molecular Weight	98.08 g/mol
Density	1.84 g/mL
Physical State	Liquid
Color	Colorless
Odor	Pungent
Solubility	Water

The processes of scale solution on chemical cleaning in sulfuric acid are shown by the following equations (Fedot'ev, N.P. and Grilikhe, S.Y, 1959).

$$FeO\ (s) + H_2SO_4\ (aq) \longrightarrow FeSO_4\ (aq) + H_2O\ (aq) \qquad (4\text{-}1)$$

$$Fe_2O_3\ (s) + 3H_2SO_4\ (aq) \longrightarrow Fe_2(SO_4)_3\ (aq) + 3H_2O\ (aq) \qquad (4\text{-}2)$$

$$Fe\ (s) + H_2SO_4\ (aq) \longrightarrow FeSO_4\ (aq) + H_2\ (aq) \qquad (4\text{-}3)$$

$$Fe_3O_4\ (s) + 4H_2SO_4\ (aq) \longrightarrow FeSO_4\ (aq) + Fe_2(SO_4)_3\ (aq) + 4H_2O\ (aq) \qquad (4\text{-}4)$$

$$Fe_2(SO_4)_3\ (aq) + Fe\ (s) \longrightarrow 3FeSO_4\ (aq) \qquad (4\text{-}5)$$

Chemical cleaning with sulfuric acid produces the iron solutions, which can be removed from the chilled water system. The solubility of the oxides in sulfuric acid is not the same for the different oxides.

Sulfuric acid is an effective solvent for iron oxide removal, and it provides a quick initial attack on scale deposits. The acid must be heated during chemical cleaning and the rate of cleaning can be controlled by varying the temperature.

Sulfuric acid cannot be used for the removal of scale containing a large amount of calcium and magnesium salts because it will produce the calcium and magnesium sulfates that are hard scales, as shown in the example of Eq. 4-6.

$$CaCO_3\,(s) + H_2SO_4\,(aq) \longrightarrow CaSO_4\,(s) + H_2CO_3\,(aq) \qquad (4\text{-}6)$$

Sulfuric acid has special remarks on corrosivity that it has a severe corrosive effect on brass and bronze, so all brass and bronze materials in chilled water system must be removed before chemical cleaning and passivation.

4.1.1.2 Hydrochloric Acid

Hydrochloric acid is a colorless liquid with an irritating odor. Hydrochloric acid solution consists of hydrogen chloride gas dissolved in water. At room temperature, hydrogen chloride is corrosive and nonflammable gas, which is heavier than air. On exposure to air, hydrogen chloride forms dense white corrosive vapors. Table 4.3 shows the physical properties of hydrochloric acid.

Table 4.3 Physical properties of hydrochloric acid

Molecular Formula	HCl
Molecular Weight	36.46 g/mol
Density	1.2 g/mL at 25°C
Physical State	Liquid
Color	Colorless
Odor	Pungent
Solubility	Water

In the past, hydrochloric acid with corrosion inhibitor is widely used for chemical cleaning. It has good solubility with a wide variety of scales and can be used at the room temperature. The key of hydrochloric acid for scale dissolution is the aggressive chloride anion associated with hydrogen ion in an acid. However, it is too aggressive for some applications such as stainless steel.

Unlike sulfuric acid, hydrochloric acid can produce ferrous chloride ($FeCl_2$) which is a strong pitting test solution, as shown in Eq. 4-7.

$$Fe^{2+}\,(aq) + 2HCl^{-}\,(aq) \longrightarrow FeCl_2\,(aq) + H_2\,(g) \qquad (4\text{-}7)$$

Furthermore, hydrochloric acid will fume when heated above ambient temperatures and provide a toxic gas of hydrogen chloride.

4.1.1.3 Rydlyme

Figure 4.1 Rydlyme descaling chemical

(Amazon, Inc. 2018)

Rydlyme is trade name of an invented descaling chemical, which composes of 5-9 % by weight of hydrochloric acid (The additional ingredients are confidential). This liquid mixture is non-toxic, non-injurious, non-flammable, non-hazardous, non-corrosive and biodegradable so it will not damage the materials, equipment and environment. Rydlyme will not corrode, oxidize or have other deleterious effects on metals or materials such as iron, copper, steel, brass, plastic, glass, rubber, ceramic, nickel and stainless. The physical properties of rydlyme are given in Table 4.4.

Table 4.4 Physical properties of rydlyme

Mixture	HCl 5-9 % by weight
Density	1.12 g/mL at 20°C
Physical State	Liquid
Color	Dark Liquid
Odor	Comparable to Almonds
Solubility	Water

Even though almost any chemical reactions will react faster under elevated temperatures, rydlyme can be applied at ambient temperatures (18°C to 35°C) with full effectiveness and obtainable results. However, the application of rydlyme may expose pre-existing under deposit corrosion that can result in leaks in pipes, equipment or system. The vendor never uses rydlyme in chemical and passivation.

Considering the selected acids used in chemical cleaning and passivation, the advantages and disadvantages of the acids are given in Table 4.5.

Table 4.5 Advantages and disadvantages of sulfuric acid, hydrochloric acid and rydlyme

	Sulfuric Acid	Hydrochloric Acid	Rydlyme
Advantages	1. Can be renewed more frequently 2. Provide a quick initial attack on scale deposits 3. The rate of pickling can be controlled by varying the temperature 4. Cheaper than using hydrochloric acid and rydlyme	1. More extensive scale removal 2. Can be used at room temperature 3. Use less cleaning time than sulfuric acid	1. Non-corrosive, non-hazardous, and biodegradable 2. Can be applied at ambient temperature 3. Does not exude any obnoxious or toxic vapors 4. Not require neutralizers and it is free rinsing with water 5. Not corrode or attack on steel, iron, brass, bronze, copper, glass, etc.
Disadvantages	1. More dangerous to handle 2. Acid solutions must be heated 3. Has severe corrosive effect on brass and bronze 4. Cannot use for the removal of scale containing a large amount of calcium 5. Has pungent odor	1. More corrosive toward equipment 2. Higher disposal costs than sulfuric acid 3. Fume when heated above ambient temperatures (provide toxic gas of hydrogen chloride) 4. Not compatible with stainless steel 5. Produce ferric chloride ($FeCl_2$) which is a strong pitting test solution 6. Has pungent odor	1. May expose pre-existing under deposit corrosion (pitting, holes or similar damage) that can result in leaks in pipes, equipment or systems 2. The more expensive than using sulfuric acid and hydrochloric acid 3. Vendor never uses rydlyme in the chemical cleaning process (vendor has no experience)

Based on the properties as mentioned above, sulfuric acid is recommended for using in the chemical cleaning and passivation of chilled water system. Unlike hydrochloric acid, sulfuric acid does not fume and provide a toxic gas although it is operated above the ambient temperature. Due to the absence of chloride ion, sulfuric acid does not produce ferrous chloride ($FeCl_2$), resulting in a strong pitting test solution. The cost of using sulfuric acid in chemical cleaning and passivation is the lowest among these three acids. In addition, the vendor has more experience in using sulfuric acid for chemical cleaning and passivation than hydrochloric acid and rydlyme. Since sulfuric acid has severe corrosive effect on equipment contained brass and bronze alloys, these materials must be removed from the chilled water system before chemical cleaning and passivation.

4.1.2 Chemicals Used in Chemical Cleaning and Passivation

The basic chemicals used in chemical cleaning and passivation are as follows:

4.1.2.1 Corrosion Inhibitor

Corrosion inhibitor is a chemical substance used to reduce or prevent the corrosion in chemical cleaning and passivation. Small concentrations of inhibitor are added to an acid solution to maintain an inhibiting films and prevent an acid to corrode on the metal surfaces. Therefore, it is necessary to use an appropriate corrosion inhibitor to the specific acid.

4.1.2.2 Acid

Acid is used to remove any rust or deposits from the metal surfaces. The acid selection depends not only on the price and how strong it is, but also depends on the associated anion with the hydronium ion in the acid. Acid will dissolve iron oxide deposits and corrosion products in the equipment so an adequate acid solution must be maintained and circulated in the circulating loop to remove all deposits.

4.1.2.3 Chelating Agent

The metal surface after cleaning with an acid solution is highly reactive and easily to corrode. A chelating agent is added to circulate in the system to remove any free iron ions and iron compounds on the metal surfaces and prevent rust on the surfaces. The most common chelating agents are nitric and citric acid.

4.1.2.4 Neutralizing Agent

After cleaning deposits by acid solution, it is necessary to add neutralizing agent to remove the remaining acid from the circulating loop and adjust the pH before passivation.

4.1.2.5 Passivating Agent or Oxidizing Agent

After cleaning free iron ions and neutralizing the circulating loop, the metal surfaces must be coated with oxide protective layers to prevent the corrosion. An oxidizing agent is added to form oxide protective layers on the metal surfaces. The layers cannot be further oxidized and can protect the metal surfaces from the corrosion.

Table 4.6 Details of chemicals used in chemical cleaning and passivation with sulfuric acid (CHC Chemical Co., Ltd, 2019. b)

Process	**Chemicals**	**Functions**
Chemical Cleaning	Rodine 31A	Use as a corrosion inhibitor for sulfuric acid
	Sulfuric Acid	Use to remove iron oxide deposits
	ABF (Ammonium Bifluoride)	Use to dissolve silica deposits in carbon steel
Passivation	Citric Acid	Use as a chelating agent to remove free iron ions from the metal surface
	Ammonium hydroxide	Use to adjust pH before passivation
	Sodium nitrite	Use as an oxidizer to form passive film
	Eliminox	Use as an oxygen scavenger to reduce oxygen in the system after passivation

Table 4.7 Details of chemicals used in chemical cleaning and passivation with hydrochloric acid (Relate Intertrade Co., Ltd, 2019. b)

Process	**Chemicals**	**Functions**
Chemical Cleaning	Armohib 28	Use as a corrosion inhibitor for hydrochloric acid
	Hydrochloric Acid	Use to remove iron oxide deposits
	Antifoam	Use as a defoamer
Passivation	Citric Acid	Use as a chelating agent to remove free iron ions from the metal surface
	Sodium hydroxide	Use to adjust pH value before passivation
	Sodium phosphate	Use as an oxidizer to form passive film

4.1.3 Advantages and Disadvantages of Chemical Cleaning and Passivation

Advantages

1) Less time to shutdown. Time to prepare and operate the chemical cleaning and passivation is 7-10 days. Therefore, the plant processing has less time to shutdown than changing new pipeline.
2) No demolition and reassembly. The piping and equipment to be cleaned does not need to dismantle or reassemble in chemical cleaning and passivation.
3) Less cost. The company will spend less cost for chemical cleaning and passivation than changing new pipeline.

Disadvantages

1) Leak in pipe. The chemical cleaning and passivation process involve the acid solutions and it can cause pipe to crack or leak after cleaning.
2) Using hazardous chemicals. Some chemicals in chemical cleaning and passivation process are hazardous chemicals and dangerous to handle so they require the special control.

3) Short service life. The chemical cleaning and passivation process should be done once every 5 to 8 years.

4.2 Changing New Pipeline

4.2.1 Material Selection Criteria

An appropriate material is very important to change new pipeline. No metal can prevent corrosion in all environments, but through monitoring and understanding the environmental conditions that are the cause of corrosion, changing the appropriate material can also reduce corrosion in the system. The material selection may involve several factors as follows:

4.2.1.1 Corrosion-resistance

Corrosion resistance is one of the important properties of pipe. To prevent the corrosion, one simple way is to use corrosion resistant material. A good corrosion resistant material helps reduce using additional corrosion protection such as corrosion inhibitors.

4.2.1.2 Design Temperature

The design temperature of the material in piping system must withstand the highest temperature of the fluid in the system.

4.2.1.3 Design Pressure

The design pressure of the piping system should be not less than the pressure at the most severe condition of the coincidental internal/external pressure and temperature expected during the service life.

4.2.1.4 Service life

The service life is a range of time that a pipe is estimated to provide adequate performance before maintenance, repair or replacement. Corrosion can cause a pipe to deteriorate and shorten its service life.

4.2.2 Piping Material Specifications (Bhatia, A, n.d.)

4.2.2.1 ASTM

The American Society for Testing and Materials or ASTM is an international standard specification covering areas such as metals, paints, plastics, textiles, petroleum, construction, energy, the environment, consumer products, medical services and devices, and electronics. It defines the material specifications and defines the exact chemical composition of pipes, fittings and flanges, through percentages of the permitted quantities of carbon, magnesium, nickel, etc.

4.2.2.2 ASTM Material Designation

The designation system of ASTM for metals consists of document collections called material specifications for standardizing materials of large use in the industry.

- Specifications starting with “A” are for steel.

- Specifications starting with “B” are for non-ferrous alloys such as brass, bronze, copper nickel alloys, aluminum alloys etc.

- Specifications starting with “D” are for plastic material, as PVC.

4.2.2.3 Pipe Grades

Grade refers to divisions of steel (A, B, C…) within different types of pipes. It defines the mechanical properties such as the maximum tensile strengths and the yield strengths.

- Grade A: a softer steel, which is easier to blend

- Grade B: this grade has higher tensile and yield strength than Grade A. It has higher stress values and is better suited for machining operations.

- Grade C: this grade has higher tensile and yield strength than Grades A and B.

4.2.3 Specifications of Piping Material in Chilled Water System of the MPM

The specification of piping for chilled water system in the MPM is shown in the Fig. 4.2.

BANGKOK TTCL THAILAND TOYO-THAI CORP.,LTD	TIGER PROJECT TTCL Job.No. D-107 ENGINEERING SPECIFICATION FOR PIPING MATERIAL	TIGER A1S < 7 >
20 Feb, 2004 / Rev.No. 3	Piping Doc.No. D107-P-002	Page 1 of 1

SERVICE	Industrial WaterCoolIng WaterChilled Water						BRANCH	T-BA0558-1	REDUCER	R-BA0558-1
C.A.(mm.)	1.0	P-T	TEMP. (C)	50	50	50	80			
PWHT	NO	RATING	PRESS. MPA	0.5	0.5	0.5	0.01			

NOM.SIZE(NPS)	MATRIAL	PRODUCT	END	WALL THICK	REF.TO	NOTE	REV
PIPE							
1/2 - 11/2	A53GR.B	SMLS	PE	SCH 80	ASME B36.10M		
2 - 6	A53GR.B	ERW	BE	SCH 40	ASME B36.10M		
8 - 16	A53GR.B	ERW	BE	SCH 20	ASME B36.10M		

Figure 4.2 Specifications of piping material in chilled water system of the MPM (Momentive Performance Materials (Thailand) Limited, 2004)

The mainline of chilled water pipe in the MPM is 3-inch carbon steel pipe. The specifications of chilled water pipeline can be concluded in Table 4.8. This specification of the pipeline will be used to compare with other materials of pipe in material selection later.

Table 4.8 Specifications of chilled water pipeline in the MPM (Momentive Performance Materials (Thailand) Limited, 2004)

Size	3”
Material	Carbon steel pipe
Product	Electric resistance weld
End	Beveled end
Wall thickness	5.49 mm
Weight	11.3 kg/m

4.2.4 Specifications of Chilled Water Pump in the MPM

TOSHIBA GE TOSHIBA SILICONES(THAILAND), LTD

CENTRIFUGAL PUMP
DATA SHEET

CUSTOMER	GE TOSHIBA SILICONES(THAILAND),LTD		
LOCATION	RAYONG, THAILAND		
PLANT	UTILITY	WORK NO.	D-107
ITEM NO.	P-924A/B	REQ. NO.	D-107-1300-R002
SERVICE	CHILLED WATER PUMP		
NO. REQ'D	2		

AUTH. BY	CHKD. BY	MADE BY
REV. NO.	DATE	DESCRIPTION
3/D	FEB. 20, 2004	

OPERATING CONDITION

LIQUID		CHILLED WATER	
- Name		Demineralizes Water	
- Temperature		20~25	[deg.C]
- Specific Gravity		0.998@20deg.C and 0.997@25deg.C	
- Vapor Pressure		0.032	[BarA]
- Viscosity		1	[cP]
PRESSURE			
- Suction	(Nor.)	0	[BarG]
	(Max.)	-	[BarG]
- Discharge		5.0	[BarG]
- Differential		5.0	[Bar]
TOTAL HEAD		51.1	[m]
T OFF HEAD		62.1	[m]

FLOW RATE	(Min.)	-	[m³/hr]
	(Nor.)	25	[m³/hr]
	(Max.)	30	[m³/hr]
LOCATION	(X) Indoor	( ) Outdoor	
	( ) Winterization Req'd		
	( ) Tropicalization Req'd		
	( ) Hazardous	(X) Non-hazardous	
	( )		
NOISE LEVEL	85	[dB(A)] and less @1m	
PROCESS	(X) Automatic Start	( ) Manual Start	
CONTROL	(X) Automatic Stop	( ) Manual Stop	
OTHER REQUIREMENTS			

Figure 4.3 Specifications of chilled water pump in the MPM

(Momentive Performance Materials (Thailand) Limited, 2004)

Fig. 4.3 shows the specifications and operating conditions of chilled water pump in the MPM and can be concluded in Table 4.9.

Table 4.9 Specifications of chilled water pump in the MPM (Momentive Performance Materials (Thailand) Limited, 2004)

Type	**Centrifugal pump**
Material	Ductile iron
Different Pressure	5 bar
Maximum Flow Rate	30 m^3/h

4.2.5 Material Selection

4.2.5.1 Carbon Steel

Chilled water pipe of the MPM uses carbon steel, which is the most widely used material for piping systems with a carbon content up to 2.1 % by weight. It is used in a variety of heavy-duty industries such as infrastructure, ships, distillers, and chemical fertilizer equipment due to high strength and ability to withstand stress. Carbon steel piping provides safety and durability because it is shock resistant. It is also recyclable, making it both environmentally friendly and cost-effective.

Figure 4.4 Carbon steel pipe

(Titan Tube and Metal, 2019)

Carbon steel pipe is made of variety of grades to use in the process requirement of the industries (Bhatia, A. n.d):

1) Low Carbon Steel

- Carbon content less than 0.3%
- Low strength and good formability
- Good weldability and machinability
- Not responsive to heat treatment; cold working need to improve the strength

2) Medium Carbon Steel

- Carbon content in the range of 0.3-0.6%
- Medium carbon steel has low hardenability
- Addition of Ni, Cr, Mo improves the heat-treating capacity
- Have moderate to high strength with good ductility

3) High Carbon Steel

- Carbon content in the range of 0.6-1.4%
- High carbon content provides high hardness and strength
- Strong carbide formers, such as Cr, V, W, are added as alloying elements to form carbides of these metals
- Used in hardened and tempered condition
- High percentage of carbon however lowers ductility, toughness and machinability
- Used in applications where surface is subject to abrasion

Properties

- Carbon steel losses all its stress resistance at 650°F/345°C.
- Tensile strength reduces at high temperature.
- As the carbon percentage content rises, steel is harder and stronger but less ductile.
- Carbon steel has high hardness, toughness and strength, and it is relatively inexpensive compared to other steels.
- Carbon steel pipe is recyclable and can be utilized many times over as a part of different shapes and structures.

4.2.5.2 Stainless Steel

Figure 4.5 Stainless steel pipe

(WQC Institute of NDT, 2018)

Stainless steel is a corrosion-resistant steel alloying with a minimum of 10.5% chromium. Unlike carbon steel, chromium has been added in stainless steel to create an invisible passive film of chromium oxide that will not let oxygen attack the surface and will prevent rust when the material is exposed to air and moisture. As more chromium is added to the stainless steel, improved corrosion resistance results, consequently there are stainless steels with chromium contents of 15, 17, and 20% (and even higher). Chromium also provides a resistance to oxidizing environments such as nitric acid. To provide even greater corrosion resistance and mechanical strength, other alloying ingredients are added. Molybdenum is extremely effective in improving pitting and crevice corrosion resistance. Stainless steel is more expensive than standard grades of steel, but it has greater corrosion resistance, needs low maintenance and has no need for painting or other protective coatings.

There are five major groups of stainless steel, depending upon their microstructure, and they are classified as: ferritic, austenitic, martensitic, duplex and precipitation hardening. The properties of these groups differ but are essentially the same within the same group. Table 4.10 lists the metallurgical characteristics of each group of stainless steel.

Table 4.10 The metallurgical characteristics of five groups of stainless steel (Bhatia, A, n.d)

Austenitic (200-300 series)	- Contains 16-26% chromium and 6-22% nickel - Non-magnetic and most corrosion resistant - Non-hardenable by heat treatment - Very easy to weld - Not subject to 885°F/475°C embrittlement - Not subject to ductile-brittle temperature range - Susceptible to chloride stress corrosion cracking (SCC)
Ferritic (400 series)	- Contains 15-30% chromium - Magnetic - Non-hardenable by heat treatment - Low carbon grades easy to weld - Resistance to chloride stress corrosion cracking - Subject to 885°F/475°C embrittlement at temperatures as low as 600°F/315°C - Subject to ductile-brittle temperature embrittlement
Duplex (Ferrite + Austenite)	- Contains both ferrite and austenite - Magnetic - Non-hardenable by heat treatment - High strength, easy to weld - Subject to 885°F/475°C embrittlement at temperatures as low as 600°F/315°C - Subject to 885°F/475°C embrittlement at temperatures as low as 600°F/315°C - Resistance to chloride stress corrosion cracking if ferritic network
Martensitic (400 series)	- Magnetic - Heat treatable to hardness levels - Hard to impossible to weld
Precipitation Hardening	- Magnetic - Ultra-high strength due to precipitation hardening - Heat treatable to hardness levels - Weldable

To change new pipeline in the chilled water system of MPM, type 304 of austenitic stainless steel is considered.

Stainless steel type 304 is the most widely used chromium-nickel stainless steel for general corrosive resistant applications because of its economical among all other common stainless steels for piping applications.

Type 304 has a maximum carbon content of 0.08%. Upper temperature limit is 1400°F/760°C but it is not recommended to use in the temperature range between 750°F/400°C because it is subject to intergranular corrosion as a result of carbide precipitation at the grain boundaries. The allowable operating pressures for type 304 stainless steel are given in Table A.1 (Appendix A).

This type of stainless steel exhibits good overall corrosion resistance. It is used extensively in the handling of nitric acid and most organic acids, but it is susceptible to chloride stress corrosion cracking (SCC).

4.2.5.3 Polyethylene-Lined Steel Pipe (Syler Pipe)

Polyethylene-lined steel pipe or syler pipe is galvanized steel pipe that the inner part is lined with polyethylene (PE). It can prevent internal rusting because the water inside the pipe will not contact the metal directly. The exterior is coated with PE powder to prevent rust on the outside layer, as shown in Fig. 4.6.

Figure 4.6 Polyethylene-lined steel pipe (syler pipe)

(Syler Group Co., Ltd, 2015)

PE-lined steel pipes are shown in Fig. 4.7 and their properties are shown in Fig. 4.8

1) Type C – for cold water, this type of pipe can be used to delivery water under 60°C.

2) Type H – for hot water, this type of pipe can be used to delivery water under 90°C.

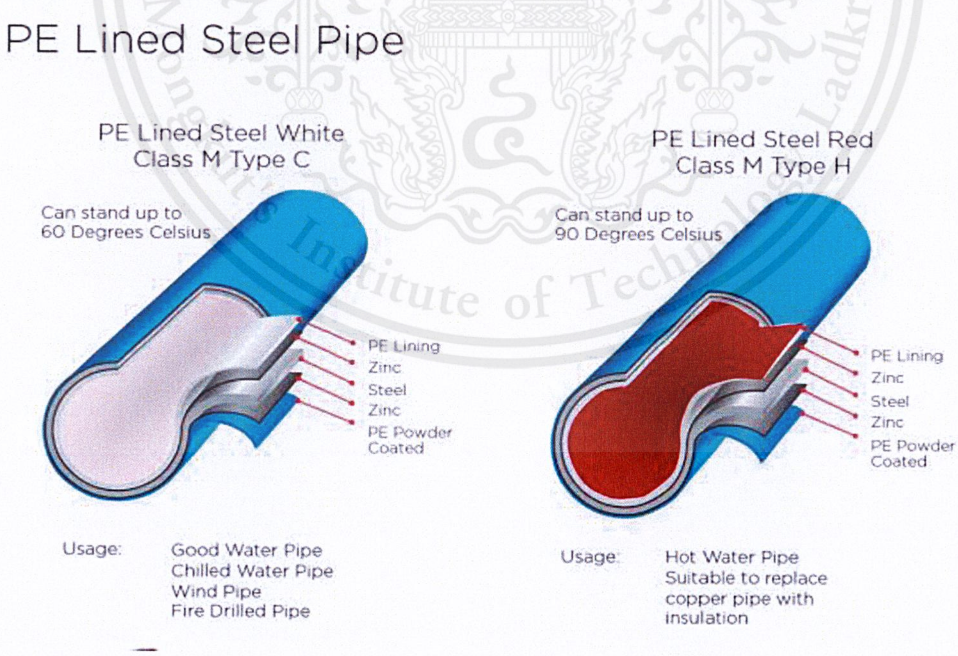
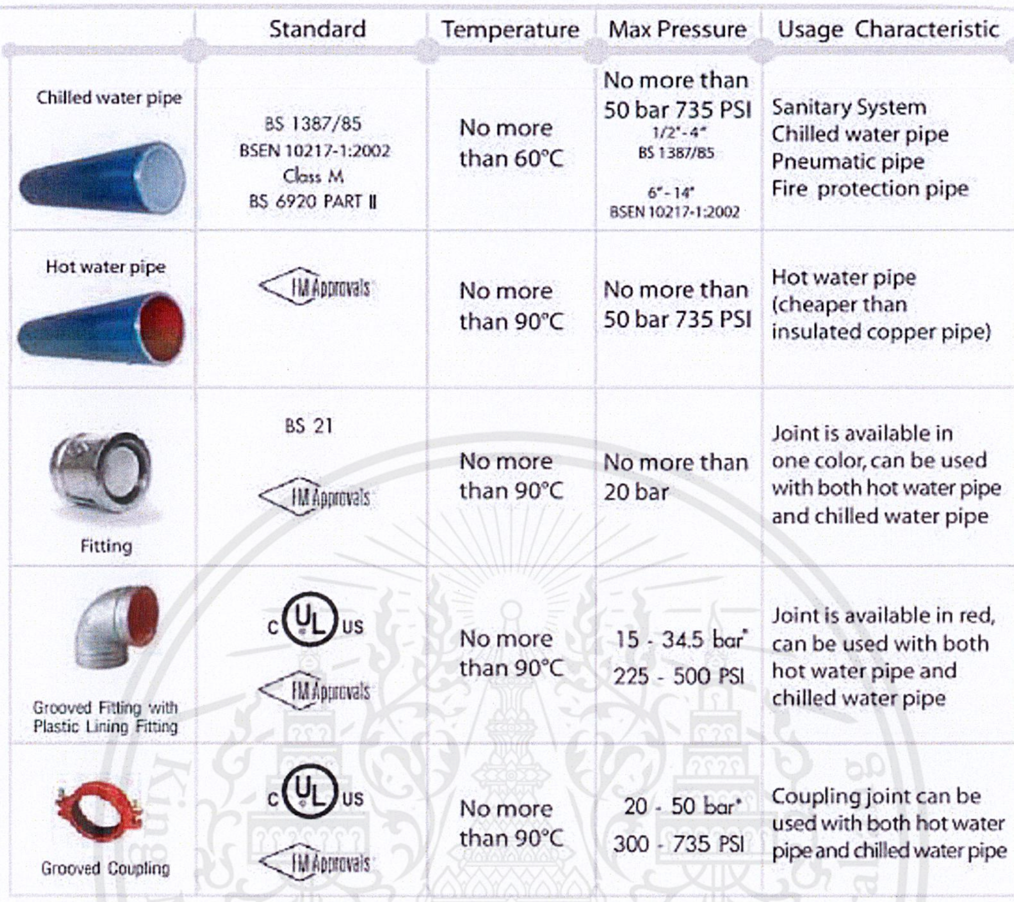


Figure 4.7 Two types of syler pipes

(Syler Group Co., Ltd, 2015)



	Standard	Temperature	Max Pressure	Usage Characteristic
Chilled water pipe	BS 1387/85 BSEN 10217-1:2002 Class M BS 6920 PART II	No more than 60°C	No more than 50 bar 735 PSI 1/2"-4" BS 1387/85 6"-14" BSEN 10217-1:2002	Sanitary System Chilled water pipe Pneumatic pipe Fire protection pipe
Hot water pipe	FM Approvals	No more than 90°C	No more than 50 bar 735 PSI	Hot water pipe (cheaper than insulated copper pipe)
Fitting	BS 21 FM Approvals	No more than 90°C	No more than 20 bar	Joint is available in one color, can be used with both hot water pipe and chilled water pipe
Grooved Fitting with Plastic Lining Fitting	c UL us FM Approvals	No more than 90°C	15 - 34.5 bar* 225 - 500 PSI	Joint is available in red, can be used with both hot water pipe and chilled water pipe
Grooved Coupling	c UL us FM Approvals	No more than 90°C	20 - 50 bar* 300 - 735 PSI	Coupling joint can be used with both hot water pipe and chilled water pipe

Figure 4.8 Properties of chilled water and hot water syler pipes and their fittings

(Syler Group Co., Ltd, 2015)

Properties

- PE-lined steel pipe can prevent problems such as pipe leaks from rust corrosion, pipe is clogged with rust or pipe is broken when used outdoor, etc.

- The transported fluid and the metal layer, which is the main source of corrosion or rust, can be separated completely and effectively. With contact only with the PE pipe, that has good corrosion resistance, the water is kept fully clean and uncontaminated.

- The PE lined steel pipe has good properties characterized by the galvanized steel pipe, such as high durability to the impact, bending and high strength.

- With its smooth internal surface, the fluid can run smoothly and quickly to avoid the block.

- Syler pipe has both good corrosion resistance of PE and high strength of galvanized steel pipe. It also has long service life for 50 years minimum.
- Syler couplings have been specially designed to prevent water and metal contact directly within the pipe.
- Syler pipe is suitable for water supply piping including chilled water piping.

To select the material for changing new pipeline in chilled water system, the properties of each material must be compared with the chilled water pipe of the MPM (3-inch carbon steel pipe), as shown in Table 4.11.

Table 4.11 Properties of carbon steel, stainless steel and syler pipe in size 3 inches.

	Carbon steel pipe	**Stainless steel pipe (Type 304)**	**PE-lined steel pipe (Syler pipe)**
Corrosion resistance	Fair to poor	Good	Good
Cost	Cheap	Expensive	Fair
Withstand pressure	156 bar at -29 to 38°C	146 bar at -198 to 28°C	50 bar
Operating temperature	-28 to 425°C	Not higher than 760°C	Not higher than 90°C
Service life	15 years minimum	20 years minimum	50 years minimum
Weight	11.3 kg/m	11.3 kg/m	8.8 kg/m
Thickness	5.5 mm	5.5 mm	5.8 mm
Insulation	Required	Required	Not required

**Remarks: 1) Design pressure of chilled water system is not higher than 6 bar.

2) Operating pressure of chilled water system is 5 bar.

3) Operating temperature of chilled water system is -20°C to 9°C

For material selection, of the three materials, i.e., carbon steel, stainless steel and PE-lined steel, the PE-lined steel is recommended for new chilled water pipeline of MPM. PE-lined steel pipe is a good corrosion resistant pipe and can be used for water supply piping including chilled water piping. The pipe is designed to prevent problems from rust and corrosion by internal PE-lining to prevent the water inside the pipe directly contact with galvanized steel pipe. The operating temperature of this pipe is not higher than 90°C while the operating temperature of chilled water is the range from -20°C to 9°C. The withstand pressure of PE-lined steel pipe is 50 bar so it can withstand the operating pressure of chilled water system. The weight of PE-lined steel pipe is less than carbon steel pipe so the support can be durable PE-lined steel pipe.

However, PE-lined steel pipe requires special fittings and couplings that are designed for the pipe.

4.2.6 Advantages and Disadvantages of Changing New Pipeline

Advantages

1) Long service life. The service life of changing new pipeline depends on the service life of piping material. The service life of PE-lined steel pipe is 50 years minimum. It is longer than chemical cleaning and passivation that should be done once every 5 to 8 years.

2) No hazardous chemicals. Changing new pipeline does not require any hazardous chemicals.

Disadvantages

1) Long time to shutdown. Changing new pipeline of chilled water system needs more time to prepare and change the pipeline than using chemical cleaning and passivation.

2) Expensive cost. Cost of new pipes, fittings, couplings, other parts of pipes, and labors when changing new pipeline is more expensive than using chemical cleaning and passivation.

CHAPTER V

CONCLUSION

This project investigated the corrosion problems of chilled water system and therefore proposed the solutions to solve the problems. The corrosion found in chilled water system of this case study is the under deposit corrosion. Under deposit corrosion involves differential aeration, in which the environment beneath the deposit becomes oxygen deficient in comparison to the bulk solution. This causes the metal below the deposit to become anodic and corroded, so the chemical treatments or corrosion inhibitors that are applied cannot solve the corrosion problems.

The study came up with two methods to solve corrosion problems of chilled water system: 1) chemical cleaning and passivation and 2) changing new pipeline.

6.1 Conclusion

5.1.1 Chemical Cleaning and Passivation

Chemical cleaning and passivation is the technique to prevent corrosion using chemical solutions to remove rust fouling from the metal surface of the equipment. It maintains operation efficiency of the equipment. To achieve the best result, the selection of appropriate acid and chemicals used is very important.

Based on the physical and chemical properties, cost, and vendor experience, sulfuric acid was considered to use in the chilled water system when comparing with hydrochloric acid, and rydlyme. It is recommended to do the chemical cleaning and passivation every five to eight years. In this project, the cost of chemical cleaning and passivation with sulfuric acid, including the labor cost and wastewater disposal, is about 1,400,000 baht. However, the scaffolding installation cost, disassembling cost of some equipment contained brass and bronze alloys, and electricity cost are not included.

5.1.2 Changing New Pipeline

In general, changing new pipeline with a corrosion-resistant material is used to solve the corrosion problems in chilled water system. To change new chilled water pipeline, the selection of appropriate material is very important.

In this study, of the three materials, i.e., carbon steel, stainless steel and PE-lined steel, the recommended material for new chilled water pipeline is PE-lined steel pipe or syler pipe. Syler pipe has a good corrosion resistance because the inner part is lined with PE, so it can prevent corrosion in the pipeline. It has a long service life and can withstand operating temperature and pressure of the chilled water system. However, it requires special fittings and couplings that are designed for slyer pipe. The cost of changing new pipeline with PE-lined steel pipe is about 5,000 baht/meter including the labor cost and special fittings and couplings for PE-lined steel pipe. However, the costs of scaffolding installation, demolition of existing chilled water pipeline, and electricity are not included.

In conclusion, the proposed two solutions can be used to solve the corrosion problems of chilled water system in this case study depending on their advantages and disadvantages, as shown in Table 5.1.

Table 5.1 Advantages and disadvantages of chemical cleaning and passivation and changing new pipeline

	Chemical Cleaning and Passivation	Changing New Pipeline
Advantages	1. Less time to shutdown the process. 2. No need to dismantle and reassemble the equipment. 3. Cheaper than changing new pipeline. (cost ≈ 1.400,000 baht)	1. Has longer service life than pipeline using chemical cleaning and passivation. 2. Does not use hazardous chemicals.
Disadvantages	1. Can cause pipe crack or leak after cleaning with acid. 2. Use hazardous chemicals. (Need special control) 3. Should be done every 5 to 8 years.	1. Need long time to shutdown the process. 2. More expensive than using chemical cleaning and passivation. (cost ≈ 5,000 baht/meter)

APPENDIX A

1. Properties of Carbon Steel

1.1 Wall Thickness of Carbon Steel Pipe

NPS Designator	DN Designator	Outside Diameter		Inside Diameter		Wall Thickness		Nominal Weight (Mass) per unit Length			
		(Inches)	(mm)	(Inches)	(mm)	(Inches)	(mm)	Plain End (lb/ft)	Plain End (kg/m)	Threads & Couplings (lb/ft)	Threads & Couplings (kg/m
1/8"	6	0.405	10.3	0.269	6.8	0.068	1.73	0.24	0.37	0.25	0.37
1/4"	8	0.540	13.7	0.364	9.2	0.088	2.24	0.43	0.63	0.43	0.63
3/8"	10	0.675	17.1	0.493	12.5	0.091	2.31	0.57	0.84	0.57	0.84
1/2"	15	0.840	21.3	0.622	15.8	0.109	2.77	0.85	1.27	0.86	1.27
3/4"	20	1.050	26.7	0.824	20.9	0.113	2.87	1.13	1.69	1.14	1.69
1"	25	1.315	33.4	1.049	26.6	0.133	3.38	1.68	2.50	1.69	2.50
1-1/4"	32	1.660	42.2	1.380	35.1	0.140	3.56	2.27	3.39	2.28	3.40
1-1/2"	40	1.900	48.3	1.610	40.9	0.145	3.68	2.72	4.05	2.74	4.04
2"	50	2.375	60.3	2.067	52.5	0.154	3.91	3.66	5.44	3.68	5.46
2-1/2"	65	2.875	73.0	2.469	62.7	0.203	5.16	5.80	8.63	5.85	8.67
3"	80	3.500	88.9	3.068	77.9	0.216	5.49	7.58	11.29	7.68	11.35
3-1/2"	90	4.000	101.6	3.548	90.1	0.226	5.74	9.12	13.57	9.27	13.71
4"	100	4.500	114.3	4.026	102.3	0.237	6.02	10.8	16.07	10.92	16.23
5"	125	5.563	141.3	5.047	158.2	0.258	6.55	14.63	21.77	14.90	22.07
6"	150	6.625	168.3	6.065	154.1	0.280	7.11	18.99	28.26	19.34	28.58
8"	200	8.625	219.1	7.981	202.7	0.322	8.18	28.58	42.55	29.35	43.73
10"	250	10.750	273.0	10.020	254.5	0.365	9.27	40.52	60.29	41.49	63.36
12'	300	12.750	323.8	12.000	304.8	0.375	9.52	49.61	73.78	51.28	76.21

Figure A.1 Standard pipe schedule 40 – ASTM A53 Grades A and B

(Wheatland Tube JMC Steel Group. n.d)

Remarks: - Grade A: A softer steel and is easier to blend

- Grade B: Has higher tensile and yield strength than Grade A. It has higher stress and suites machining operations better.

1.2 Pressure Rating for Carbon Steel Pipe

Maximum Allowable Operating Pressure *(MPa)*													
Nominal Size		Outside Diameter	Schedule		Wall Thickness	Temperature (°C)							
						-29 to +38	204	260	343	371	399	427	
(DN)	*(NPS)*	*(mm)*			*(mm)*	Maximum Allowable Stress *(MPa)*							
						137.9	137.9	130.3	117.2	113.8	89.6	74.5	
15	½	21.3	STD	40	2.77	34.5	34.5	32.6	29.3	28.5	22.4	18.6	
20	¾	26.7	STD	40	2.87	28.1	28.1	26.5	23.8	23.1	18.2	15.1	
			XS	80	3.91	39.4	39.4	37.2	33.5	32.5	25.6	21.3	
25	1	33.4	STD	40	3.38	26.3	26.3	24.8	22.3	21.7	17.1	14.2	
			XS	80	4.55	36.3	36.3	34.3	30.9	30.0	23.6	19.6	
32	1¼	42.2	STD	40	3.56	21.6	21.6	20.4	18.4	17.8	14.1	11.7	
			XS	80	4.85	30.2	30.2	28.5	25.6	24.9	19.6	16.3	
				160	6.35	40.6	40.6	38.4	34.5	33.5	26.4	21.9	
40	1½	48.3	STD	40	3.68	19.4	19.4	18.4	16.5	16.0	12.6	10.5	
			XS	80	5.08	27.4	27.4	25.9	23.3	22.6	17.8	14.8	
				160	7.14	39.8	39.8	37.6	33.8	32.8	25.9	21.5	
50	2	60.3	STD	40	3.91	16.4	16.4	15.5	13.9	13.5	10.7	8.9	
			XS	80	5.54	23.7	23.7	22.4	20.1	19.5	15.4	12.8	
				160	8.74	38.9	38.9	36.8	33.1	32.1	25.3	21.0	
65	2½	73.0	STD	40	5.16	17.9	17.9	17.0	15.3	14.8	11.7	9.7	
			XS	80	7.01	24.8	24.8	23.5	21.1	20.5	16.1	13.4	
				160	9.53	34.7	34.7	32.8	29.5	28.6	22.5	18.7	
80	3	88.9	STD	40	5.49	15.6	15.6	14.7	13.2	12.8	10.1	8.4	
			XS	80	7.62	22.0	22.0	20.8	18.7	18.2	14.3	11.9	
				160	11.13	33.1	33.1	31.3	28.1	27.3	21.5	17.9	
100	4	114.3	STD	40	6.02	13.2	13.2	12.5	11.2	10.9	8.6	7.1	
			XS	80	8.56	19.1	19.1	18.0	16.2	15.7	12.4	10.3	
				120	11.13	25.2	25.2	23.8	21.4	20.8	16.4	13.6	
				160	13.49	31.0	31.0	29.3	26.4	25.6	20.2	16.8	
			XXS		17.12	40.4	40.4	38.2	34.3	33.3	26.2	21.8	

Figure A.2 Maximum allowable operating pressure of carbon steel pipe at different temperature (Winter, J., Lilie, H. and Rudolph, R. Atlas Specialty Metals Technical Services Department. 2002)

1.3 Weight of Carbon Steel Pipe

Nominal Dimension (in)	Outside Diameter D(mm)	Weight Class	Schedule No.	Thickness T(mm)	Weight	
					kg/m	kg/6m
1/2"	21.3	STD	40	2.77	1.27	7.62
3/4"	26.7	STD	40	2.87	1.69	10.14
1"	33.4	STD	40	3.38	2.50	15.00
1 1/4"	42.2	STD	40	3.56	3.39	20.34
1 1/2"	48.3	STD	40	3.68	4.05	24.30
2"	60.3	STD	40	3.91	5.44	32.64
2 1/2"	73.0	STD	40	5.16	8.63	51.78
3"	88.9	STD	40	5.49	11.29	67.74
3 1/2"	101.6	STD	40	5.74	13.57	81.42
4"	114.3	STD	40	6.02	16.07	96.42
5"	141.3	STD	40	6.55	21.77	130.62
6"	168.3	-	-	4.78	19.27	115.62

Figure A.3 Weight of carbon steel pipe (http://www.pipework2544.com)

2. **Properties of Stainless Steel (Type 304)**

2.1 Thickness and Weight of Stainless Steel Pipe (Type 304)

ท่อสแตนเลสมีตะเข็บ/ไร้ตะเข็บ

ขนาด	SPEC	OD (mm)	T (mm)	น้ำหนัก (kg/pcs)
1/8"	#10	10.29	1.20	0.275
	#40	10.29	1.73	0.369
1/4"	#10	13.72	1.65	0.464
	#40	13.72	2.24	0.629
3/8"	#10	17.15	1.65	0.637
	#40	17.15	2.31	0.851
1/2"	#10	21.34	2.11	1.020
	#40	21.34	2.87	1.310
3/4"	#10	26.67	2.77	1.300
	#40	26.67	2.38	1.740
1"	#10	33.40	2.77	2.150
	#40	33.40	3.56	2.570
1-1/4"	#10	42.16	2.77	2.760
	#40	42.16	3.56	3.470
1-1/2"	#10	48.26	2.77	3.160
	#40	48.26	3.56	4.100
2"	#10	60.33	2.77	3.980
	#40	60.33	3.91	5.440
2-1/2"	#10	76.30	3.05	5.420
	#40	76.30	5.20	9.120
3"	#10	88.90	3.09	6.370
	#40	88.90	5.49	11.300

ขนาด	SPEC	OD (mm)	T (mm)	น้ำหนัก (kg/pcs)
3-1/2"	#10	101.50	3.05	7.290
	#40	101.50	5.74	13.500
4"	#10	114.30	3.05	8.230
	#40	114.30	6.02	16.000
5"	#10	139.80	3.40	11.400
	#40	139.80	6.60	21.700
6"	#10	165.20	3.40	13.600
	#40	165.20	7.10	27.700
8"	#10	216.30	4.00	20.900
	#40	216.30	8.20	42.100
10"	#10	267.40	4.00	26.000
	#40	267.40	9.30	59.200
12"	#10	318.40	4.50	34.800
	#40	318.40	10.30	78.300
14"	#10	355.60	-	-
	#40	355.60	11.10	94.300
16"	#10	406.40	-	-
	#40	406.40	12.70	123.000
18"	#10	457.20	-	-
	#40	457.20	14.30	156.000
20"	#10	508.00	-	-
	#40	508.00	15.10	184.000

Figure A.4 Thickness and weight of stainless steel pipe (Type 304)

(https://www.xn--m3cdh2cwadq9mg1e.net/product)

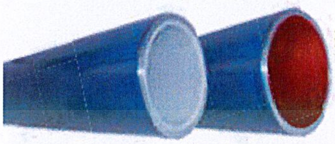
2.2 Pressure Rating for Stainless Steel Pipe (Schweitzer, P.A. 1994)

Table A.1 Maximum allowable operating pressure of seamless schedule 40S type 304 stainless steel pipe, plain end

Nominal pipe size (in.)	**Maximum operating pressure (psi) at °F/°C**							
	-325 to 100/-198 to 38	200/93	300/149	400/204	500/260	600/316	800/427	1000/538
½	4690	4160	3750	3410	3150	2900	2500	2200
¾	3820	3400	3060	2780	2550	2370	2040	1800
1	3580	3180	2860	2600	2390	2210	1910	1680
1½	2650	2350	2120	1930	1770	1640	1420	1250
2	2230	1980	1790	1630	1490	1380	1200	1050
3	2120	1880	1700	1550	1420	1310	1130	1000
4	1800	1600	1440	1310	1200	1110	960	850
6	1430	1270	1150	1040	960	890	770	680
8	1260	1120	1010	920	840	780	680	590
10	1150	1020	920	840	770	710	610	540
12	990	880	790	720	660	610	530	462

3. **PE-Lined Steel Pipes**

3.1 Thickness and Weight of PE-Lined Steel Pipe



Size and Thickness of SYLER Pipe

Class M (Medium)

Size		PE Lining Steel Pipe			Galvanized Steel Pipe		PE Pipe		Weight
Mm	Inch	Outer diameter(mm)		Thickness mm	Thickness mm		Thickness mm		Kg / Meter
15	1/2"	21.1		3.8	2.6		1.2		1.27
20	3/4"	26.6		3.9	2.6		1.3		1.65
25	1"	33.4		4.5	3.2		1.3		2.75
32	1-1/4"	42.1	± 0.5	4.7	3.2		1.5		3.28
40	1-1/2"	48.0		4.7	3.2		1.5		3.77
50	2"	59.8		5.1	3.6	± 10%	1.5	± 0.1	5.17
65	2-1/2"	75.4		5.1	3.6		1.5		7.02
80	3"	88.1	± 1%	5.8	4.0		1.8		8.84
100	4"	113.3		5.8	4.0		1.8		11.48
150	6"	164.1		6.7	4.5		2.2		18.91
200	8"	219.1		7.7	5.0		2.2		
250	10"	Please contact dealer							

Figure A.5 Thickness and weight of syler pipe

(Syler Group Co., Ltd. 2015)

3.2 Prices of PE-Lined Steel Pipes

The prices of PE-lined steel pipes: type C for cold water, and type H for hot water.

ความยาวท่อ 6 เมตร

Code	Size (mm.)	Size (inch.)	Unit Price Excluded VAT
10C015-600	15	1/2"	โปรดติดต่อ
10C020-600	20	3/4"	ผู้จัดจำหน่าย
10C025-600	25	1"	1,440.00
10C032-600	32	1 1/4"	1,867.00
10C040-600	40	1 1/2"	2,287.00
10C050-600	50	2"	2,908.00
10C065-600	65	2 1/2"	3,949.00
10C080-600	80	3"	5,013.00
10C100-600	100	4"	6,526.00
10C150-600	150	6"	10,633.00
10C200-600	200	8"	17,500.00

ความยาวท่อ 6 เมตร

Code	Size (mm.)	Size (inch.)	Unit Price Excluded VAT
10H015-600	15	1/2"	โปรดติดต่อ
10H020-600	20	3/4"	ผู้จัดจำหน่าย
10H025-600	25	1"	1,588.00
10H032-600	32	1 1/4"	2,060.00
10H040-600	40	1 1/2"	2,524.00
10H050-600	50	2"	3,207.00
10H065-600	65	2 1/2"	4,356.00
10H080-600	80	3"	5,529.00
10H100-600	100	4"	7,199.00
10H150-600	150	6"	11,950.00
10H200-600	200	8"	19,000.00

Figure A.6 Unit price of syler pipe type C and type H

(Syler Group Co., Ltd. 2015)

BIOGRAPHY

Name:	Rungnapa Wattanapant	
Date of Birth (DD/MM/YY):	02/09/1998	
Address:	36/19 Soi Nuankaewuthit, Hat Yai, Songkhla 90110	
E-mail:	59011145@kmitl.ac.th	
Academic Background:	2016-Present	Bachelor of Chemical Engineering Department of Chemical Engineering King Mongkut's Institute of Technology Ladkrabang
	2013-2016	Hatyaiwittayalai School, Songkhla, Thailand Science and Mathematics Program
Working Experience:	June 2019 - July 2019	Internship program Thai Lube Base Public Company Limited Project: Product Yield Prediction for Lube Production
	August 2019 - November 2019	Co-operative education program Momentive Performance Materials (Thailand) Limited
	Student leader (Petrochemical Engineering) for 4 years	