การปรับปรุงประสิทธิภาพการทำความเย็นและการกำจัดตะกรันสำหรับหอทำความเย็นแบบแพคโดยการใช้สารเคมี

นาย ประกาศิต จ่วงพานิช

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IMPROVING COOLING EFFICIENCY AND FOULING REMOVAL OF FILL PACK COOLING TOWER BY USING CHEMICAL

Mr. Prakasit Juangpanich

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Chemical Engineering
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By	Prakasit Juangpanich
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Thesis Advisor	Assistant Professor Soorathep Kheawhom, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.... Dean of the Faculty of Engineering

(Associate Professor Boonsom Lerdhirunwong, Dr.Ing.)

THESIS COMMITTEE

.... Chairman

(Associate Professor Tharathon Mongkhonsi, Ph.D.)

Soorathep Kheawhom

.... Thesis Advisor

(Assistant Professor Soorathep Kheawhom, Ph.D.)

.... Examiner

(Kasidit Nootong, Ph.D.)

.... External Examiner

(Assistant Professor Prakorn Ramakul, Ph.D.)

ประกาศิต จ๋วงพานิช : การปรับปรุงประสิทธิภาพการทำความเย็นและการกำจัดตะกรันสำหรับหอทำความเย็นแบบแพคโดยการใช้สารเคมี. (IMPROVING COOLING EFFICIENCY AND FOULING REMOVAL OF FILL PACK COOLING TOWER BY USING CHEMICAL) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร.สุรเทพ เขียวหอม, 105 หน้า.

สิ่งสำคัญที่ควรตระหนักสำหรับโรงผลิตพลังงานกระแสไฟฟ้าคือการรักษาผลกำไรโดยการดำเนินงานสำหรับอาคารทำความเย็นแบบระเหยอย่างมีประสิทธิภาพ หากประสิทธิภาพการทำความเย็นของหอทำความเย็นลดลงต่ำกว่าการออกแบบ จะส่งผลกระทบทำให้มีการเพิ่มของอัตราการสูญเสียพลังงาน โดยทั่วไปแพคกิ้งสำหรับหอทำความเย็นของหอทำความเย็นในโรงผลิตพลังงานไฟฟ้า เคยพบกับเหตุการณ์การสูญเสียความสามารถในการลดความร้อนของหอทำความเย็น โดยการสูญเสียประสิทธิภาพในการทำความเย็นมักจะเกี่ยวข้องกับการก่อตัวของตะกรันในแพคกิ้ง

เป้าหมายของการวิจัยนี้คือการปรับปรุงประสิทธิภาพการทำความเย็นให้ได้ตามค่าออกแบบโดยการกำจัดการก่อตัวของสารแขวนลอยด้วยการเติมด้วยสารเคมีในกลุ่มของสารขจัดคราบ และทำการประเมินปริมาณการเติมสารเคมีที่เหมาะสม สารขจัดคราบสามารถทำให้สารแขวนลอยบนพื้นผิวหลุดออกโดยความร่วมมือกันของความสามารถทางด้านเคมีที่ทำให้เกิดการละลาย และการทำให้หลุดลอยการกลศาสตร์ด้วยฟองอากาศ การทดลองถูกทำที่โหลด 40 และ 50 เมกะวัตต์ สารขจัดคราบถูกทดลองที่ความเข้มข้น 0, 3, 5, 10 มิลลิกรัมต่อลิตร ผลการทดลองแสดงให้เห็นได้ว่าประสิทธิภาพการทำความเย็นเพิ่มขึ้นมากกว่าค่าออกแบบ 0.45% เมื่อสารขจัดคราบถูกเติมที่ความเข้มข้น 3 มิลลิกรัมต่อลิตรที่โหลด 40 เมกะวัตต์ และประสิทธิภาพการทำความเย็นเพิ่มขึ้นมากกว่าค่าออกแบบ 10.1% เมื่อสารขจัดคราบถูกเติมที่ความเข้มข้น 5 มิลลิกรัมต่อลิตรที่โหลด 50 เมกะวัตต์

ภาควิชา.....วิศวกรรมเคมี......... ลายมือชื่อนิสิต.......ประกาศิต จ๋วงพานิช.......
สาขาวิชา....วิศวกรรมเคมี......... ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก....................
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PRAKASIT JUANGPANICH: IMPROVING COOLING EFFICIENCY AND FOULING REMOVAL OF FILL PACK COOLING TOWER BY USING CHEMICAL. ADVISOR: ASST.PROF.SOORATHEP KHEAWHOM, Ph.D., 105 pp.

The major consideration for all power generation plants is sustainable the profitable by operating for cooling towers effectively. If the cooling tower efficiency is less than design, this can increase heat rate penalty. Normally, filled pack material of cooling towers in power generation plant has experienced of gradual loss in thermal performance. The loss in efficiency is usually involved with fouling in fill packing.

The objective of the research is to increase the cooling efficiency to specify design by removing fouling matter from filled pack by chemical detergent. And determine the suitable chemical dosage. Detergent can removes surface deposits through a combination of chemical solubilization and physical scrubbing by entrained air bubbles. The study was performed at load megawatt 40 and 50 MW and dosage of detergent was varied between 0, 3, 5 and 10 mg/l. The result show 0.45% increasing of cooling efficiency compare with design when detergent was dosed at 3 mg/l at load megawatt 40 MW. And 10.12% increasing of cooling efficiency compare with design when detergent was dosed at 5 mg/l at load megawatt 50 MW.

Department : Chemical Engineering Student's Signature Prakast.
Field of Study : Chemical Engineering Advisor's Signature Soorathep Kheawhom
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CONTENTS

Page

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

.

CHAPTER I

INTRODUCTIONS

1.1 Introduction

Cooling towers are widely used in industry, such as industrial power generation plants, refrigeration and air conditioning plants and chemical petrochemical industries.

The cooling towers are designed to cool a hot water stream, which received the heat from process, through evaporation of some of the water into an air stream. Hot water coming from the process is pumped evenly over the top deck of the cooling tower. Then hot water falls down as form the droplet water and is broken into small droplets as it passes through a series of fill plates (Zubair and Qureshi, 2006). This section called “tower filled pack material”. This filled pack normal make from plastic sheets to provide maximum surface area. Figure 1.1 details a general cooling tower diagram.

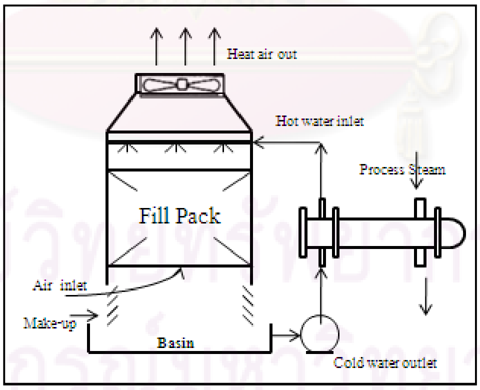

Figure 1.1 Cooling tower diagram.

The material of fill pack in utility power industry is plastic film-type because of its excellent cooling capabilities, compact design. Fill packing materials is able to form a film of hot water on a very large surface contact area between water and air. For example, hot recalculating water (27-38°C) pass though the cooling tower can be cooled up to -1.11°C with only a three or four foot depth of this fill material (Nalco company, 2005:43-266, 2007:1).

Over the past several years, the utility power industry has experienced that these high efficient cooling tower filled materials are subject to fouling, due to the manufacturer differences in fill design (McCarthy and Ritter, 1993). Actually, this also depends on types of makeup water quality and tower operating practices. The fouling in fill pack can cause from a small amount of nucleation or water-formed deposit on fill pack.

Almost the serious cases, filled pack replacement is required due to dramatically decrease in cooling tower performance. Fouling may cause high discharge water temperatures that can decrease the efficiency of steam condenser. This situation may result in fines or unit shut down by government agencies for violation of environmental permits.

1.2 Current Problem of Suspended solid fouls in fill pack.

The eight cooling systems have similarly serious problem of suspended solid matter fouling in filled pack due to high turbidity in makeup water. This impact is due to suspended solid is fouled in filled pack. The suspended solid blocks channel of hot water flow down to contact with inlet air. The hot water temperature is rise up over acceptable limited (55oC) due to decrease of cooling efficiency.

1.3 Motivation

Plant must replace the new filled pack for eight cooling towers every year because of the hot water temperature is higher than acceptable limited (55oC). The replacement cost is 8 million Thai baths.

From theory, the suspended solid in fill pack can be removed into bulk water by using detergent chemical. If suspended solid is removed from filled pack, the cooling efficiency will be enhanced. And plant can save the cost of filled pack replacement.

1.4 Research Objective

The research objective is to investigate the effect of cooling tower efficiency and water chemistry after dose with detergent chemical. And to determine the optimized dosage of detergent chemical.

1.5 Research Scope

1.5.1 Collect the data of cold and hot water temperature, wet bulb temperature load megawatt, turbidity, conductivity, corrosion rate, and microbial during the study.

1.5.2 Prepare feeding system which consists of feeding pump, chemical tank, pipe line, calibration cylinder.

1.5.3 Implement the manual weighting and visual inspection for some cooling system.

1.5.4 Investigate the effect of detergent where treated 0, 3, 5, 10 mg/l at loading megawatt 40 and 50 MW. And find the optimize dosage of detergent and improve cooling efficiency to meet the design value.

1.6 Benefit from the research

1.6.1 To enhance cooling efficiency with suitable dosage of detergent.

1.6.2 Minimize the heat penalty by increase cooling efficiency

1.6.3 Get the lowest cold water temperature to reduce turbine exhaust steam backpressure, thus maximizing efficiency of the turbine.

CHAPTER II

THEORY AND LITERITURE REVIEW

2.1 Theory of cooling tower system

This system consists of three main pieces of equipment: the recirculating water pump, the heat exchanger or processing unit, and the cooling tower.

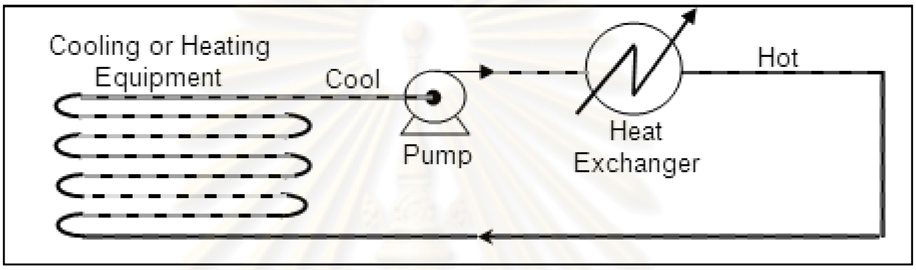

Figure 2.1.1 The cooling system diagram.

Because the cooling tower is the site where evaporation removes heat from the water they are called “wet towers”, with the cooling water coming in direct contact with the air that flows upward in the tower.

Water coming from the heat exchanger is pumped to the top deck of the cooling tower. It fall down and is broken into droplets as it passes through a series of splash plates, called tower fill. This “fill pack” can be corrugated plastic sheets, wooden slats, or other devices that provide maximum surface area. The splashing and film forming action increases the amount of surface area, breaking up the water molecules and enhancing evaporation.

During the water droplets pass through the tower fill, the hottest molecules break away from the water and are carried up and out of the tower with fresh air. Called “Evaporated water”. The remaining cooled water collects in a tank at the bottom of the tower, called the basin. This cooled water can now be pumped back into the heat exchanger. These designs are chosen where larger temperature changes are desired, and where the cost of water drives the “closing up” of the system so the water can be reused. The drawback to this, is that water evaporating over and over, concentrates dissolved and suspended solids. These solids eventually reach a saturation point and begin to precipitate and deposit. Treating the water can extend the saturation point, prevent scaling and corrosion, and also conserve water (Nalco Company, 2005:43-266, 2007:1).

2.1.1 Types of Cooling Water Systems

Recently, Two main types of cooling towers: the natural draft and mechanical draft cooling towers.

2.1.1.1 Natural draft cooling tower

Normally the natural draft is used of the difference in temperature between the ambient air and the hotter air inside the tower. Normally hot air will move upwards through the tower (because hot air rises), fresh cool air is drawn into the tower through an air inlet at the bottom. Due to the layout diagram of the tower, no fan is required and there is almost no circulation of hot air that could affect the performance. These cooling towers are mostly only for large heat duties because large concrete structures are expensive.

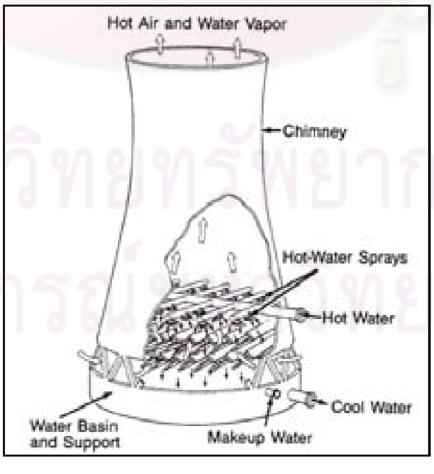

Figure 2.1.2 Natural draft hyperbolic Cooling Tower (Nalco Company, 2005:43-266, 2007:1).

The natural cooling tower type in figure 2.1.2 shows air draw up through the falling water. And the fill is therefore located inside the tower, although design depends on specific site conditions.

2.1.1.2 Wet Evaporative Cooling Tower: Mechanical draft cooling tower

The common concept of type of cooling tower is the wet (evaporative), which a portion of the recirculating water is evaporated. When some of the hot cooling water changes to vapor, heat is given off to the atmosphere, thereby cooling the remaining water. Wet evaporative towers can also be described as either mechanical or natural draft towers.

Mechanical draft towers have large fans to force or draw cold air through circulated water to remove heat. The waterfalls downwards over fill surfaces, which help increase the contact time between the water and the air - this helps maximize heat transfer between the two. Cooling rates of mechanical draft towers is depended on various parameters such as fan diameter and speed of operation, fills for system resistance etc.

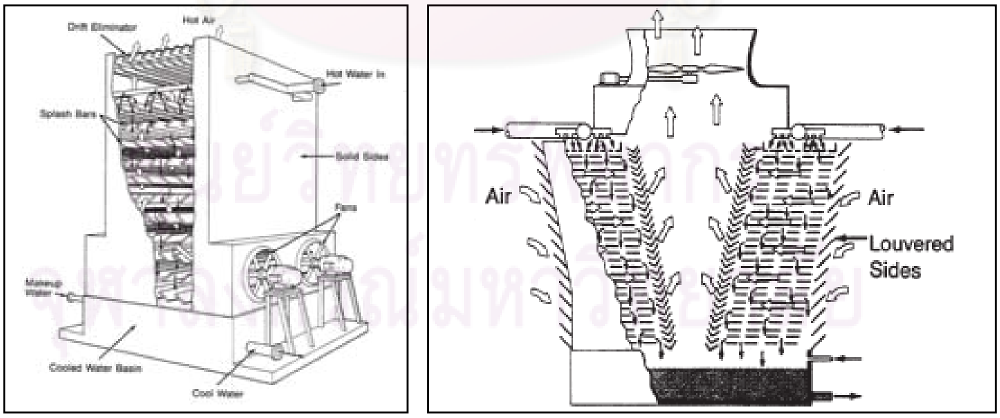

Figure 2.1.3 (a) Force draft (b) induce draft cooling tower (Nalco company, 2005:43-266, 2007:1).

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The recent many cooling towers are designed to two or more individual cooling towers or "cells." The number of cells they may have eight-cell tower, often refers to such towers. Multiple-cell towers can be lineal, square, or round depending upon the shape of the individual cells and whether the air inlets are located on the sides or bottoms of the cells.

The major components of a cooling tower include many parts such as the fill pack, cold-water basin, drift eliminators, air inlet, louvers, nozzles and fans. All will be described below. (Nalco Company, 2005: 43-45: 2007:1).

2.1.1.2.1 Fill Packing. Most towers using fills which often made of plastic or wood to facilitate heat transfer by maximizing water and air contact. There are two types of fill:

Splash pack type: waterfalls over successive layers of horizontal splash bars, continuously breaking into smaller droplets, while also wetting the fill surface. Plastic splash fills promote better heat transfer than wood splash fills.

Fill pack type: consists of thin, closely spaced plastic surfaces over which the water spreads, forming a thin film in contact with the air. These surfaces may be flat, corrugated, honeycombed, or other patterns. The film type of fill is the more efficient and provides same heat transfer in a smaller volume than the splash fill. (United Nations Environment Programme [UNEP], 2006:2-3).

The type of fill packing material used in the cooling tower has an important portion to provide a very large surface area for evaporative heat and mass transfer to take away hot water to ambient air and increases the contact time between the two fluids phases.

Recently, the new type packing was used in evaporative cooling systems. This packing was shown in below figure 2.1.4 (a) and 2.1.4 (b). It consists of vertical grids between walls in the form of zigzag channel. The concept is that: the ambient fresh air enters by the bottom of the tower and arrives by the top of that while crossing several times the vertical grids, whereas the water is conducted at the top of the tower and flows along the vertical channel. The concern is that, the change of the air flow direction several times within the tower fill will get a better condition that can improve the heat and mass transfer between water and air inside the cooling tower (Boumaza, Lemouari and Kaabi 2010).

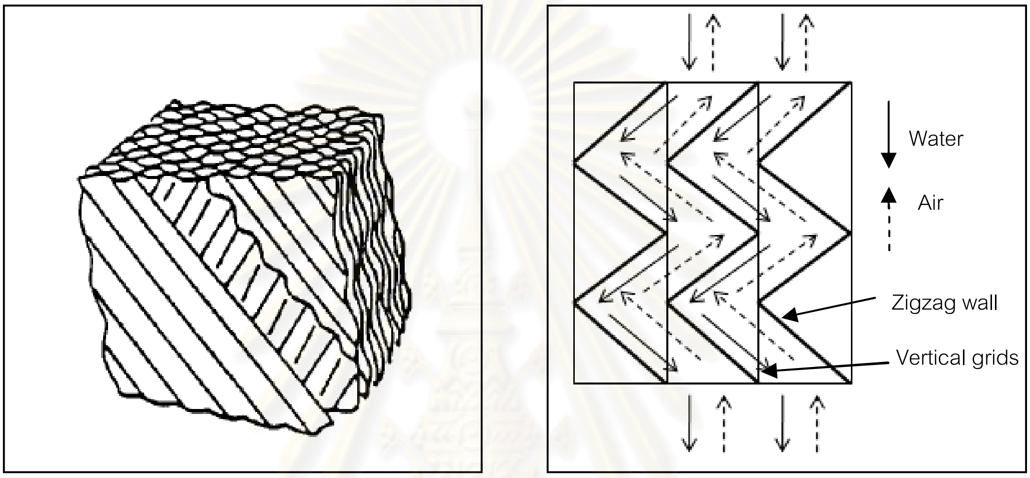


Figure 2.1.4 (a) Tower film-fill pack type (Nalco, 2005:42-266, 2007:1) (b) working principle of zigzag type packing material (Boumaza et al., 2010).

2.1.1.2.4 Cold-water basin The cold water basin is area that receives the cooled water which is just removed the heat and flows down through the tower and fill. The basin usually has a sump or low point area for the cold-water discharge connection. In some forced draft counter flow design, the water at the bottom of the fill is channeled to a perimeter trough that functions as the coldwater basin.

2.1.1.2.5 Drift eliminators these capture water droplets entrapped in the air stream that otherwise would be lost to the atmosphere.

2.1.1.2.6 Air inlet this is the point of entry for the air entering a tower. The inlet may take up an entire side of a tower or be located low on the side or the bottom of the tower.

2.1.1.2.7 Louvers generally, cross-flow towers have inlet louvers. The purpose of louvers is to equalize airflow into the fill and retain the water within the tower. Many counter flow tower designs do not require louvers.

2.1.1.2.8 Nozzle these spray water to wet the fill. Uniform water distribution at the top of the fill is essential to achieve proper wetting of the entire fill surface. Nozzles can either be fixed and spray in a round or square patterns, or they can be part of a rotating assembly as found in some circular cross-section towers. (UNEP, 2006)

2.1.1.2.9 Cooling Fan both of propeller type and. centrifugal fans are used in towers. Generally, propeller fans are used in induced draft towers and both propeller and centrifugal fans are found in forced draft towers. Depending upon their size, the type of propeller fans used is either fixed or variable pitch.

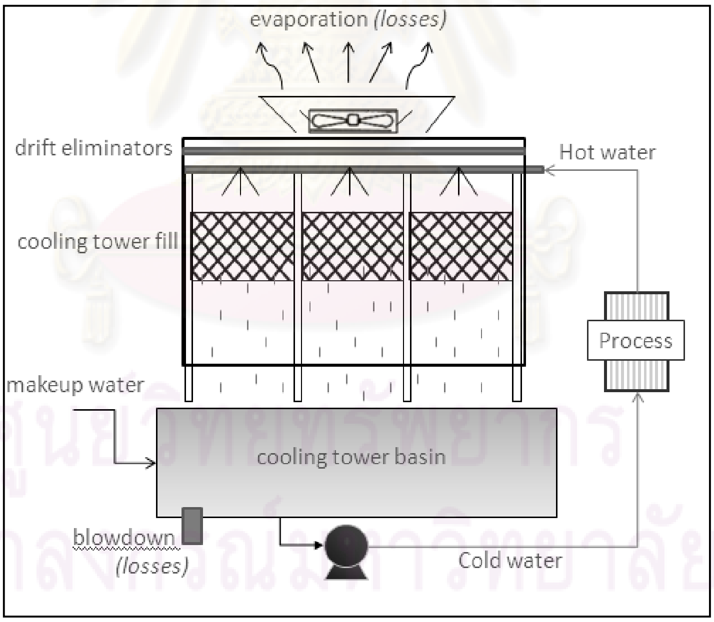


Figure 2.1.5 Typical cooling tower components

Table 2.1.1 Summary the strong and weak point for each cooling tower type (UNEP, 2006)

Type of cooling tower	Strong point	Weak point
1. Forced draft : Cooling tower: air is blow through the tower by a fan located in the air inlet	Suited for high air resistance due to centrifugal blower fans : Fans are relatively quiet	Recirculation due to high air-entry and low air-exit velocity, which can be solved by locating towers in plant rooms combined with discharged ducts
2.1 Induced draft : Cross flow cooling tower Water enters at top and passes over fill pack. Air enters on one side or opposite sides. An induced draft fan draws air cross fill toward exit at top of tower	Less recirculation than forced draft towers because the speed of exit air is 3-4 times higher than entering air	Fans and the motors drive mechanism require weather-proofing against moisture and corrosion because they are in the path of humid exit air
2.2 Induced draft : Counter flow cooling tower Hot water enters at the top air enters bottom and exits at the top uses forced and induced draft fans		

2.2 General four water characteristic of cooling water system

2.2.1 pH measures the relative acidity of the water and is a very important property for measurement and control of water quality. A common working definition of pH is that the negative logarithm10 of the hydrogen ion concentration in the water. A pH of 7 is considered neutral ([H+] = 10-7 mol/L.) Water with a pH > 7 is increasingly alkaline, while water with a pH < 7 is increasingly acidic. Water with a low pH tends to be more corrosive, while water with a high pH has a greater tendency to form mineral scales. Many chemical treatment programs are designed to work within a limited pH range.

2.2.2 Hardness is a measure of the concentration of dissolved calcium and magnesium. Calcium and magnesium form a number of compounds having an inverse solubility with respect to temperature. These may precipitate in the hotter parts of a cooling system forming scale deposits.

2.2.3 Conductivity is a measure of the electrical conductivity of water and is determined by the concentration and composition of dissolved solids in water. Under some circumstances, conductivity can be used as a rough measure of the relative concentration of dissolved solids in water.

2.2.4 Turbidity is a measure of insoluble chemical species that is dispersed in a liquid. Coal, dust, clay, iron, and a variety of insoluble precipitates are examples of suspended solids

Turbidity is a relative measure of suspended matter in a water sample. Higher turbidity water sources generally represent a higher fouling potential in cooling systems.(Nalco Company, 2005:43-266, 2007:1)

2.3 Common Problems of Cooling Water

2.3.1 Fouling Deposit

Fouling is the aggregation of insoluble material through physical processes. Fouling can be caused by 2 major of sources:

2.3.1.1 Silt — term silt refers to a combination of insoluble particles consisting of silica and alumina from the earth's crust and any other suspended solids that can contaminate the system. The important source of silt is come from Makeup water

2.3.1.2 Suspended solids— introduce into cooling towers through contact with air or from turbid makeup sources. Road dust, suspended silt, and clay are commonly seen.

The source of makeup water has a substantial impact on the amount of silt entering the system. Silt from makeup water can generally enter a system in two ways: Well waters are generally low in silt and suspended solids and of consistent quality Surface waters (rivers, lakes) generally have higher amounts of silt, and the quality of water is greatly influenced by environmental factors, such as runoff after a heavy rain or upsets in a lake. The quantity of silt in surface waters can vary considerably from day to day.

Mud and silt from turbid waters usually form hard, baked-on deposits when they collect on heat transfer surfaces. They also have a tendency to settle in low-flow (low velocity) areas of a system, causing deposits.

Additionally, mud and silt can be easily incorporated in a scale deposit, thus increasing its bulk volume and insulating characteristics. A deposit that is made up of mostly silica and aluminum is likely a silt deposit. The typical ratio of silica to aluminum is 3:1 as SiO_2 to Al_2O_3 (Nalco Company, 2005:43-266, 2007:1).

2.3.2 Corrosion

Corrosion is the undesirable deterioration of metal or alloys as a result of interactions with the surrounding environment. It is an electrochemical process in which a difference in potential exists at the metal surface and between different areas on the metal surface.

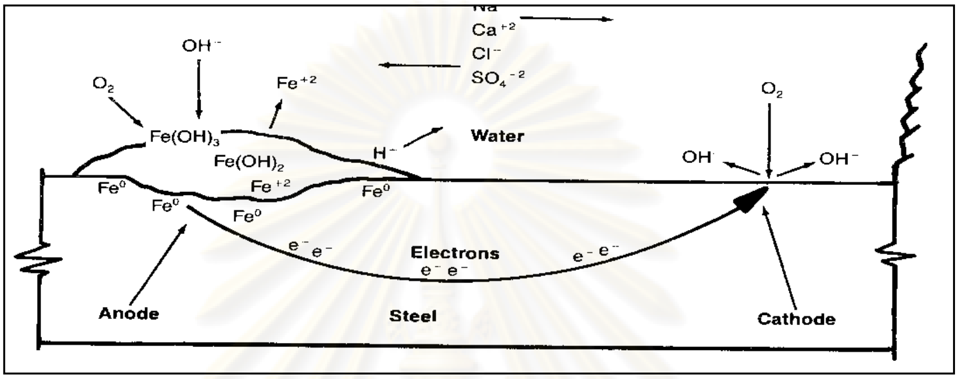


Figure 2.3.1 Typical corrosion cell. (Nalco Company, 2005:43-266, 2007:1)

Electrical current passes through the metal from the area of low potential to the area of higher potential. Metal dissolves at the anode (lower potential) and generates free metal ions (through oxidation). These liberated electrons migrate through the metal and over to an area of higher potential at the cathode. Here, they are used in the reduction of other ions or oxygen. In neutral to alkaline water, the reduction of oxygen produces hydroxyl ions (-OH). Thus, the pH is higher at the cathode than in the bulk water. Also iron and copper ions (Fe3+, Cu2+) are reduced, causing deposits and hydrogen ions (H+) may evolve as gas at the cathode. As a result of the reactions at the anode and cathode; metal loss occurs at the anode.

For copper and its alloys, copper metal (Cu oxidizes to cuprous ion (Cu^+) at a high rate. It forms a thin, defective cuprous oxide film (Cu_2O). Cupric ion (Cu^{2+}) is formed as cuprous ions migrate through cuprous oxide film and are oxidized.

Copper alloying elements such as AL, Zn, As, P and Ni help improve normal defective cuprous oxide film, by plugging the holes in the film and preventing the migration of cuprous ions through the film. For this reason, alloys are often chosen for tube construction because they offer the resistance to corrosion, and the high thermal conductance desired for exchangers (Nalco Company, 2005:43-266, 2007:1).

2.3.2.1 Corrosion influencers in water treatment

2.3.2.1.1 pH: Lower pH is generally associated with higher corrosion rates. The solubility of iron and copper increases as pH decreases. Many metals passivate to a more noble galvanic series potential by forming a tightly adherent corrosion product layer. An electrolyte that prevents this layer from forming will accelerate corrosion. The pH influences the solubility of oxidized metal ions greatly.

2.3.2.2 Temperature: Higher temperatures cause increased corrosion rates. The rate approximately doubles for every 10°C

2.3.2.3 Dissolved solids/ dissolved gases: In general, increasing TDS (conductivity) makes a better environment for corrosion, as electrolyte concentrations go up. Some ions such as hardness and alkalinity are beneficial helping to minimize corrosion; while other ions such as chloride and sulfate can add to corrosivity of the water. Dissolved ammonia, sulfide, and chloride are extremely corrosive for copper alloys.

2.3.2.4 Suspended solid or turbidity: They are sources of pitting and under-deposit corrosion.

2.3.2.5 Water velocity: Low velocities such as less than 2 feet per second can cause deposit build-up. On the other hand, high velocity, delivers more oxygen to the corrosion site. At real high velocities, greater than 7 feet per second, erosion corrosion of the protective film may occur.

2.3.2.6 Microbiological Growth: Bio-fouling and Microbial Induced Corrosion (MIC) are recognized drivers of exchanger corrosion. Some bugs, if allowed to grow in the system, will eat iron and copper. When dead bacterial matter deposits on metal surfaces; conditions for a corrosion cell are born (Nalco Company, 2005:43-266, 2007:1).

2.4 Concept of Cooling Tower Performance

In the present study, two parameters are recently used in monitoring the performance characteristics of the cooling tower

2.4.1 Temperature Approach.

2.4.2 Cooling tower efficiency

2.4.1 Temperature Approach

The one approach of cooling performance efficiency can be measured by how closely the cold water temperature in the tower basin calling "Approaches". The ambient wet bulb temperature theory should produce cold water at the same temperature as the wet bulb temperature. Because of the real cooling towers are not ideally efficient. Both range and approach should be monitored, the `Approach' is a one better indicator of cooling tower performance (UNEP, 2006).

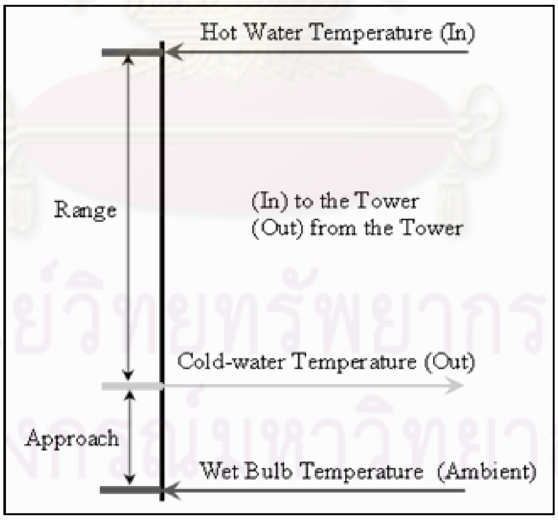


Figure 2.4.1 Relationship between cooling range and approach (UNEP, 2006).

Because of the cold-water temperature never reach the wet bulb temperature. The approach temperature should generally be in the range of 2-10°C. The approach temperature is often specified for a given tower by the manufacturer for a certain conditions, such as ambient temperature, relative humidity, and barometric pressure. The design approach temperature can be compared to existing approach temperature to determine any changes in efficiency.

2.4.2 Cooling Tower Efficiency

A cooling tower is mainly designed to cool circulating water from a process. As such, the definition for the cooling tower effectiveness is described as the ratio of actual energy to maximum possible energy transfer. Note that the dimensionless temperature difference described in the cooling tower literature is defined as the ratio of actual to maximum water temperature drop (Boumaza et al., 2010).

In cooling tower, using the Merkel approach (Yingjian, Xinkui and Jiezhi, 2010), the heat transfer rate from waterside is formulas

$$\mathrm{dQ} = \mathrm{LC}_{\mathrm{p,w}}\left(\mathrm{t}_{\mathrm{w,out}} - \mathrm{t}_{\mathrm{w,in}}\right) \tag{1}$$

Table 2.4.1 cooling tower performance nomenclature

Symptom	Definitions
Q	Heat reject by cooling tower, kW
L	Water mass flow rate, kg/hr
$C_{p,w}$	Specify heat of water, kJ/kg°C
$t_{w, in}$	Inlet cooling water temperature °C
$t_{w, out}$	Outlet cooling water temperature °C
$t_{awb, in}$	Average inlet wet bulb temperature °C
E	Cooling efficiency

The actual heat transfer equation given off by the water during its fall is expressed as follows.

$$\mathrm{dQ} = \mathrm{LC}_{\mathrm{p,w}}\left(\mathrm{t}_{\mathrm{w,out}} - \mathrm{t}_{\mathrm{w,in}}\right) \tag{2}$$

The maximum possible heat that would be given off by the water is shown in formulas.

$$\mathrm{dQ_{max}} = \mathrm{LC_{p,w}}\left(\mathrm{t_{w,out}} - \mathrm{t_{awb,in}}\right) \tag{3}$$

And the cooling effectiveness is determined as the ratio of actual to maximum water temperature drop. Consequently, the cooling tower effectiveness is express as:

$$\mathrm{e} = \frac{\mathrm{t_{w,out}} - \mathrm{t_{w,in}}}{\mathrm{t_{w,out}} - \mathrm{t_{awb,in}}} \tag{4}$$

Because the definition of temperature range is differential of hot water and cold water, and approach is differential of cold water and wet-bulk temperature. The cooling tower efficiency is express in alternative form as:

$$\mathrm{e} = \frac{\mathrm{t_{w,out}} - \mathrm{t_{w,in}}}{(\mathrm{t_{w,out}} - \mathrm{t_{w,in}}) + (\mathrm{t_{w,in}} - \mathrm{t_{awb,in}})} \tag{5}$$

$$\mathrm{e} = \frac{\mathrm{Range}}{\mathrm{Range} + \mathrm{Approac}h} \tag{6}$$

2.5 Current problem of fouling problem in fill pack and root-cause identification

Generally filled pack is fouled by the deposition of either inorganic scale, suspended solids (silt) or biological growth. Occasionally deposits from film fill exhibit one predominant type of fouling. However, the actual deposits are combinations of these materials, and it is difficult to determine the one component that “caused” the deposit (Nalco Company, 2005:43-266, 2007:1).

The eight cooling systems which are used to study have similarly a serious problem of suspended solid fouling in fill packing. It was blocking channel of heated water flow to contract with fresh air in fill pack.

Fouling of cooling tower fills is one of the most important factors affecting its thermal performance, which reduces cooling tower efficiency with time (Zubair and Qureshi, 2006). Figures 2.5.1 to 2.5.4 are suspended solid in eight cooling tower system that fouled in fill pack before testing and analytical result of their sampling deposit.

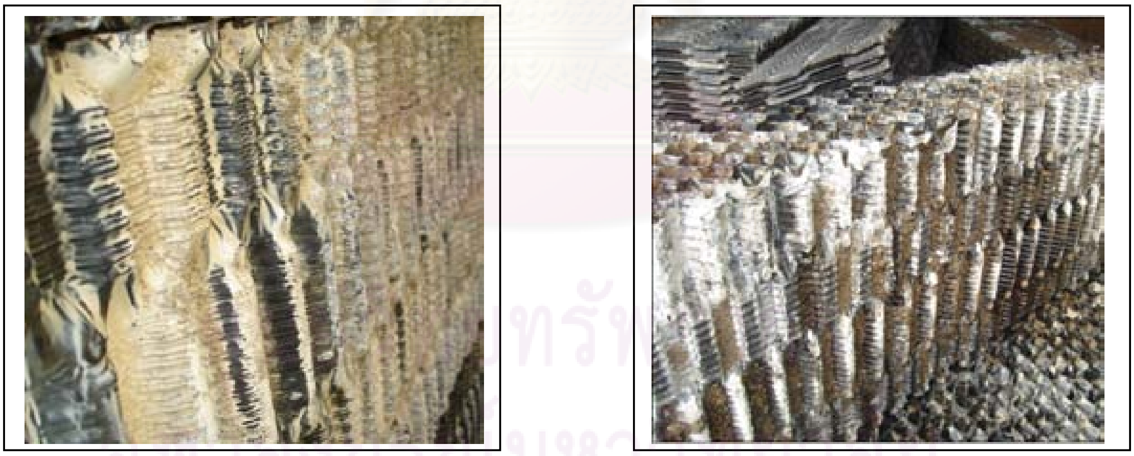


Figure 2.5.1 (a) and (b) show the fouling problem (90-95%) in fill pack CW#1 and CW#2

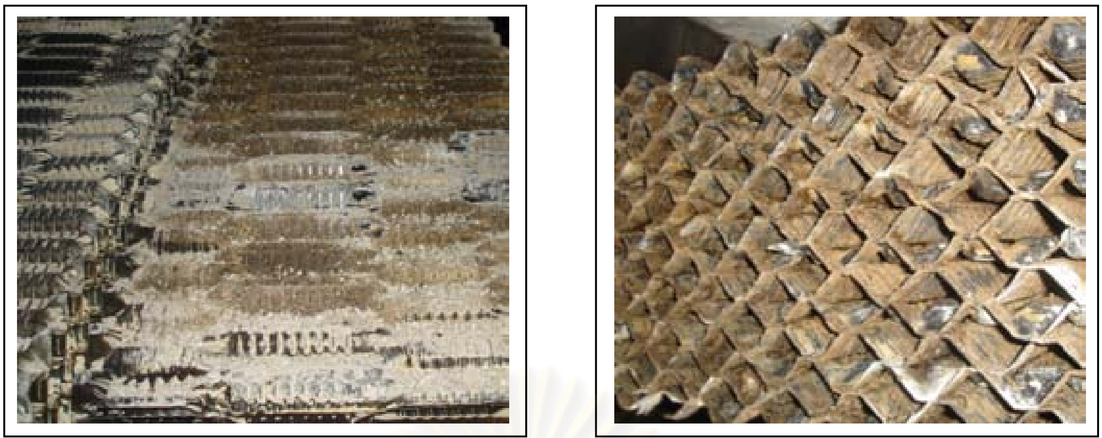


Figure 2.5.2 (a) and (b) show the fouling problem (90-95%) in fill pack CW#3 and CW#4

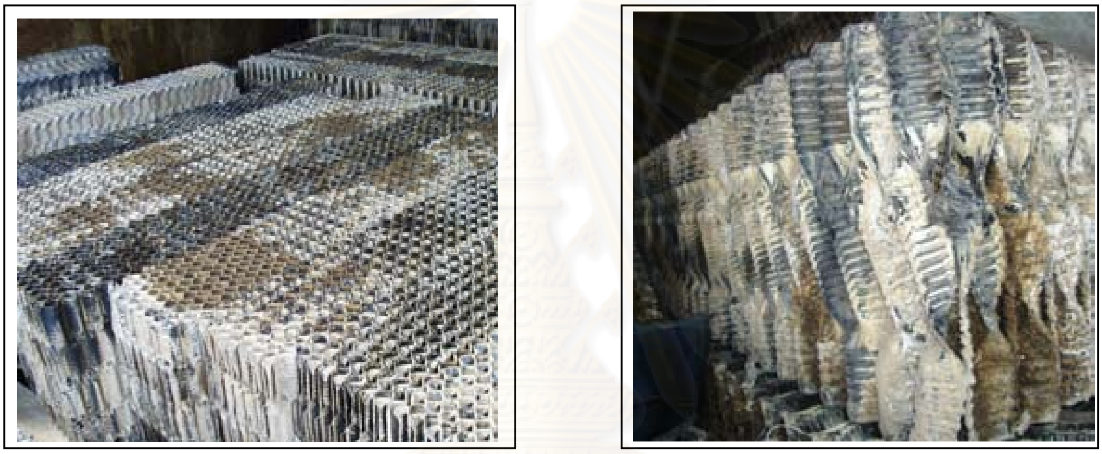


Figure 2.5.3(a) and (b) shown the fouling problem (90-95%) in fill pack CW#5 and CW#6

Figure 2.5.4(a) and (b) shown the fouling problem (90-95%) in fill pack CW#7 and CW#8

Table 2.5.1 identifies four samples of deposit analysis of fouled fill sections, elemental composition of fill deposit (weight percent) of dried sample by X-ray Fluorescence.

Sample	Silicon % SiO_2	Aluminum % Al_2O_3	Iron % Fe_2O_3	Calcium %CaO	Phosphorus %P2O5
CW#1	51	15	1	5	1
CW#4	57	16	2	5	2
CW#6	49	14	1	4	2
CW#8	53	13	3	4	1

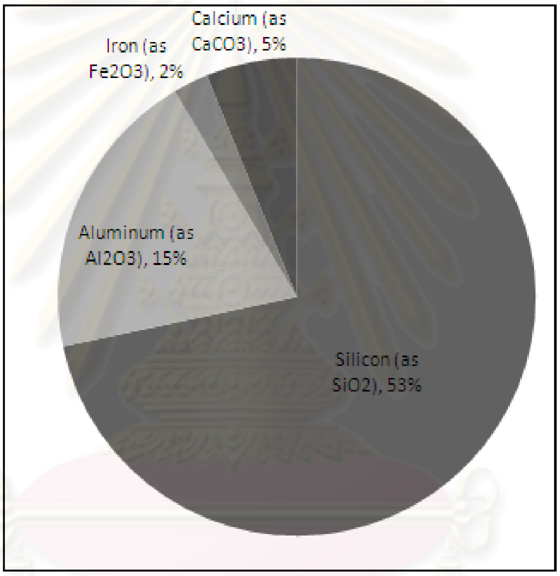


Figure 2.5.6 Summary of the majority of fill pack cooling tower deposit.

2.5.1 Cause from suspended solid deposit

Table 2.5.1 shows the deposit analyses of four samples from filled pack material. The results were similarities. All fill deposits contained a significant amount of silica (quartz) and aluminum.

Table 2.5.2 shows silicon (Quartz) and aluminum ratio of deposit analysis

Sample	Silicon / Aluminum ratio
#CW1	3.4 : 1
#CW4	3.6 : 1
#CW6	3.5 : 1
#CW8	4.1 : 1

The ratio of silica and aluminum in table 2.5.2 can identified that all samples were silt matter. Because the general ratio of silicon: aluminum to identify silt matter for unknown samples is between 4:1 and 5:1. (Nalco Company, 2005:43-266, 2007:1)

These can conclude that all sample fouled in fill pack was type of suspended solid (silt and clay material).

2.5.1.2 Root-cause of suspended solid fouling in filled pack.

2.5.1.2.1 Silica component come from silt and clay that are usually finely divided colloidal materials that have a negative charge. The electrostatic charge on the surface of the fill itself may contribute to deposition. Particle size is also believed to contribute to the deposit of suspended solids; the smaller the particle size, the greater the tendency to “stick” or deposit.

The temperature of the cooling water also affects viscosity of the water, the movement of suspended solids, and the effectiveness of treatment chemicals. The water is slowed as it passes as a film from the top of the tower to the bottom. This decrease in velocity also decreases the ability of the water to rinse or dislodge suspended particles from the fill surface (Nalco Company, 2005:43-266, 2007:1).

All of these factors can contribute to the deposition of suspended solids within the fill pack.

2.5.1.2.2 Aluminum component fouling was come from aluminum sulfite $(\mathrm{Al_2(SO_4)_3.18H_2O})$ or Alum which is used as coagulant for raw water clarifier system. Alum will react with alkalinity $(\mathrm{HCO_3^-})$ in water. The produces is description.

$$\mathrm{Al_2(SO_4)_3.18H_2O + 6HCO_3^- \rightarrow 2Al(OH)_3 + 3SO_4^{-2} + 6CO_2 + 18H_2O} \quad (7)$$

The aluminum sulfite will hydrolyze then to form aluminum complex $(\mathrm{Al(OH)_3})$ which can fouled into surface material as deposit fouling (Nalco company, 2005:43-266, 2007:1).

This is consistent with the mud-like appearance of all the deposits encountered. Normally, utility power plant show very high levels of silt within the deposits. Suspended solids such as silt, clays or hydrated metal oxides are the materials most commonly found in film fill deposit samples. With seasonal rainfall and runoff cycles, the suspended solids levels of cooling tower makeup water sources often become extremely high (>1000 ppm). Silt type materials have been known to completely plug film fill packing in as little as five years of tower operation. In other cases, extremely low levels of suspended solids (<10 ppm) have caused large decreases in tower operating efficiencies as discussed in the following case history. Several factors are contributed to the deposition of suspended solids on the plastic PVC film fill surface. The results of deposit analyses from cooling tower fill must be combined with water analyses of both the quality make-up water and plant operating condition (high heat flux rate). This information, along with the analytical results of fouled fill sections, is essential for a thorough evaluation of the cooling system.

One possible root-cause of serious fouling problem in fill pack of cooling system is poor control of raw water quality; the turbidity was over target at 81%. To enhance the removal suspended solid, aluminum coagulant was considered to increase. This reason why the deposit analysis fouled in fill pack was component with Silicon (Quartz) and aluminum.

Deposition of suspended solids has been effectively controlled with anionic (negatively-charged) polymeric dispersants. This treatment chemical works through a mechanism called “charge reinforcement” where the negatively charged polymer acts to repel or disperse the solids particles. Once treated with the dispersant, the solids are removed with the normal cooling tower blow-down. Cleanup of film fill that had been fouled with silt deposition has also been demonstrated with this copolymer chemical treatment (McCarthy and Ritter, 2006).

2.5.2 Cause from Scale Deposits

Another major elemental component in Sample CW4 and CW6 indicates possible of phosphate deposition. Sample CW8 was iron. High iron levels can indicate a problem with mild steel corrosion in the cooling system or cycling of iron in the makeup water. Phosphate based chemical treatments are used for corrosion protection of mild steel cooling system components.

2.5.2.1 Root-cause of scaling in fills pack.

As cooling water forms a film and courses its way downward through the fill pack, evaporation tends to concentrate the dissolved solids to the point where the salt saturation indices can be exceeded, and precipitation occurs.

Operation of the cooling system at high cycles of concentration often results in high pH and alkalinity conditions that contribute to precipitation of the dissolved solids. Figure 2.5.10 shows the effect of pH on mineral solubility.

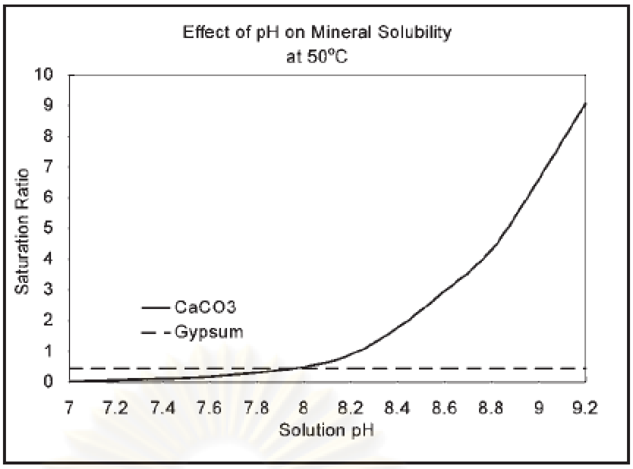


Figure 2.5.7 Effect of pH on mineral solubility at 50°C. (Nalco Company, 2005:43-266, 2007:1)

Utilities often operate in this mode to conserve water and/or treatment chemicals. The resulting mineral scale can be tenacious and completely plug the fill material. In some cases, mineral scale forms first on the plastic fill and provide a rough substrate for the subsequent deposition of silt and/or biological material.

The formation of inorganic mineral scale within cooling tower film fill is the most difficult type of deposit to inhibit with chemical treatment. Lowering the cooling water pH and alkalinity, reducing tower cycles, and using certain organic scale inhibitors have achieved some success. Because of the great efficiency that this fill has for concentrating dissolved salts, it is sometimes not possible to control scale formation and subsequent pluggage with adjustments in tower cycles, water quality or the use of water treatment chemicals. The only recourse is to remove or change sections of the film fill to decrease the overall driving force for the precipitation of dissolved solids. However, several new chemical treatments are being evaluated which may prove effective for this problem. (McCarthy and Ritter, 2006)

2.5.3 Cause from Biological Deposits

Biological activity within cooling tower film fill includes many types of organisms such as algae, slime-forming bacteria, sulfate-reducing bacteria, iron and manganese fixing bacteria and others.

Table 2.5.3 identify the loss of ignition and FT-IR for microbial analysis

Sample	Loss of ignition at 925°C / FT-IR
#CW1	FT-IR indicate some of bio slime
#CW4	LOI > 22 wt%
#CW6	LOI > 22 wt%
#CW8	LOI > 22 wt%

The high loss on ignition at 925°C (ranging from 20-43% for all samples) reflects that a substantial portion of all samples are organic and biological in nature (Nalco company, 2005:43-266, 2007:1). While FT-IR of CW1 was bio slime.

2.5.3.1 Root-cause of microbial foul in fills pack.

Algae deposits often occur within the lower fill layers where sunlight reaches the surface. This can form an initial deposit allowing silt and other material to collect; the plug process proceeds from there. Bacteria growth can proliferate throughout the depth of the fill pack, forming a gelatinous layer. The slime formers are particularly troublesome and contribute to further deposition of suspended material. Biological deposits can be a problem after other types of deposits have formed. A layer of scale and/or silt can form a substrate for both aerobic and anaerobic bacteria to proliferate within the fill pack.

2.6 Concept of detergent to remove fouling in filled pack material.

Chemical detergent is a nonionic detergent for removing and dispersing microbiological-based slime, algae and silt deposits on surfaces. As a detergent, disrupts biofilm integrity removing surface deposits and facilitating biocide penetration into the slime. As a dispersant, Detergent dislodged biofilm aggregates into the bulk water preventing redeposition. Detergent removes surface deposits through a combination of chemical solubilization and physical scrubbing by entrained air bubbles.

Functional of detergent is also very effective at removing biological and silt-based deposits from system components other than tower fill. It may be used as a general detergent to improve the microbial control program by limiting biofilm (sessile bacteria) populations (Nalco Company, 2005:43-266, 2007:1).

2.6.1 Benefits of Detergents:

- Can remove bio-films by themselves.
- Clean continuously even if biocide feed is restricted.

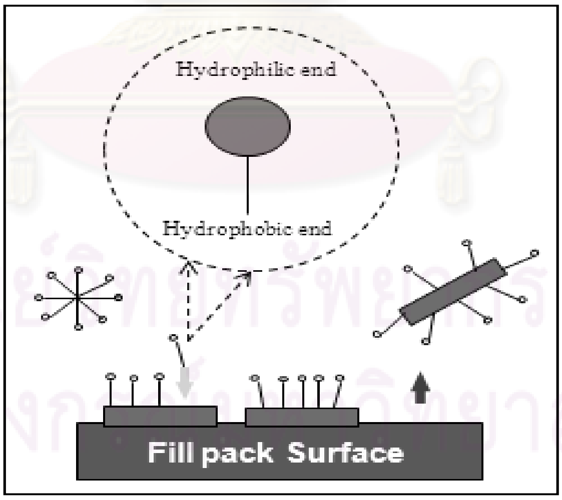


Figure 2.6.1 Functional of detergent to remove fouling film from surface and individual molecule of detergent. (Nalco Company, 2005:43-266:2007:1)

Detergency is the process where a surfactant removes solids or organic materials from a surface to which it is attached. The soil and surface and the choice of surfactant are important considerations in detergency. Detergency is ideally associated with complete solubilization into a clear solution.

Table 2.6.1 physical and chemistry property of detergent

Form	Liquid
Color	Light Yellow
Specific Gravity @ 25^{o}C	1.1 kg/l
pH (neat)	7.5-8.5
Viscosity @ 40^{o}C	300 cp
Viscosity @ 30^{o}C	450 cp
Viscosity @ 20^{o}C	700 cp
Viscosity @ 10^{o}C	1050 cp
Viscosity @ 0^{o}C	1520 cp
Flash Point	>93^{o}C
Freeze Point	-3^{o}C
Odor	None

Component	**Function**
Blend of alkyl polyglycosides	Detergent

2.6.3 Detergent Mechanism

A detergent molecule is composed of two distinct ends a long hydrocarbon tail that is neutral (not electrically charged) . And the other end has either a strong electrical charge or is a polar group (like -OH).

The end that carries an electrical charge is soluble in water (hydrophilic or water-loving). The hydrocarbon end is called hydrophobic (water-hating) and is insoluble in water but very soluble in greases, fats, and petroleum oils. It is because of this balance that surfactants are able to remove and solubilize soils and act as dispersants. A simplified way of thinking of this is that the water-hating end is capable of getting anchored into the oil or particle and the water loving end into the water. (Nalco Company, 2005:43-266, 2007:1)

However, in the research, the methods by which surfactants function, are Detergency In the most basic terms, detergency is the process where a surfactant removes soil (solids or organic materials) from a surface to which it is attached. The soil and surface and the choice of surfactant are important considerations in detergency

2.7 Literature Review

This section will be present the literature review during year's 1995 – 2010 of approaching of cooling tower improvement by vary air flow, water flow, inlet cooling temperature with using cooling tower characteristics to evaluate the result.

2.7.1 Increase cooing efficiency by variation of physical property.

G.A Ibrahim and M.B.W Nabhan (Ibrahim and Nabhan, 1995) has been studied the model in a falling film packing with counter flow force-draught cooling tower in 1995. The dimensions of the tower are hypothetical. One parameter is also described here is the tower efficiency.

The controlled Parameter was the filled packing length and height. And variable Parameter were

- Water Flow rate
- Air Flow rate
- Inlet wet bulk temperature

The result show the liquid thermal resistance reduces when the interface water temperature and hence affects the cooling tower performance. It has also been shown that increasing the tower characteristic and/or reducing the mass flow-rates ratio can enhance the cooling tower performance. The efficiency can be increased by increasing the tower characteristic and/or reducing the flow rate ratio.

Jameel-Ur-Rehman Khan, M. Yaqub, Syed M. Zubair (Zubair , Rechman, and Yaqub, 2002) shown the reliable computer program model of a counter flow wet cooling tower in 2002. They has been used to study the heat transfer mechanisms from a water droplet as it moves from the top to the bottom of the tower, while the air is forced vertically upward. One parameter to use here is approach. The cooling efficiency and tower characteristic were used to evaluate the modeling. The Controlled Parameter were range of volume of tower, fill packing size. And variable Parameter were

- Heat Rates

- Water temperature

The results clearly demonstrate that with an increase in water mass flow rate for the same fill packing, the surface area required both for convection and evaporation is reduced, resulting in higher water outlet temperatures and reduced heat transfer rates.

M. Lemouari, M. Boumaza (Boumaza et al., 2010) has enabled to investigate the effect of the air and water flow rates on the effectiveness and the heat rejected by a counter flow wet cooling tower filled with a VGA type packing in 2010. The tower efficiency and tower characteristic were used to evaluate the study. The Controlled Parameter were inlet water temperature, fill packing sizing. The variable parameters were water flow rate

The results show decreasing of cooling tower efficiency will be increasing with water/air mass flow ratio, L/G, whereas it increases with increasing the inlet water temperature, and higher water flow rates provided the ambient air conditions remain constant. Higher values of ‘e’ are obtained with an L/G ratio of approximately 1.25 at higher inlet water temperature, for the BDR regime

Li Yingjian, You Xinkui, Qiu Qi, Li Jiezhi (Yingjian et at., 2010) has study on 2 systems consist of centrifugal chiller units mounted underground, and three cooling towers mounted are parallelly connected and operated. The cooling efficiency, tower characteristic and thermal efficiency were used to evaluate the study. The controlled parameter were inlet water temperature, fill packing sizing. The variable parameter was water flow rate.

The result show the larger the mass rate ratio of water and air is, the lower the thermal efficiency When the air conditioning load is increased, it is needed to increase the air mass rate to maintain the thermal efficiency constant. When the latent heat transfer process is predominated, certain water supply needs to be maintained. If the dry bulb temperature of the entering air is obviously lower than the entering water temperature, and that the relative humidity is on the higher side, the total heat transfer will be predominated by sensible. The serious filling clogs in cooling tower could significantly influence the mass flow rate of the water and the air, as well as process of the heat and the mass transfer.

2.7.2 The Study of fouling in filled pack material.

Bilal, Qureshi, Syed and Zubair (Zubair et al., 2006) have presented mathematical modeling of three parts. The spray zone, packing and rain zones. The importance of incorporating fouling model is also highlighted. In this regard, a case study is presented to show the validity of using spray and rain zone models in conjunction with the packing model for accurate sizing and performance evaluation purpose.

A computer program is written in Engineering Equation Solver (EES) for solving the above equations. In this program, properties of air–water vapor mixture are needed at each step of the numerical calculation, which are obtained from the built-in functions provided in EES. The program gives the dry-bulb temperature, wet-bulb temperature and humidity ratio of air as well as water temperature at each step of the calculation starting from air-inlet to air-outlet values.

The conclusion is that fouling is a major source of cooling tower performance deterioration and, therefore, a strategy to model fouling in cooling tower fills is also outlined to highlight the importance of fouling in rating calculations of cooling towers.

2.7.3 The Study of chemical removes fouling in cooling system.

T. Reg Bott (Bott, 2009) has studied about common chemicals is used in fouling removal is a biocides. This may be classified as oxidizing or non-oxidising. Oxidising chemical include with group of chlorine and chlorine yielding chemicals, ozone, and hydrogen peroxide. Amongst with the non-oxidizing compounds are amines, heavy metal compounds, aldehydes, organo-bromine compounds, and isothiazolones.

The objective is to remove any biofilm as it forms. To be economical and effective. The addition of chemicals to cooling water may be made in three ways.

Table 2.7.1 Summary the literature review during 1995 – 2010.

Author Name	Year	Variable parameter	Study Method
Study the method to increase cooling efficiency			
G.A Ibrahim and M.B.W Nabhan	1995	Water Flow, Air Flow and Inlet wet bulk temperature.	Reducing Liquid/Gases ratio.
Jameel-Ur-Rehman Khan, M. Yaqub, SyedM. Zubairin	2002	Heat Rates, water temperature	Increasing water mass flow
M. Lemouari, M. Boumaza	2010	Liquid flow rate, water flow rate	Increasing water mass flow
Li Yingjian, You Xinkui, Qiu Qi, Li Jiezhi	2010	Liquid flow rate, water flow rate	Vary water / air mass flow
Study the fouling in filled pack material			
Qureshi, Zubair	2006	-	Computer program.
Study the chemical removes fouling in cooling system			
T. Reg Bott	2009	-	Use biocide to prevent fouling

CHAPTER III

EXPERIMENTALS

3.1 Plant diagram and parameters for study

Open cooling water system for testing is used at steam turbine condenser to condense low pressure steam into liquid phase as detail in figure 3.1.1.

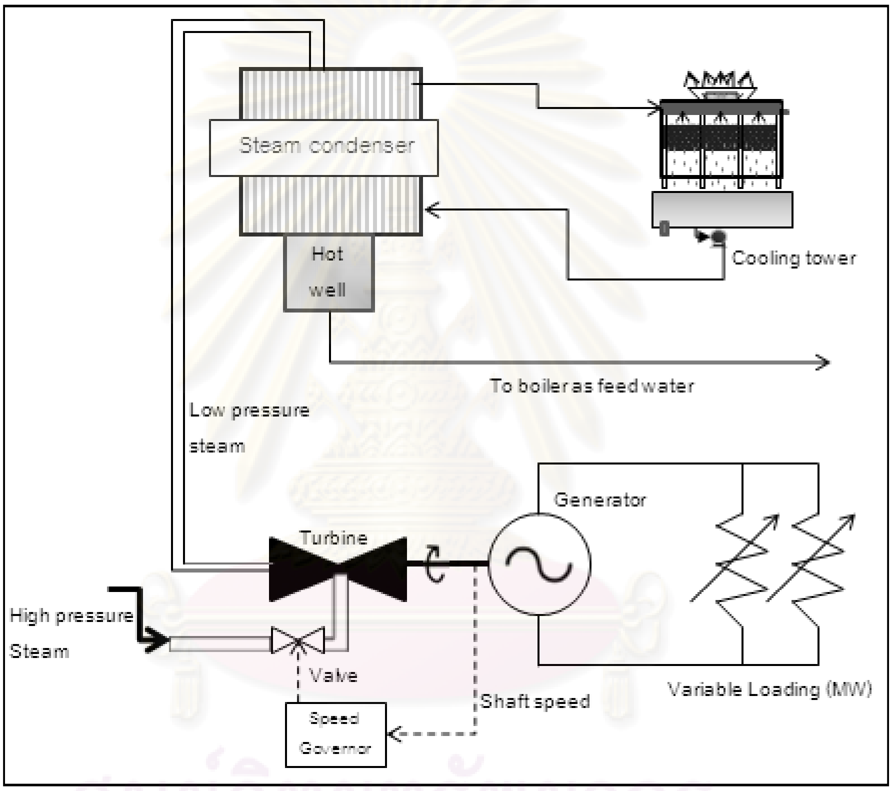


Figure 3.1.1 Diagrams for cooling water system and steam turbine and condenser processing.

The cooling water system is consisting of two plants and eight cooling towers counter flow, which has similarly status.

The make-up water of cooling system in figure 3.1.2 is coming from pretreatment system of raw water source that consists of lamella clarifier and clarified water tank. The pretreatment does not have filter to polish the effluent of clarifier.

The testing consists of eight cooling towers which are similarly operated. Two of the cooling towers are not dosed with chemical program (blank) while others are dosed to remove foulant in fill packing.

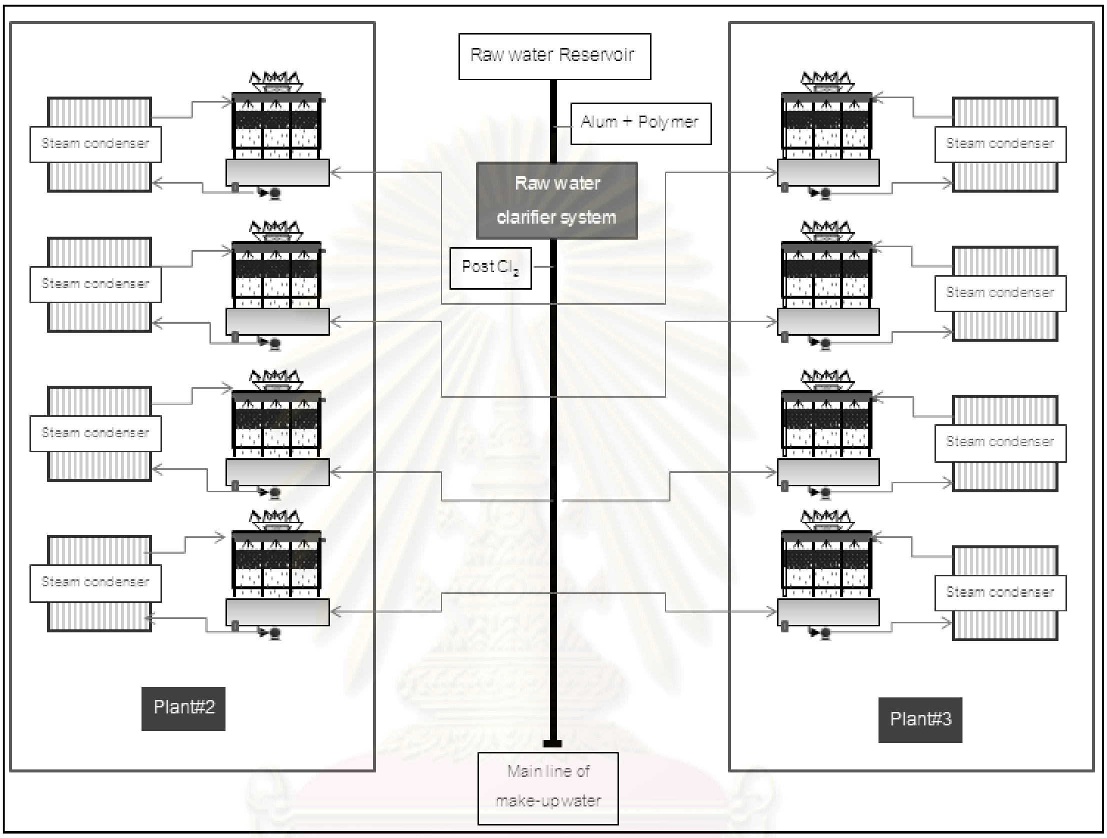


Figure 3.1.2 the overall diagram of eight cooling towers on two plants that used the one source of make-up water.

The frequent of sample is 2 time a day. The runtime is 30 days. The loading megawatt was a variable parameter. The data of inlet and outlet cooling tower temperature and loading megawatts were collected by plant's computer for every hour. The inlet wet-bulk temperature of cooling water was done as daily by manual sling psychrometer. The flow rates of two cooling waters and electronic power of cooling fans were kept constant. This testing will proposed 2 important variable parameters.

- Loading megawatt which is varied between 40 and 50 MW.
- Chemical dosage of detergent which varied between 0, 3, 5 and 5 mg/l.

Table 3.1.1 is detail the variable parameters for using this test.

Variable parameters	Unit	Vary Range
Loading megawatt	MW	40, 50
Dosage of detergent	mg/l (ppm)	0, 3, 5 and 10

The evaluating parameters that will used to evaluate the improving of cooling during testing at any loading megawatt are cooling tower efficiency. Table 3.1.2 is detail the depended parameters for using this test.

Table 3.1.2 the evaluating parameter of test

Evaluating parameters	Unit	Acceptable Range
Cooling tower efficiency	-	More design (> 0.5087)

Others parameter to monitor the water chemistry after testing is shown in table 3.1.3 as follows.

Table 3.1.3 the detail of water chemistry for test.

Other parameters	Unit	Acceptable Range
Temperature approach	^{o}C	Lower design (7.9 ^{o}C)
Heat reject	kW	Higher design (98,348 kW.)
Turbidity	NTU	Lower than 15 NTU
Conductivity	us/cm	Lower than 2500 us/cm
Corrosion rate	mpy	Lower than 3 mpy
Total aerobic bacterial	Cfu/ml	Lower than 100,000 cfu/ml

The meteorological conditions during test period were that the approximately inlet wet-bulk temperature was 27.6-28.3oC. The maximum inlet cooling temperature (hot temperature) was 53^{o}C, and the minimum outlet cooling system temperature (Cold temperature) was 30^{o}C.

Because eight cooling towers were in equilibrium with total conditions, the chemical program, detergent, was only dosed at CW#2-4 and CW#6-8 while CW#1 and CW#5 without chemical program. The data was collected for 2 times / every day to compare and analyzed the result. Table 3.1.4 shows the typical data and variation during runtime.

Table 3.1.4 Cooling tower design information for eight cooling towers system.

Items	Unit	Design Value
System Volume	m^3	1,000 (Constant)
Recirculation rate	m^3/hr	12,000 (Constant)
Inlet CW Temperature	^oc	44
Outlet CW Temperature	^oc	36
Temperature Range	^oc	8
Temperature Approach	^oc	7.9
Wet bulb temperature	^oc	28.1
Motor power	BKW/fan	270 (Constant)
Cooling tower efficiency	-	0.5087

3.1.1 Feeding rate calculation

Feeding rate is one important to check during study. The calibration cylinder is required to ensure the feed rate of chemical is added into water. The chemical feed rate can be expressed as follows.

$$\text{Feeding rate} = \frac{\text{dosage x blow down rate}}{\text{Density x 60}} \qquad (8)$$

Where: Unit of feeding rate is milliliter/minute (ml/min)

Unit of Blow down rate is cubic meters / hour (m3/hr)

Detergent density is 1.10 kg/l.

Table 3.1.5 Feed rate calculations for variation of blow down rate.

Descriptions	unit	CW2	CW3	CW4	CW6	CW7	CW8
Recirculation rate	m^3/hr	10031	10029	10032	10024	10040	10018
Range	°C	8.08	9.36	9.11	9.8	11	11.3
Cycle	-	7.11	6.95	7.05	7.11	7.08	7.1
Evaporation rate	m^3/hr	125.3	145.1	141.2	151.8	170.7	175.0
Blow down water	m^3/hr	20.5	24.4	23.3	24.8	28.1	28.7
Makeup water	m^3/hr	145.8	169.5	164.6	176.7	198.8	203.6
Feed rate 3 ppm	L/min	4.06	-	-	4.92	-	-
Feed rate 5 ppm	L/min	-	8.05	-	-	9.26	-
Feed rate 10 ppm	L/min	-	-	15.41	-	-	18.93

3.2 Study equipment and method

3.2.1 Sling psychrometer BACHARACH: model 12-1072

3.2.2 Prominent Dosing pump (1.7 LPH) Model: LMI: 6 set

3.2.3 Poly Ethylene dosing tank 100 Lit: 6 set

3.2.4 Poly Ethylene pipe line: 6 set

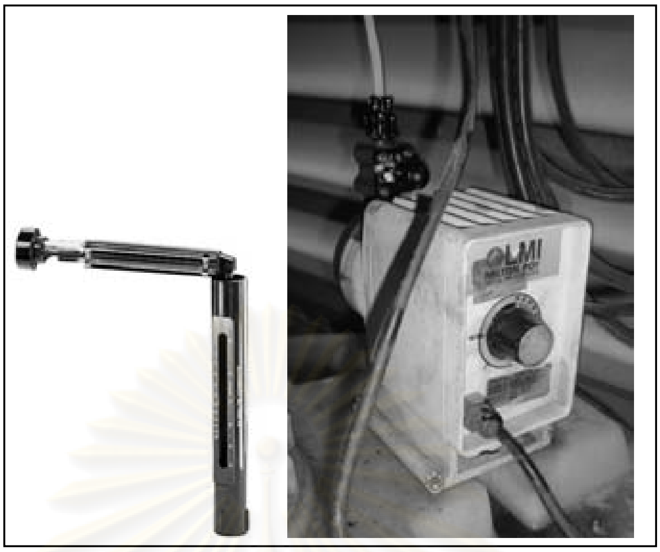


Figure 3.2.1 Sling phychrometer, dosing pump of feeding system.

Table 3.2.1 specification of the measurements

Device	Model	Function	Unit	Range	Accuracy
Handheld meter	001H-2827.88	pH	-	0-14	± 0.05
Handheld meter	001H-2827.88	Conductivity	us/cm	0-20000	± 1%
Nalco turbid meter	400-PT100.88	Turbidity	NTU	0-1000	±2%
Nalco Spectrophotometric	DR2800	Phosphate	mg/l	1-25	± 1%
Hardness test kit	Titration	Hardness	mg/l	10-200	-
Nalco Colorimetric	DR890	Chlorine	mg/l	0.03-5.00	± 1%
Nalco Spectrophotometric	DR2800	Total iron	mg/l	0.1-3.0	± 1%
Nalco Corrosion Online (NCM100)	400-NCMP1B.88	Corrosion rate	mpy	0.1-99.9	± 10%
Total Bacteria Dip Slides	500-P1673.88	Microbial	cfu/ml	Unlimited	± 15%

3.2.1 Principle of measurement operating of turbid meter and corrosion rate.

3.2.1.1 Turbidity Measurement meter: The waterproof Turbidity Meter is ideal for monitoring turbidity in industrial applications. The micro-processor based turbidity meter uses an infrared LED light source and delivers excellent repeatability and accuracy while offering resolution as low as 0.01 NTU. This lightweight meter is valuable analytical tool for field testing and quality control. An LED light source transmits a beam of infrared light into the sample stream at an angle of 45° to the sensor face. A pair of photoreceptors in the sensor face detects scattered light at 90° to the transmitted beam. It appears on the display in units of nephelometric turbidity units (or NTU) which come from a calibrated nephelometer.

3.2.1.2 Nalco corrosion online monitoring (NCM100): is measured the electrical current resulting from the application of a small voltage across the electrodes on the probe (or measures the electrochemical polarization of ± 10 mV between two electrodes or liner polarization resistances). The electrodes are embedded in an epoxy mounting material to minimize crevice corrosion and improve the accuracy of measurements. It appears on the display in units of mils per year (mpy) or millimeters per year (mm/y).

Table 3.2.2 Detail of test procedure

Description of Test	Runtime	Collect Method	By
1. Prepare feeding system of detergent chemical product.	3 days	-	Researcher
2. Start to dose detergent at 3, 5 and 10 mg/l into cooling basin.	1 day	Check the accuracy of dosage by calibration cylinder	Researcher
3. Keep 30 days for recording the resulting	2 times/ day (30 days).	-	Researcher
4. Collect the data			
● Cold and hot cooling temperature and loading megawatt.	2 times/ day (30 days)	● Online collecting Program (PI)	Plant
● Wet bulk temperature	2 times/ day (30 days)	● Manual Sling psychrometer	Researcher
● Water chemistry	2 times/ day (30 days)	● Water analyze	Researcher
● Manual weighting and visual inspection	2 times (before and after test)	● Scale apparatus and photographic	Plant
5. Calculated the cooling tower efficiency after testing.	10 days	-	Researcher
6.Investigate the result	15 days	-	Researcher

CHAPTER IV

RESULTS AND DISCUSSIONS

Study result

The real data which will be collected to interpret in this study are the temperature cold and hot temperature water, turbidity, conductivity, mild steel corrosion rate which are collected by plant.

However, evaporative wet cooling tower always has an “Evaporated water” to carry out the heat from hot water to ambient. The remaining water in system will over and over concentrate either of dissolved and suspended solids. To prevent the limited exceed of scale precipitation, fresh make-up water is added to keep the concentration within limited. In the contrast, if make-up water is a problem, especially high turbidity the scale and fouling potential will be faster than normal situation (Nalco company, 2005:43-266, 2007:1).

The test was collected the turbidity during pre-post test and following are the result and discussed.

4.1 The turbidity results from make-up water.

Make-up water, especially turbidity, can cause the fouling potential when it is over acceptable limited (<1.0 NTU).

. The turbidity was analyzed by turbid spectrophotometer. The turbidity trend of make-up water was collect 2 times per day. All have 150 days before test and 30 days testing.

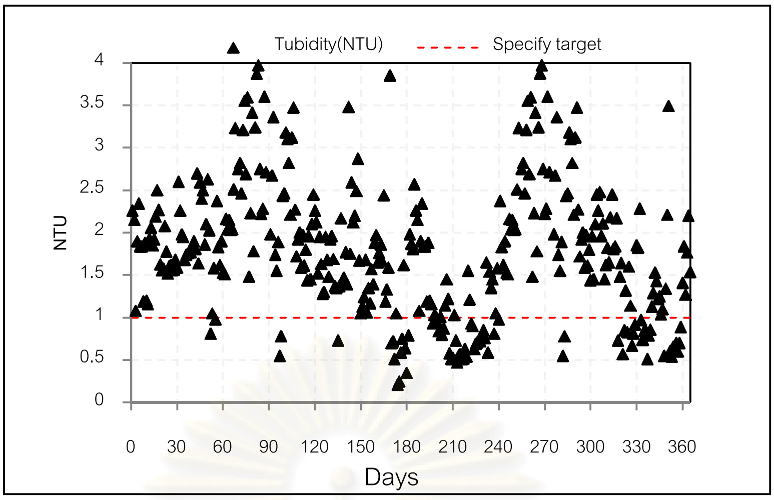


Figure 4.1.1 illustrate the highly fluctuate of turbidity of make-up water over than specify target (<1.0 NTU) during pre-test and post-test (360 sample time).

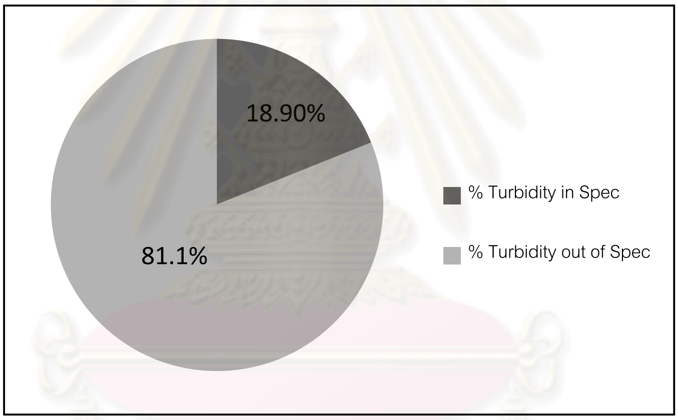


Figure 4.1.2 illustrate the turbidity within/out of target (%) of make-up water during test

Figure 4.1.1 and 4.1.2 illustrates turbidity resulting in make-up water. The result shows very higher value than specify target limit (1.0 NTU).

This can summarize that turbidity from makeup water is always higher than target required (Out of spec 81.1%). This can cause a fouling problem to cooling tower. Because of turbidity is represents amount of suspended solid. High turbidity measurement means high suspended solid matter in system.

4.1.1 Suspended solid calculation from makeup water.

Figures 4.1.3 illustrates the cooling tower diagram of input water, output water and evaporate water. From mathematically the mass balance for a system without a chemical reaction, the mass balance around cooling tower can be expressed.

$$\text{Input} = \text{Output} + \text{Accumlation} \qquad (9)$$

During study (30 days), the suspended solid was collected from makeup water and cooling water to analyze the result once a week. The analyzed data of suspended solid of Cooling 1 was collected 4 times. The averages were as following.

- Suspended solid in makeup was 15.32 mg/l.
- Suspended solid in blow down water was 127.5 mg/l.

Flow rate of makeup water and blow down water flow rate was collected by plant. Collecting date was 30 days. The data are as follows.

- Capacity of makeup water = 127,062 m3
- Capacity of blow down water = 17,979 m3

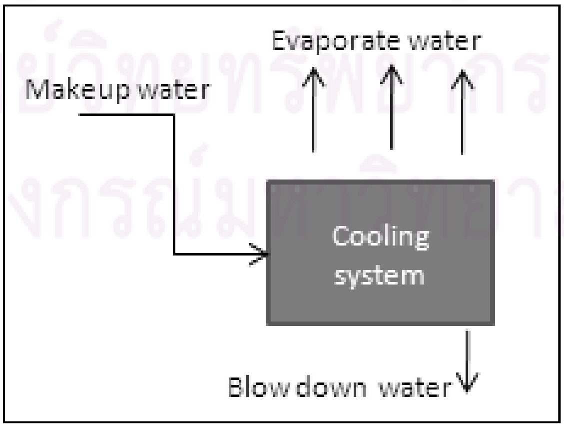


Figure 4.1.3 mass balance around cooling tower system

Input is subscripted with makeup. Output is subscripted with blow down and evaporates. But it's due to no suspended solid in evaporating water. Substituent with mass balance around cooling tower diagram, find that.

$$\text{SS makeup} = \text{SS blowdown} + \cancel{\text{SS evaporat}} + \text{SS accumlat} \qquad (10)$$

After arrangement, find that.

$$\text{SS accumlation} = \text{SS makeup} - \text{SS blowdown} \qquad (11)$$

Where: SS is defined as suspended solid concentration (mg/l).

Calculate the suspended solid in makeup water, blow down water. Summary mass balance of fouling accumulation in filled pack is shown in figure 4.1.4.

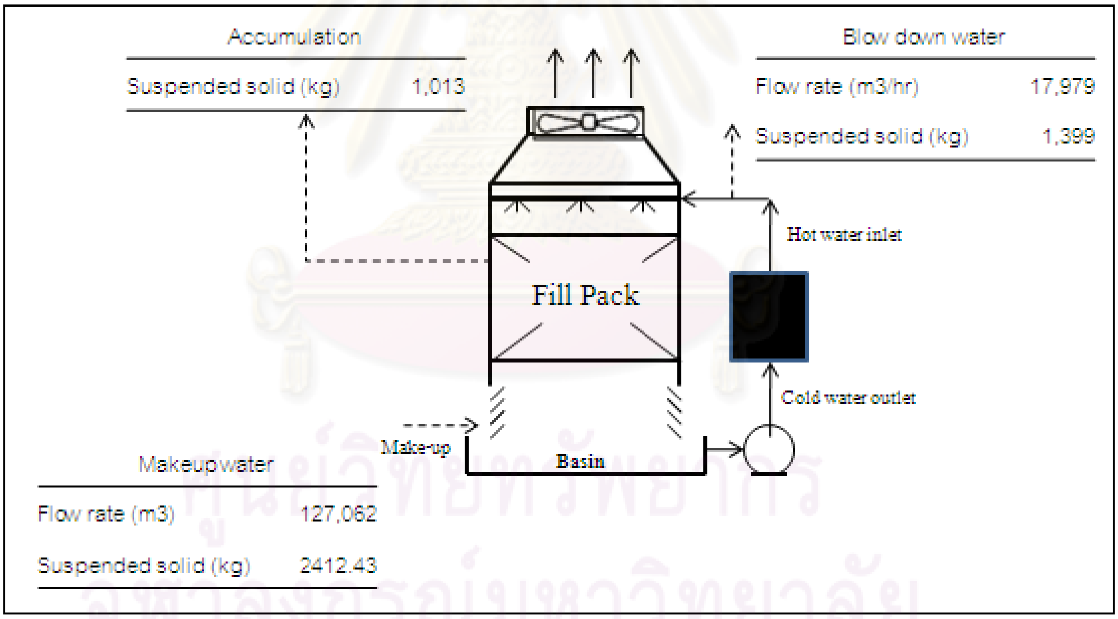


Figure 4.1.4 mass balance of suspended solid around cooling system.

The 1,013 kg of suspended solids is accumulated in cooling system, some deposit out in the exchangers, but most settle out in the filled pack

4.2 The wet bulb temperature results in makeup water.

The inlet wet-bulk temperature is one parameter directly effect on cooling performance (Wanchai Asvapoositkul, Thirapong Muangnoi, Somchai Wongwises, 2008). The lower or highest profile of inlet wet-bulk temperature is caused an inaccuracy reading of approach temperature by reduce or increase the efficiency of cooling tower. The pre-test collecting data of wet bulb temperature is done 2 times per day (30 days) and during test 2 times per day (30 days) by manual sling phychrometer.

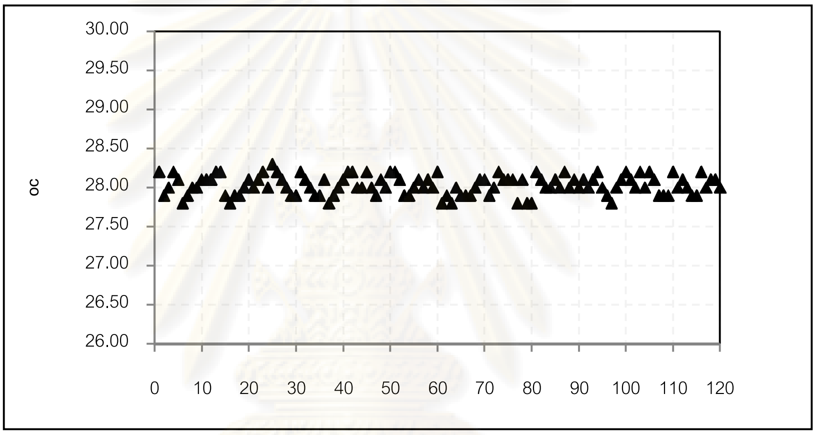


Figure 4.2.1 The inlet wet-bulb temperature profile during study

Figure 4.2.1 show profile of inlet wet bulb temperature during test. The profile is smooth and do not fluctuate (less than 2oC). This can summarized that wet bulb temperature at study area is not impact to inaccuracy reading of approach temperature and cooling efficiency.

Table 4.2.1 is summarized the inlet parameters Cooling water system 1 to Cooing water system 8 during study. The result shows 81.1% out of target of turbidity make-up. And wet bulb temperature is constant.

Table 4.2.1 averages, minimum and maximum value of turbidity in make-up water and wet bulk temperature during testing.

Parameters	unit	Average	Minimum	Maximum	Target	%Out of spec
Make up Turbidity	NTU	1.812	0.21	5.63	< 1.0	81.1%
Wet bulk Temperature	C	28.03	27.8	28.3	-	-

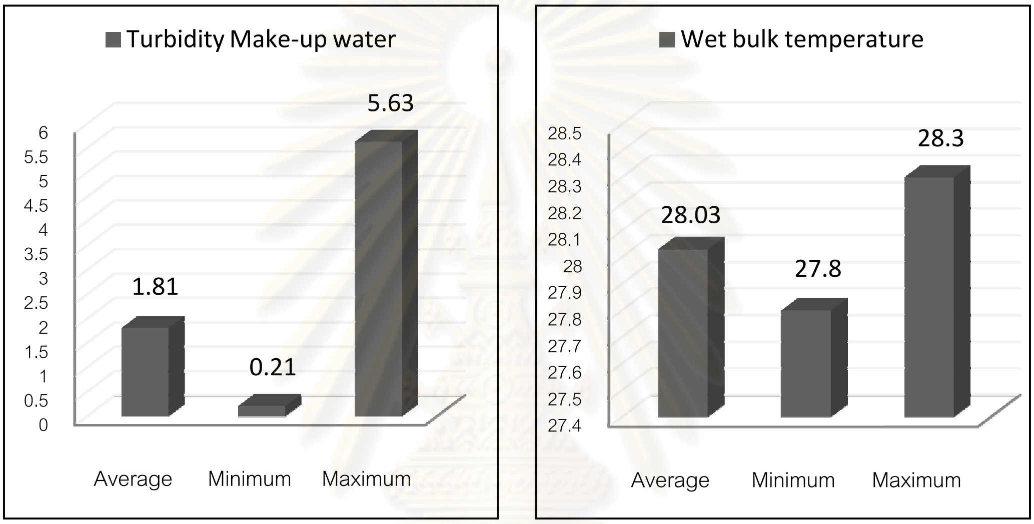


Figure 4.2.2 Graph of average, minimum and maximum profile of turbidity in makeup water and wet bulk temperature during study.

Discussion on turbidity in makeup water and wet bulb temperature.

Turbidity in makeup water is highly fluctuated. High turbidity is high suspended solid in makeup water. From the mass balance of suspended solid in cooling system, suspended solid from makeup water was 2,412 kg. This was accumulated in cooling system = 1013 kg. Most of accumulation will be in filled pack zone.

The wet bulb temperature in study area is not differential all time. The average is 28.03 oC. This can summarize that inlet wet bulb temperature which used to calculate cooling efficiency in this research is constant.

4.3 Cooling efficiency and water chemistry after detergent at loading megawatt 40 and 50 MW.

This section will separate into 2 range of loading megawatts (40 and 50 MW). Plant 2 is operated at loading 40 MW and plant 3 is operated at loading 50 MW. Table 4.3 is description the detail of test.

Table 4.3 descript three of the detergent dosing (mg/l) at any loading (MW).

Location	CW name	Study Loading (MW)	Test range of Detergent (mg/l)
Plant 2	CW#1	40	0.0
	CW#2		3.0
	CW#3		5.0
	CW#4		10.0
Plant 3	CW#5	50	0.0
	CW#6		3.0
	CW#7		5.0
	CW#8		10.0

Where: CW#1 is define as cooling water system 1
CW#2 is define as cooling water system 2
CW#3 is define as cooling water system 3
CW#4 is define as cooling water system 4
CW#5 is define as cooling water system 5
CW#6 is define as cooling water system 6
CW#7 is define as cooling water system 7
CW#8 is define as cooling water system 8

4.3.1 Study effect of water chemistry and cooling efficiency after detergent 0, 3, 5, 10 mg/l loading megawatt 40 MW.

The test was proceeded as figure 4.3.1.1 the CW#1 was not dosed. CW#2, CW#3 and CW#4 was dosed with detergent at dosage 3, 5, 10 mg/l (ppm) respectively.

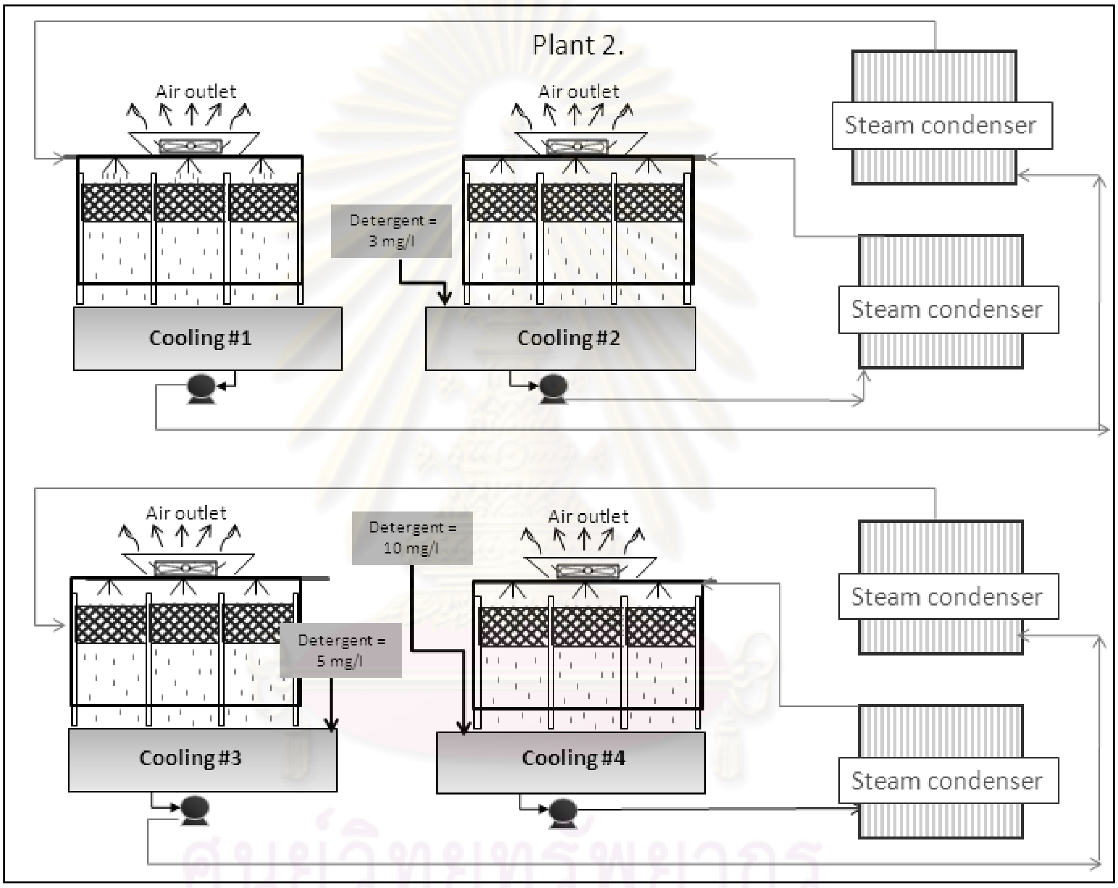


Figure 4.3.1.1 illustrate the cooling diagram of plant 2 during study at load megawatt 40 MW.

The result was separated into 2 parts. Part 1 is a average result of water chemistry and part 2 is calculate result.

4.3.1.1 Measurement parameters which consist of

- Calcium hardness (mg/l)
- Ortho-phosphate (mg/l)
- pH
- Conductivity (us/cm)
- Feed Chlorine (mg/l)
- Total iron (mg/l)
- Turbidity (NTU)
- Suspended solid (kg)
- Manual weighting of tower fill pack (kg) and visual inspection.
- Corrosion rate (mpy)
- Microbiological analysis (cfu/ml)

4.3.1.2 Calculated parameters which consist of

- Cooling efficiency
- Temperature approach (^{o}C)
- Heat reject (kW)

4.3.1.1 Cooling water chemistry result after perform detergent at loading 40 MW.

Table 4.3.1.1 Averaging of water chemistry results for CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

Water Chemistry Average At load megawatt : 40 MW						
				Post-test (Dosed Detergent)		
Parameters	unit	Target	0 mg/l	3 mg/l	5 mg/l	10 mg/l
Calcium	mg/l (ppm)	< 300	251	222	238	214
Phosphate	mg/l (ppm)	4-8	5.3	6.1	5.8	5.5
pH	-	7.0-7.5	7.32	7.52	7.29	7.29
Conductivity	us/cm	<2500	1490	1626	1977	2027
Chlorine	mg/l (ppm)	0.2-0.5	0.30	0.26	0.33	0.37
Suspended solid	mg/l (ppm)	-	77.84	84.52	98.54	100.03
Turbidity	NTU	< 15	9.97	9.23	15.85	17.89
Corrosion rate	mpy	<3	0.99	1.20	1.19	1.08
Microbial	cfu/ml	<100,000	11000	13000	16000	25000

Table 4.3.1.1. shows that Calcium hardness was not differentail during study. The phosate which is corrosion inhibitor and pH result was maintain during study as well.

Chlorine must to maintain with target status (0.2-0.5 mg/l) to kill microbial. Microbial will be present in the matter that fouled in tower fill pack (consist of silt, mud enmeshed in biofilm). At higher dosage of detergent effect to need more fee chlorine than normal condition.

4.3.1.1.1 Turbidity Result

Turbidity profile was significant increased after dosed detergent due to functional of detergent chemical. It disperses a fouling matter in fill pack into bulk water. Higher dosage of detergent caused increasing trend of turbidity.

Because of turbidity is a parameter that represents the amount of suspended solid/dirty into bulk water (Nalco Company, 2005:43-366, 2007:1). If suspended solid is removed from tower fill, turbidity should be higher value than normal condition. Figure 4.3.1.2 shows turbidity profile after dosed.

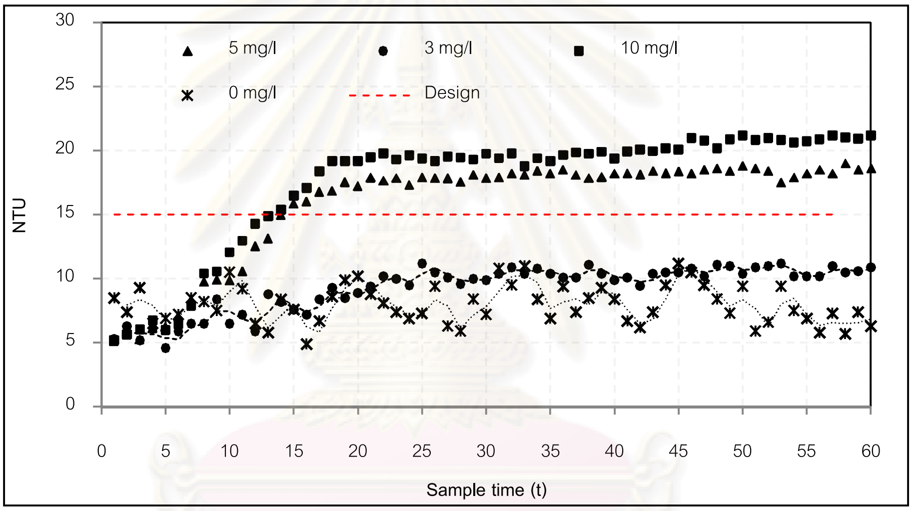


Figure 4.3.1.2 Turbidity results CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

The turbidity profile at CW#1 which not dosed, the turbidity line was not changed (Not a decrease or increase trend). CW#2 was dosed at 3 mg/l of detergent, turbidity during 1 < t < 20 was not different with from CW#1. When t>20, the turbidity profile at 3 mg/l dosed was above turbidity profile (no dosed) but overall was still within target limited (15 NTU). This mean that detergent at 3 mg/l can a little removed suspended solid / dirty from fill pack. This is a preliminary of sufficiency dosage of detergent to use to remove suspended solid in tower fill pack. CW#3 performs detergent at 5 mg/l. These was dramatically increased over target when t >7 after dosed. This proof that detergent at 5 mg/l can effectively removed suspended solid / dirty from fill pack. Because at no dosed condition, turbidity was not changed. But at 5 mg/l of detergent, turbidity (represent of suspended solid) was increased. The turbidity profile of CW#4 after performs at 10 mg/l detergent. This was dramatically increased over target (similar to 5 mg/l detergent). Anyways the overall turbidity result trend between dosed at 5 and 10 mg/l were not a big differential (only 2% differential).

Turbidity and suspended solid can removed because of detergent product can act as the dispersancy. This will do the actual removal of soft foulant deposits (Nalco Company, 2005:43-366, 2007:1). Figure 4.3.1.3 shows a detergent allows the product to lift off soft foulant from a surface. This is reason of the fouling of suspended solid especially in tower fill pack will be removal into cooling water to directly affect increased turbidity. And it was without then fouled on heat exchanger surface due to dispersancy functional.

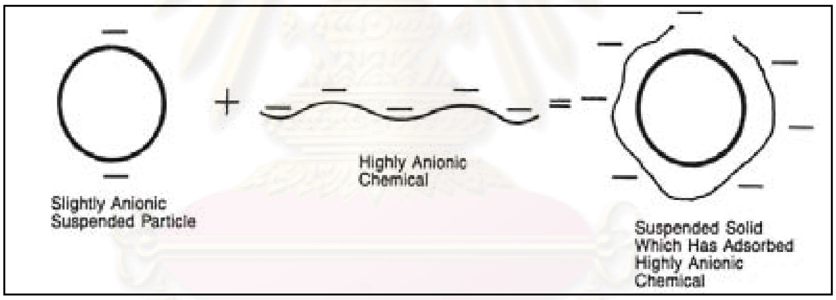


Figure 4.3.1.3 Functional of dispersancy to remove soft folant deposit by highly anionic chemical charge on suspended solid surface (Nalco, 2005:43-266, 2007:1).

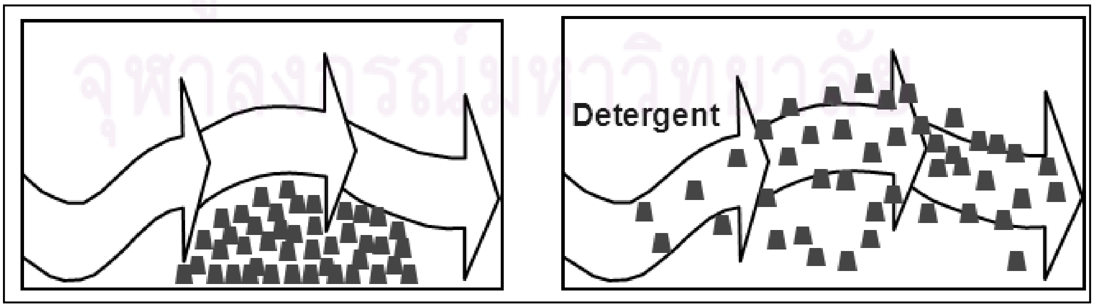


Figure 4.3.1.4 illustrate detergent can remove solid matter on surface (Nalco, 2005:43-266, 2007:1).

4.3.1.1.2 Suspended solid removal:

From the mass balance equal around cooling tower system. The equation of suspended solid can be expressed.

$$\text{SS accumlation} = \text{SS makeup} - \text{SS blowdown} \qquad (12)$$

From analyzed data in table 4.3.1.1.

- Suspended solid in makeup was 15.32 mg/l (Average value).
- Suspended solid in cooling water after dose detergent at 3 mg/l was 84.52 mg/l
- Suspended solid in cooling water after dose detergent at 5 mg/l was 98.54 mg/l
- Suspended solid in cooling water after dose detergent at 10 mg/l was 100.03 mg/l

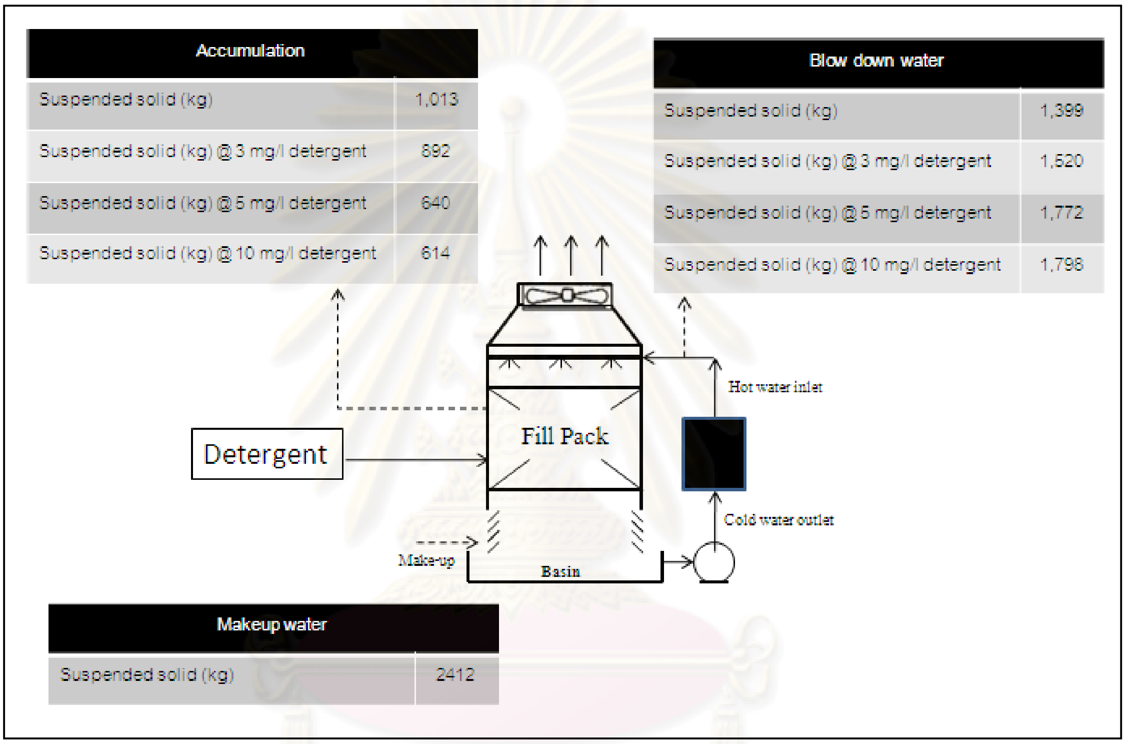
Table 4.3.1.2 shows mass balance of suspended solid in makeup water, blow down water and accumulate in cooling system at loading megawatt 40 MW.

	Lab Analyze	Mass balance of Suspended solid (kg)			
Dosing	mg/l	Makeup	Blow down	Accumulate	% Removal
0 mg/l	77.84	2412	1399	1013	58%
3 mg/l	84.52	2412	1520	892	63%
5 mg/l	98.54	2412	1772	640	73%
10 mg/l	100.03	2412	1798	614	75%

Table 4.3.1.2 shows the suspended solid that is increase in bulk water when dosing detergent is increased. With no detergent condition, the suspended solid in bulk water is 2412 kg. From mass balance, accumulate of suspended solid is 591.

When detergent is dosed at 3, 5, 10 mg/l. The suspended solid in blow down is increased. And accumulate of suspended solid is decreased.

This can summarized that fouling of suspended solid in filled pack material van removed by detergent chemical. Figure 4.3.1.5 show increasing of in bulk water when dosing detergent is increased.



Accumulation	
Suspended solid (kg)	1,013
Suspended solid (kg) @ 3 mg/l detergent	892
Suspended solid (kg) @ 5 mg/l detergent	640
Suspended solid (kg) @ 10 mg/l detergent	614

Blow down water	
Suspended solid (kg)	1,399
Suspended solid (kg) @ 3 mg/l detergent	1,520
Suspended solid (kg) @ 5 mg/l detergent	1,772
Suspended solid (kg) @ 10 mg/l detergent	1,798

Makeup water	
Suspended solid (kg)	2412

Figure 4.3.1.5 shows mass balance after dosed detergent at 3, 5 and 10 mg/l during study. The accumulation of suspended solid in filled pack is decreased when detergent is increased to 5 and 10 mg/l.

Detergent can remove the suspended solid in filled pack. This enhances heat transfer of hot water and air inlet in filled pack zone cooling tower. The efficiency will increase. Figure 4.3.1.6 shows relation between % suspended solid removes from filled pack into bulk water by detergent and cooling efficiency.

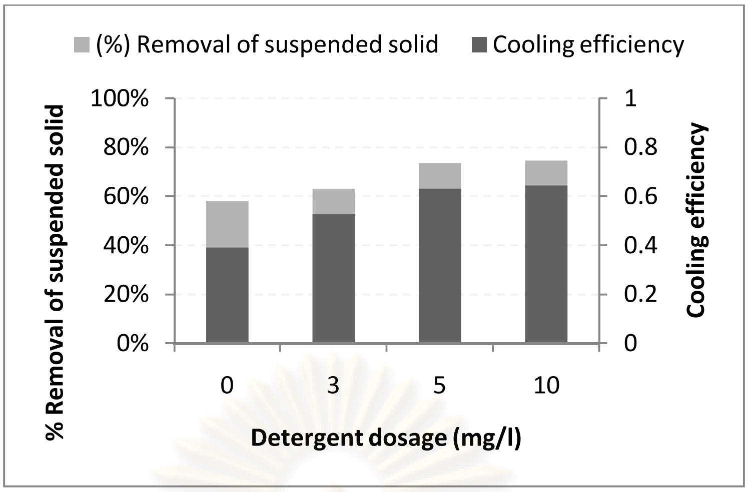


Figure 4.3.1.6 Relation of % suspended solid removes by detergent and cooling efficiency at loading megawatt 40 MW.

4.3.1.1.3 Manual weighting result and visual inspection of filled pack

And manual weighing of filled packing is implemented during study to actual measure the weight of suspended solid. The result has taken 1 week before dose with detergent and after dosed. Anyways, the weighting data can be collected for only four units. The cooling 1 was represented to un-dose condition while cooling 3 is was represented with dosed detergent at 5 mg/l. Table 4.3.1.3 was summary data and percentage removal of weighting

Table 4.3.1.3 shows the actual weighting result before and after used detergent.

Unit	Chemical (mg/l)	Before dosed (kg)	After dosed (kg)	Fouling Removal (%)
CW#1	0	5.83	5.98	-
CW#3	5	6.68	2.56	61.7%

The actual weighting of fill packing material before and after dosed with detergent can summarized that the detergent can effectively remove fouling matter from fill pack. And figure shows some of visual inspection of fill pack after dosed with detergent. The overall was clean when compared with un-dose condition.

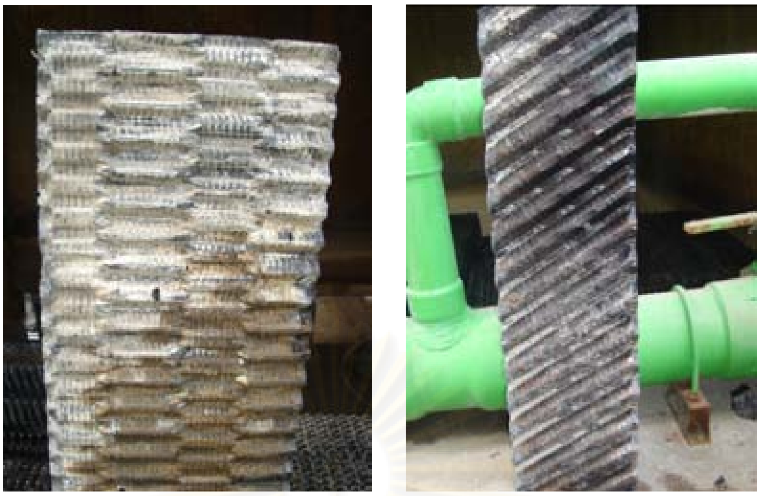


Figure 4.3.1.7 the filled pack weighting of cooling 1 (Left: un-dosed) and cooling 3 (Right: 5 mg/l of detergent)

4.3.1.1.3 Conductivity result

Figure 4.3.1.8 shows the conductivity profile at CW#1 (not dosed), the result was maintain during 1<t<50 because of turbidity was not changed. When 51<t<60 the profile was looked a decreasing trend due to plant operating. CW#2 was dosed at 3 mg/l of detergent. The conductivity trend was not different with CW#1 during 1<t<20 and increasing trend after t > 25. CW#3 perform detergent at 5 mg/l was dramatically increased over target (2500 us/cm) when t > 7 after start dosed. Because of turbidity profile was increased. While conductivity profile of CW#4 after performs at 10 mg/l detergent. This was dramatically increased over target similarly with CW#3.

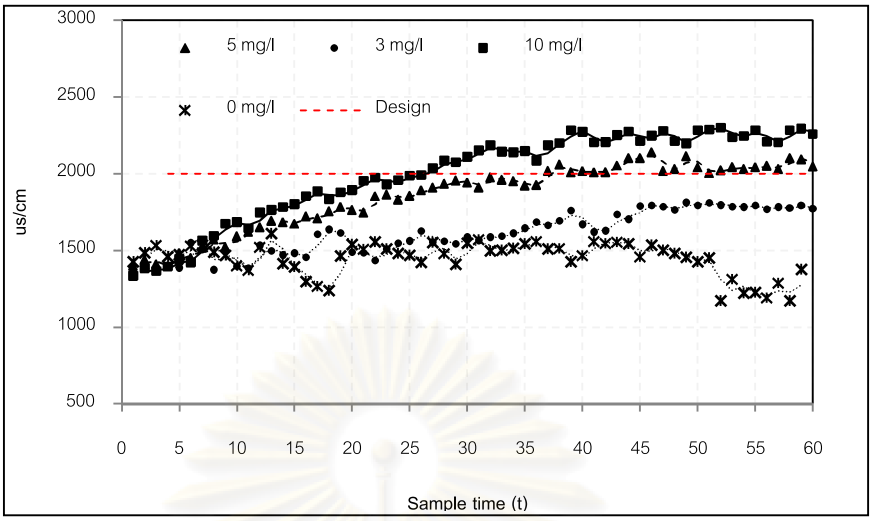


Figure 4.3.1.8 Conductivity results of CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

The reason of conductivity increase when dosed detergent is that detergent chemical can act as the dispersancy. It will remove soft foulant deposits that fouled in fill pack. The impact is increased turbidity trend and consequent to increase conductivity profile after added detergent chemical.

4.3.1.1.4 Corrosion rate result

Corrosion rate was collected by online corrosion reading apparatus, called NCM100. NCM100 measure the electrical current resulting from the application of a small voltage across the electrodes on the probe. The current measured is translated by the corrosion meter into a general corrosion rate, which appears on the display in units of mils per year (mpy) or millimeters per year (mpy) (Nalco company, 2005:43-266, 2007:1). It was installed for all cooling units. Figure 4.3.1.9 shows the corrosion rate after dosed detergent.

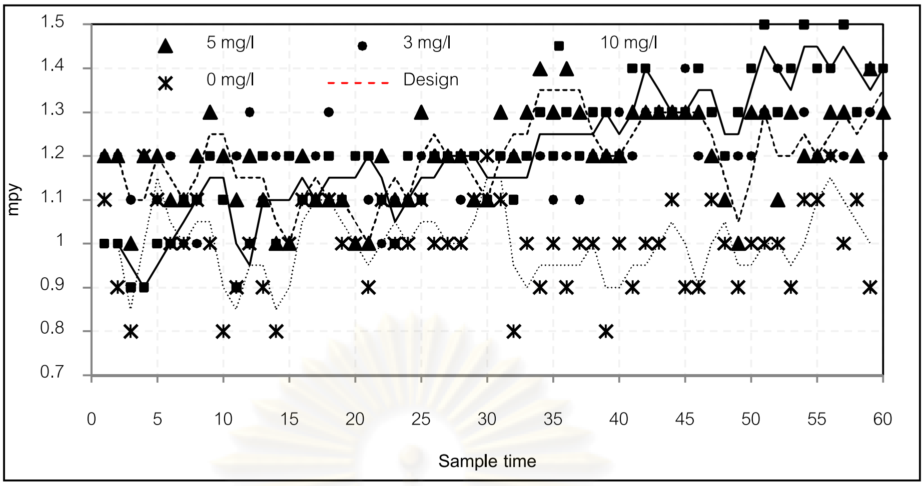


Figure 4.3.1.9 Corrosion rate of CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

Corrosion rate was increased trend when detergent was dosed every dosage (3, 5, 10 mg/l). Actually, the detergent should not influence to corrosion but side-effect of detergent is increased turbidity that consequently to increased conductivity trend. The corrosion process is chemical reaction, high conductivity can caused high electro donor and receive rate then increasing of corrosion rate is occurred.

The corrosion rate profile after perform detergent at CW#2 (3 mg/l detergent) was not differential compared with CW#1 (do not dosed). While corrosion rate at CW#3 (5 mg/l detergent) was a little increased. Corrosion rate at CW#4 (10 mg/l detergent) was a little increasing too.

The corrosion rate increase when detergent increase due to corrosion process is an electrochemical process in which a difference in potential exists at the metal surface and between different areas on the metal surface. Increase of liquid conducting will increase the electrochemical corrosion process.

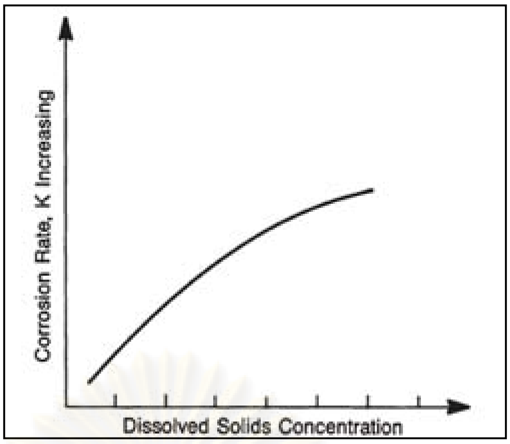


Figure 4.3.1.10 relation between corrosion rate and total dissolved solids concentration (Nalco Company, 2005:43-266, 2007:1).

Figure 4.3.1.10 show that corrosivity trend does not increase at a linear rate with increasing total dissolved solids concentration. The influence of dissolved solids on corrosivity is complex. Not only is the concentration important, but also the ion species involved. For example, some dissolved solids (such as carbonate and bicarbonate) reduce corrosion, while other aggressive ions (such as chloride and sulfate) typically increase corrosion by interfering with the protective film. Figure 4.3.1.11 shows the corrosion coupon result after study. The overall results were not detected the serious of corrosion pitting and corrosion rate were within specify target of lower than 3.0 mpy during study.

Figure 4.3.1.11 shows the result of corrosion coupon analysis for cooling water number one to four after study

4.3.1.1.5 Microbial result

The Microbial was increased trend when dosed detergent because functional detergent can disperse fouled in tower fill pack. In occasion deposits that fouled in tower fill pack is consist of silt, mud, and clay enmeshed in bio-film (McCarthy and Ritter, 2006).

The microbiological analysis was analyzed to ensure the system without microbial fouling after dosed with detergent. Figure 4.3.1.12 microbial result of CW#1 to CW#4

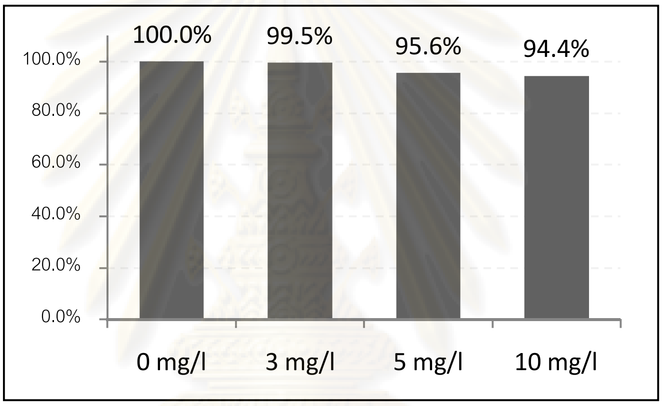


Figure 4.3.1.12 Shows percentage (%) in control of microbiological analysis between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

The microbial analysis CW#1 (without chemical dosed) is 100% in control. After perform detergent at 3 mg/l, microbial was dropped to 99.5% in control. At detergent 5 mg/l was dropped to 95.6% in control and 10 mg/l was dropped to 94.4% in control.

Detergent has functional of dispersant to remove the dislodged biomass from fill pack and return into the bulk water, preventing re-deposition onto surfaces. High detergent is required more fee chlorine than normal condition to maintain microbial

Figure 4.3.1.13 to 4.3.1.20 will summarized the effect of detergent at 0, 3, 5, and 10 mg/l on cooling water chemistry via percentage in control of all parameters at loading megawatt 40 MW.

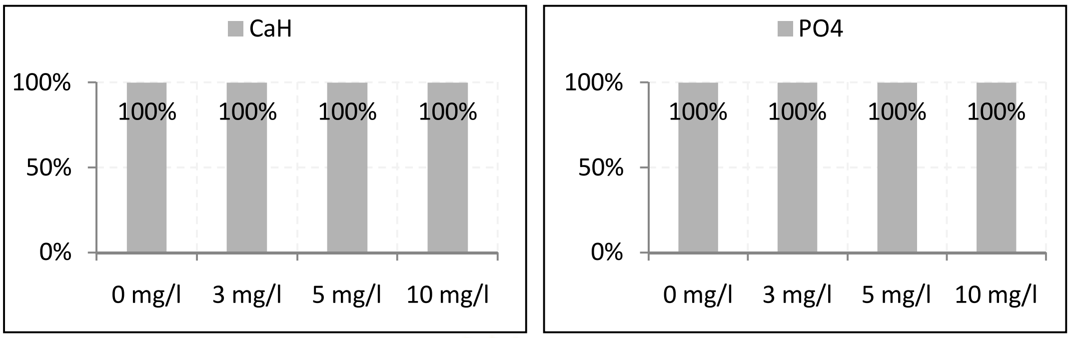


Figure 4.3.1.13 and 4.3.1.14 Shows percentage (%) in control of Calcium hardness and phosphate between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

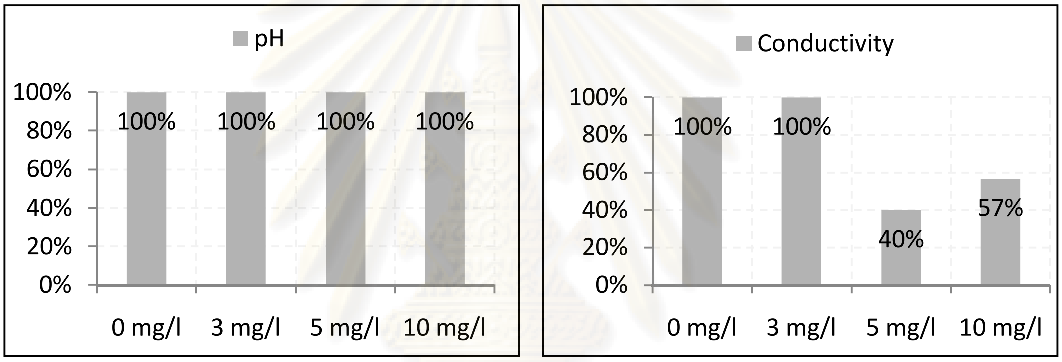


Figure 4.3.1.15 and 4.3.1.16 Percentage (%) in control of pH and conductivity between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

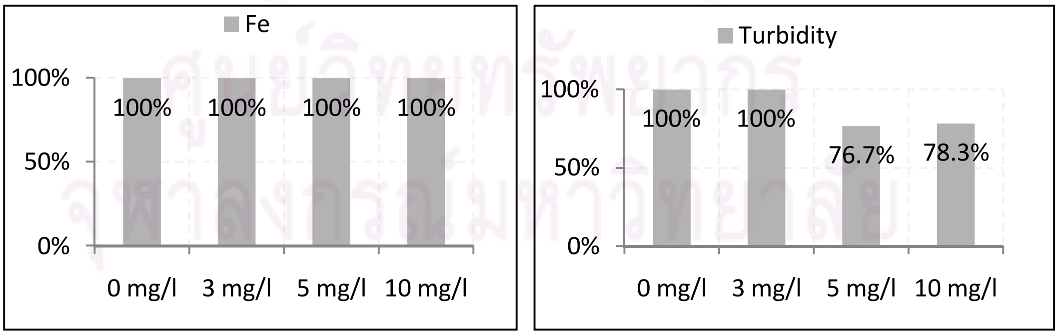


Figure 4.3.1.17 to 4.3.1.18 Percentage (%) in control of iron and turbidity between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

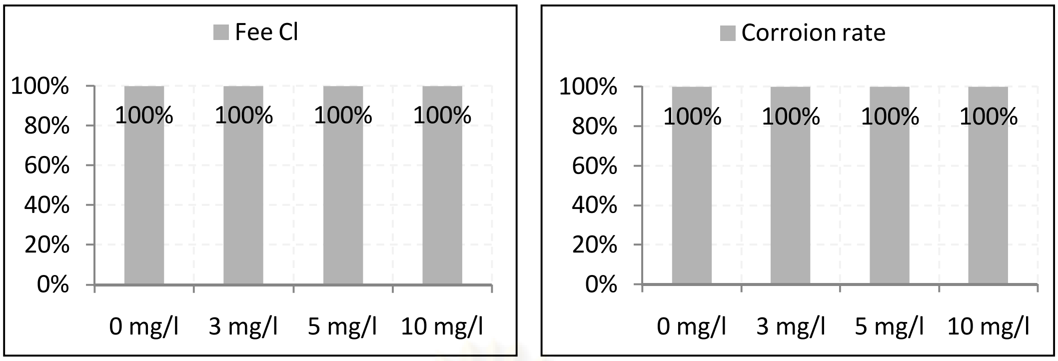


Figure 4.3.1.19 to 4.3.120 Percentage (%) in control of Fee chlorine and corrosion rate between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW

4.3.1.2 Cooing efficiency result after perform detergent at loading 40 MW.

The CW#2, 3, 4 are dosed with detergent chemical continuously. The cooling efficiency result is compared with the design and un-dosed condition of CW#1. This is operated with the same conditions of fan speed, recirculation flow rate. During testing, others chemistry parameters were sustained as normal condition (such as chlorine residual to control microbial growth, phosphate to control corrosion rate, synthesis polymer to control scaling from exceed mineral of calcium, magnesium, silica, etc. And cycle of concentration to limit the cooling water concentration).

4.3.1.2.1 Cooling efficiency result.

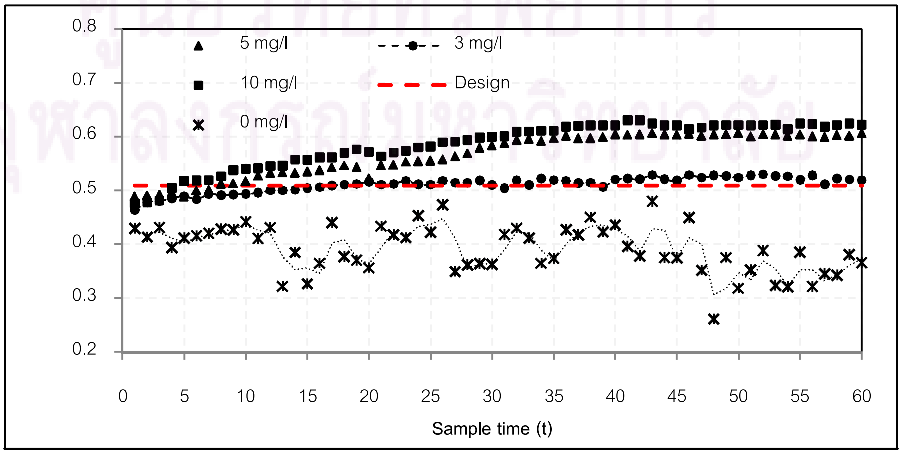


Figure 4.3.1.21 Cooling efficiency results between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

The figure 4.3.1.21 shows cooling efficiency at CW#1 (do not dosed). This was decreased. The trend was maintained at lower design and reduced after t > 45. The cooling efficiency at CW#2 was increased after perform detergent at 3 mg/l. It was near the specify design value when the end of study. The overall result was 35.1% increasing (compared with CW#1) and 3.6% increasing with specify design. Cooling efficiency of CW#3 was fast increase after perform 5 mg/l detergent. This was significant increased trend over specify design when t > 7. The cooling efficiency at 5 mg/l was 62.1% increasing and 24.2% increasing with design. And the cooling efficiency at CW#4 after performs 10 mg/l detergent. It was fast increased over specify design when t > 5. The overall result was 65.1% increasing compared with CW#1 and 24.2% increasing with design. Anyways, the overall efficiency trend line of CW#4 was not a big differential with efficiency trend line of CW#3.

The cooling efficiency of CW#2, CW#3 and CW#4 was increased trend from lower specify design to higher than specify design. The reason of increasing of cooling efficiency is that detergent has removed the suspended solid fouling in fill packing. Reduced blocking channel of air flow to contract with heated of water droplet in fill pack. (McCarthy and Ritter, 1993).

This can summarized that detergent can remove soft fouling deposits that fouled on fill pack material. It can improve cold and hot water temperature and gets a cooling efficiency to higher than specify design. Figure 4.3.1.22 shows the improving temperature approach after perform detergent

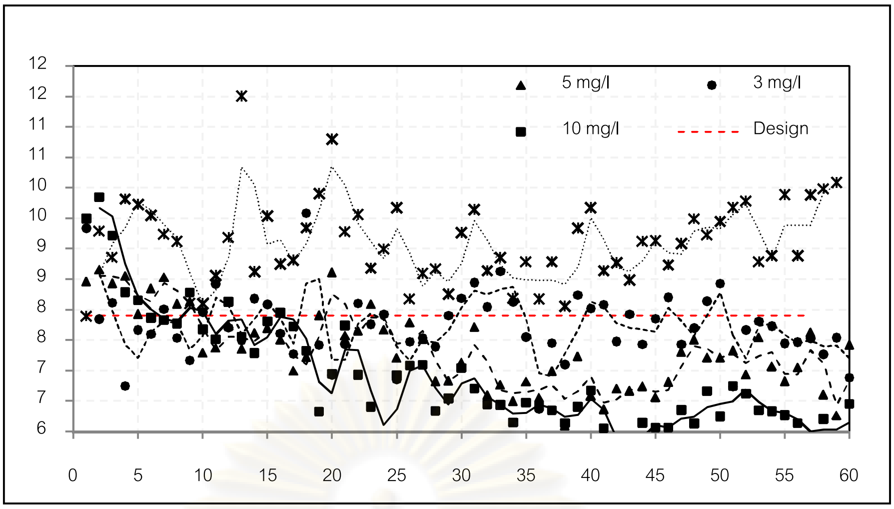


Figure 4.3.1.22 Temperature approach results between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

4.3.1.2.2. Approach temperature

Figure 4.3.1.22 details the approach on CW#1 (Do not dosed detergent) was not changed and increase when t > 45. The approach at CW#2 after performs detergent at 3 mg/l shows a decreasing trend. The average of approach was 7.79oC which lower than specify design. The approach of CW#3 after dosed 5 mg/l shows a better result of approach than CW#2. The approach of CW#4 was similar trend with CW#3, the overall result do not a big differential.

4.3.1.2.3 Heat rejection

This is important to note than lower approach will give the benefit to heat rejection from cooling tower. Figure 4.3.1.23 shows heat rejection before and after dose detergent.

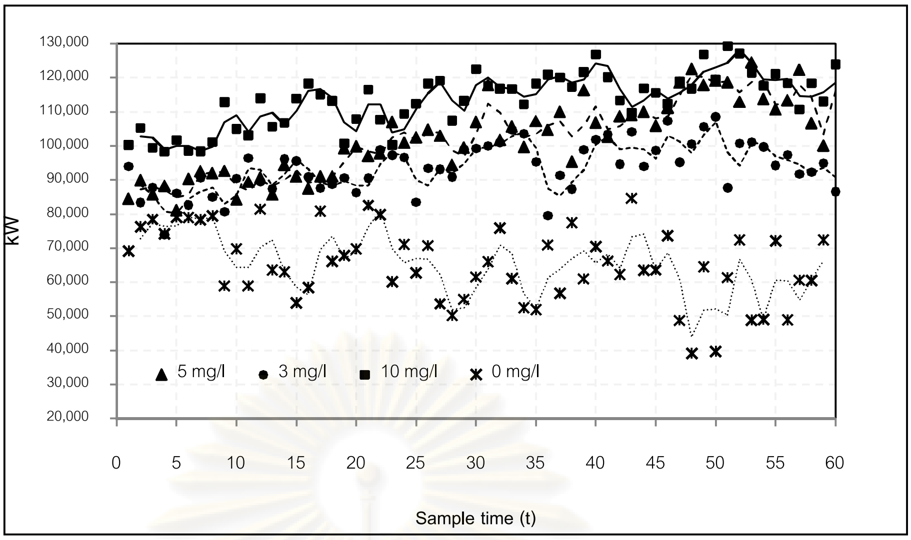


Figure 4.3.1.23 Heat rejection between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

Heat reject at CW#1 (Do not dosed detergent) do not change and decrease when t > 40. Heat reject at CW#2 after performs detergent at 3 mg/l shows increased trend of heat rejection. Heat rejection of CW#3 after dosed 5 mg/l shows a better result than CW#2. The heat reject of CW#4 was similar trend with CW#3, the result line do not a big differential compare with CW#3.

Table 4.3.1.4 Summary the result test of CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

Cooling Tower Performance Summary

At load megawatt : 40 MW

Items	Design	Average result				Totalize deviation (%)
		0 mg/l	3 mg/l	5 mg/l	10 mg/l	
Water circ.rate (m3/hr.)	12,000	10,023	10,031	10,029	10,032	-
Cold Water Temperature (°C)	36.0	36.73	35.76	35.34	35.41	-
Hot Water Temperature (°C)	44.0	42.33	43.85	44.47	44.66	-
Range (°C)	8.0	5.61	8.08	9.36	9.11	-
Wet Bulb Temperature (°C)	28.1	28.02	28.03	28.01	28.05	-
Approach (°C)	7.9	9.14	7.73	7.33	7.38	-
Variance Design (%)	-	-15.6%	2.15%	7.21%	12.53%	7.3%
Heat Reject (kW)	98,349	65,343	100,027	112,284	113,421	-
Cooling Efficiency	0.5087	0.39	0.527	0.632	0.644	-
Variance with no dosed (%)	-	-	35.1%	62.1%	65.1%	54.1%
Variance with Design (%)	-	-	3.6%	24.2%	24.2%	17.4%

Table 4.3.1.4 shows water circulated rate was kept at constant 10,000-10,300 m3/hr during study. The averaged of inlet wet-bulk temperature was not significant differential during test.

Cold water temperature and approach after dosed with detergent were decreased when compared with design.

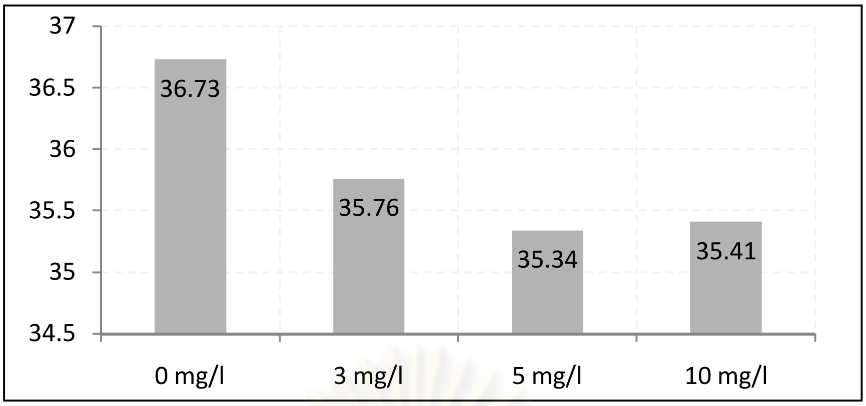


Figure 4.3.1.24 average of cold water temperature between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

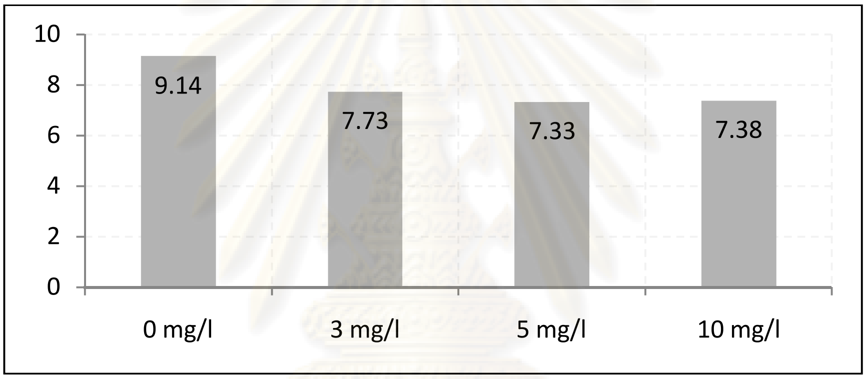


Figure 4.3.1.25 average of temperature approach between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

Heat reject was increased after dose detergent 3, 5 mg/l because of temperature range (Differential of hot and cold water temperature) was increased.

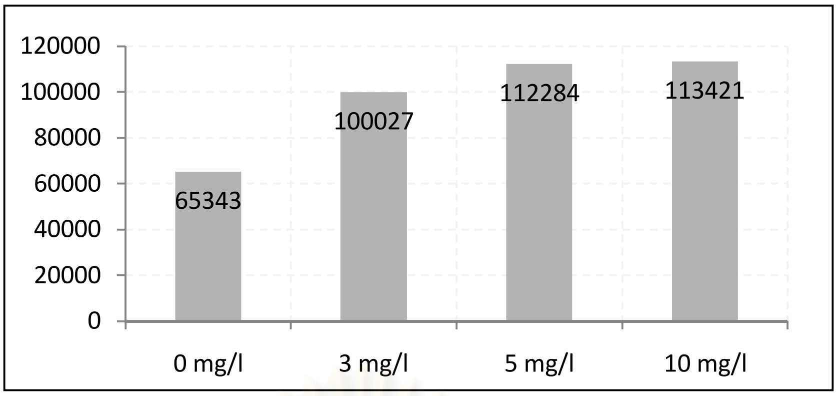


Figure 4.3.1.26 average of heat reject between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

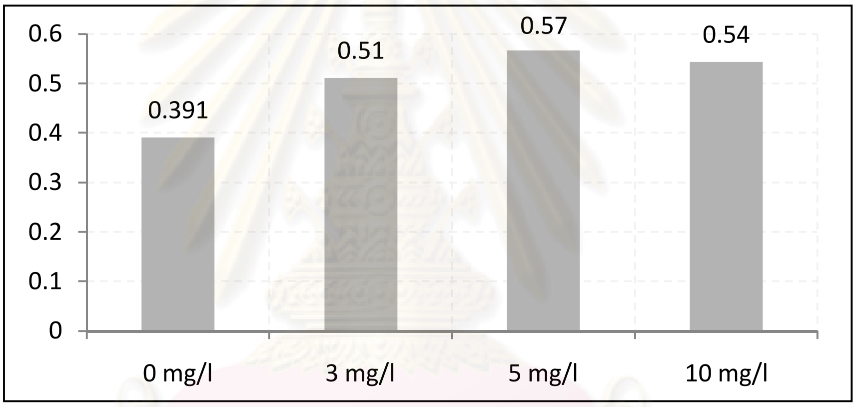


Figure 4.3.1.27 average of cooling efficiency between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 40 MW.

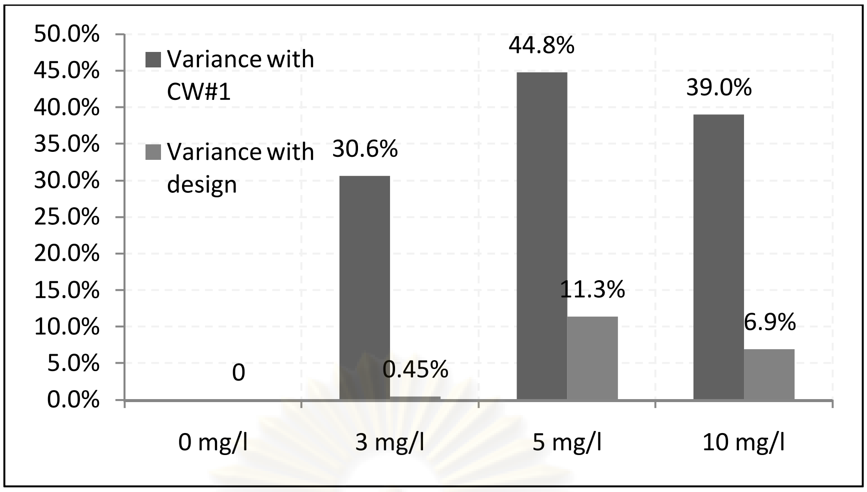


Figure 4.3.1.28 Deviation of cooling efficiency with CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) and specify design at loading 40 MW.

Figure 4.3.1.24 to 4.3.1.28 illustrate that CW#3 (5 mg/l dosed) has a better result of cooling efficiency compare with CW#1 (44.8%) and design (11.3 %)

4.3.1.3 Discussion after dose detergent chemical at load megawatt 40 MW.

The conclusion for loading megawatt 40 MW is that the average of hot water temperature is 44.32oC that is still within acceptable limit. The suitable range of detergent can dose at 3 mg/l. Because of dosage 3mg/l can increase the cooling efficiency from under specify design to upper specify design (0.45% deviation). The consequent is to decrease the approach and increase heat rejection as well.

The suspended solid in bulk water increase when detergent was dosed into cooling system. Because detergent chemical will remove suspended solid from filled pack and disperse it in bulk water. During study, the dosage 5 mg/l can show the best of removing suspended solid into bulk water.

The overall water chemistry (pH, phosphate, chlorine, total iron, microbial) is not different with pre-test. The corrosion rate is increase due to turbidity and conductivity are increased. Although at detergent 5 mg/l is get better of cooling efficiency (10.1%) more than dosing 3 mg/l. But chemical cost will increased 40% when increase dosage from 3 to 5 mg/l. So that the suitable dosage of detergent should be 3 mg/l.

4.3.2 Study effect of cooling efficiency on detergent 0, 3, 5, 10 mg/l loading megawatt 50 MW.

System diagram of plant 3 is shown in figure 4.3.2. The CW#5 do not dose detergent. CW#6, CW#7 and CW#8 was dosed with detergent at dosage 3, 5, 10 mg/l (ppm) respectively.

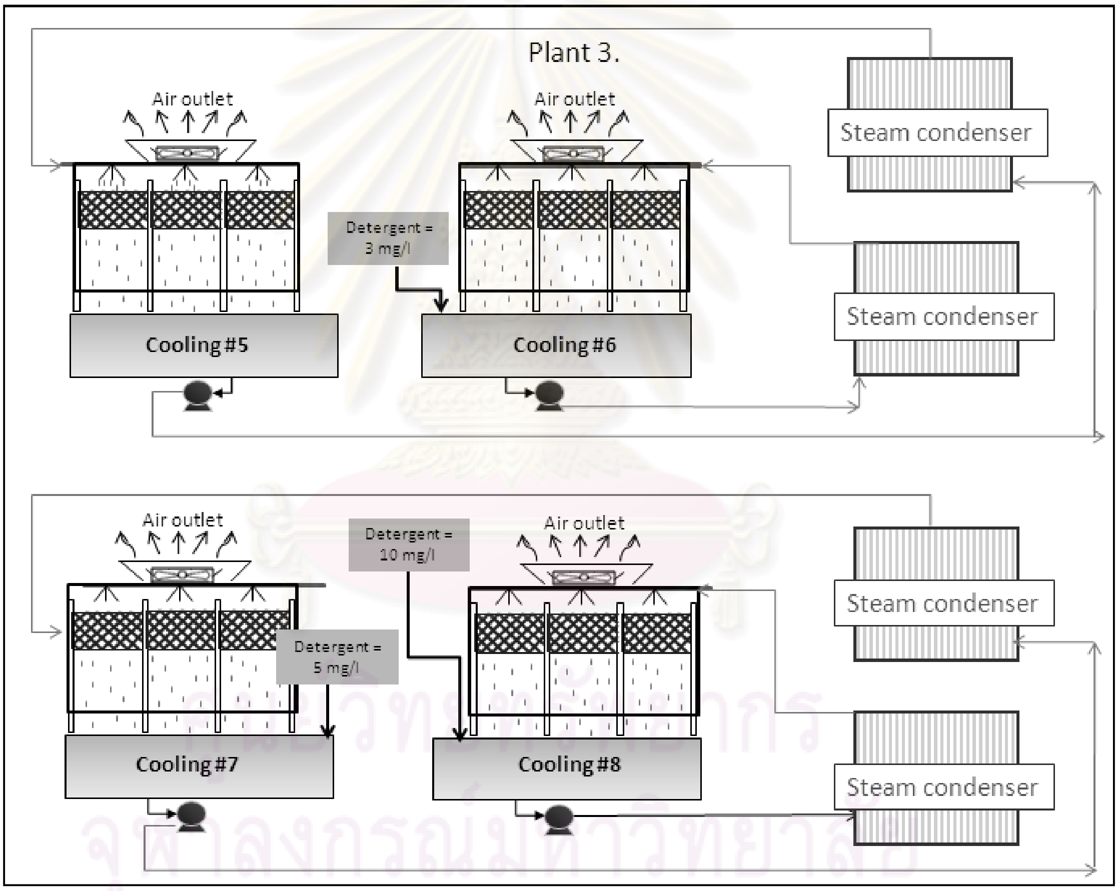


Figure 4.3.2 illustrate the cooling diagram at plant 3 during study at loading megawatt 50 MW.

The result was separated into 2 parts. Part 1 is chemistry result of water chemistry and part 2 is calculation result.

4.3.2.1 Water chemistry which consists of.

- Calcium hardness (mg/l)
- phosphate (mg/l)
- pH
- Conductivity (us/cm)
- Chlorine residual (mg/l)
- Total iron (mg/l)
- Turbidity (NTU)
- Manual weighting and visual inspection
- Corrosion rate (mpy)
- Microbiological analysis (cfu/ml)
- Summary of percentage in control (%) of all parameters

4.3.2.2 Calculating parameters which consist of

- Cooling efficiency
- Temperature approach (oC)
- Heat reject (kW)

4.3.2.1 Cooling water chemistry result after perform detergent at loading 50 MW.

Table 4.3.2.1 Average of water chemistry for CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

Water Chemistry Summary

At load megawatt : 50 MW

				Post-test (Dosed Detergent)		
Parameters	unit	Target	0 mg/l	3 mg/l	5 mg/l	10 mg/l
Calcium	mg/l (ppm)	< 300	231	252	249	237
Phosphate	mg/l (ppm)	4-8	6.0	6.6	6.3	6.1
pH	-	7.0-7.5	7.28	7.37	7.23	7.30
Conductivity	us/cm	<2500	1708	1803	2056	1963
Chlorine	mg/l (ppm)	0.2-0.5	0.30	0.26	0.33	0.37
Suspended solid	mg/l (ppm)	-	69.85	72.55	96.89	98.11
Turbidity	NTU	< 15	7.77	12.16	17.9	17.46
Corrosion rate	mpy	<3	0.96	1.42	1.18	1.17
Microbial	cfu/ml	<100,000	12500	13500	20700	25000

Table 4.3.2.1 show that Calcium hardness was not differentail during study. The phosate which is corrosion inhibitor and pH result was maintain.

Conductivity is increased due to functional of detergent can disperse the fouled matter (silt, suspended solid) from tower fill pack into water. Higher dosage of detergent caused increased trend of conductivity. Chlorine must to maintain with target status (0.2-0.5 mg/l) to kill microbial. Microbial will be present in the matter that fouled in tower fill pack (consist of silt, mud enmeshed in biofilm). At higher dosage of detergent effect to need more fee chlorine than normal condition. Turbidity profile significant increased after dosed detergent due to functional of detergent chemical. It disperses a fouling matter in fill pack into bulk water. Higher dosage of detergent caused increasing trend of turbidity

4.3.2.1.1 Turbidity result

Turbidity profile in figure 4.3.2.1 shows result after dosed with detergent at 3, 5 and 10 mg/l.

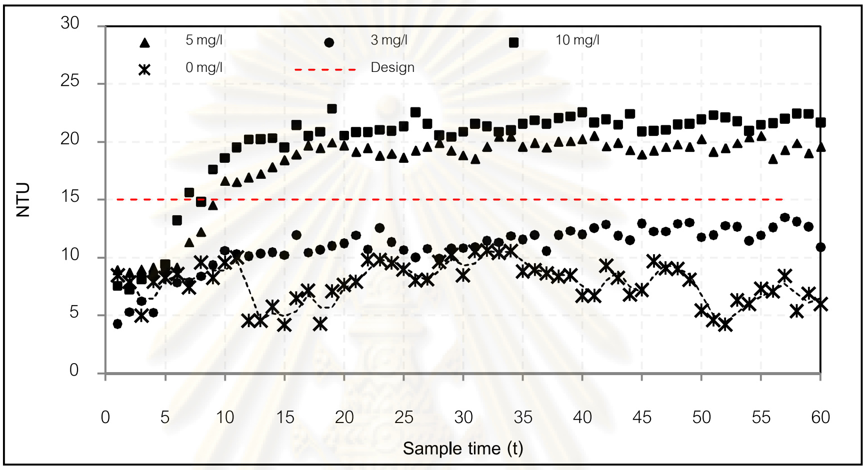


Figure 4.3.2.1 Turbidity between CW#5 (un-dosed) and CW#6,7 and 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

The turbidity result at CW#5 (do not dosed) was not changed (Not a decrease or increase trend). CW#6 was dosed at 3 mg/l of detergent, turbidity during 1 < t < 10 was not different with from CW#5. When t>10, the turbidity profile at 3 mg/l was above result when compare with CW#5. But overall was still within target limited (15 NTU).

This proof that detergent at 3 mg/l can a little removed suspended solid / dirty from fill pack. These may not insufficiency dosage of detergent to use to remove suspended solid in tower fill pack on load megawatt 50 MW.

CW#7 was dosed detergent at 5 mg/l. These was dramatically increased over target when t >7. This proof that detergent at 5 mg/l can effectively removed suspended solid / dirty from fill pack on loading megawatt 50 MW. CW#8 was dose at 10 mg/l detergent. This was dramatically increased over target (similar to 5 mg/l detergent). Anyways the overall turbidity result trend between dosed with 5 and 10 mg/l were not a big differential (only 1-2% differential). If compared the risk of scale and corrosion by increasing trend of conductivity profile and also concern with chemical cost. The suitable dosage of detergent is 5 mg/l.

4.3.2.1.2 Suspended solid removal.

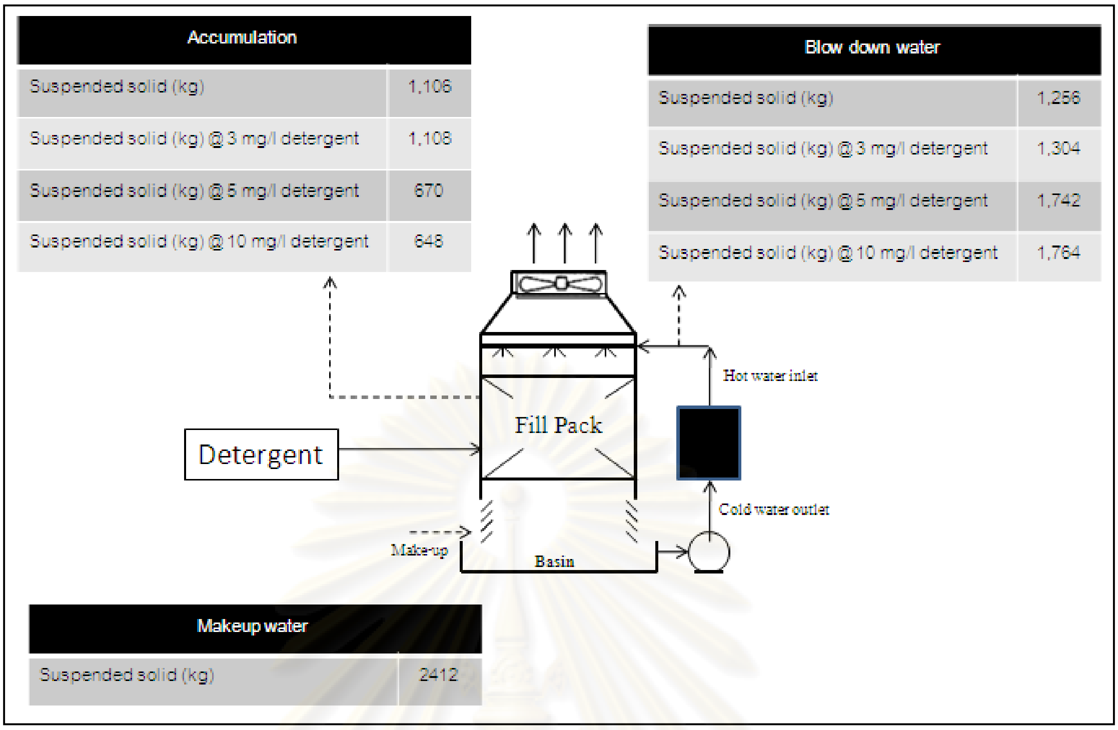
From the mass balance equal around cooling tower system. The equation of suspended solid around cooling tower can be expressed.

$$\text{SS accumlation} = \text{SS makeup} - \text{SS blowdown} \quad (13)$$

From analyzed data in table 4.3.1.1.

- Suspended solid in makeup was 15.32 mg/l (Average value).
- Suspended solid in cooling water after dose detergent at 3 mg/l was 72.55 mg/l
- Suspended solid in cooling water after dose detergent at 5 mg/l was 96.89 mg/l
- Suspended solid in cooling water after dose detergent at 10 mg/l was 98.11 mg/l

Diagram of the suspended solid in figure 4.3.2.2 shows increase in bulk water when dosing detergent is increased.



Accumulation	
Suspended solid (kg)	1,106
Suspended solid (kg) @ 3 mg/l detergent	1,108
Suspended solid (kg) @ 5 mg/l detergent	670
Suspended solid (kg) @ 10 mg/l detergent	648

Blow down water	
Suspended solid (kg)	1,256
Suspended solid (kg) @ 3 mg/l detergent	1,304
Suspended solid (kg) @ 5 mg/l detergent	1,742
Suspended solid (kg) @ 10 mg/l detergent	1,764

Makeup water	
Suspended solid (kg)	2412

Figure 4.3.2.2 shows mass balance after dosed detergent at 3, 5 and 10 mg/l. The suspended solid which accumulated in filled pack is decreased when detergent is increased to 5 and 10 mg/l.

The suspended solid will increase in bulk water when detergent is dosed. Removing of suspended solid from filled pack can increase the cooling efficiency as illustrate in figure 4.3.2.2

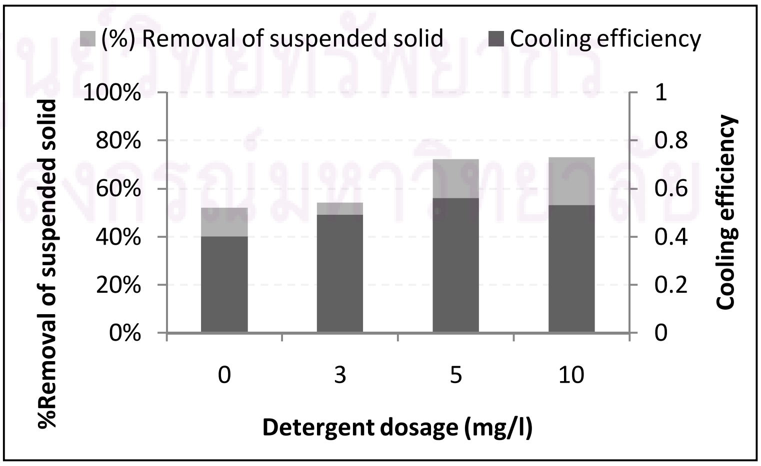


Figure 4.3.2.2 Relation of % suspended solid remove in bulk water by detergent and cooling efficiency.

4.3.2.1.3 Manual weighting result and visual inspection of filled pack

Manual weighing of filled packing is implemented during study to actual measure the weight of suspended solid. The result has taken 1 week before dose with detergent and after dosed. Anyways, the weighting data can be collected for only 2 units due to plant condition. The cooling 5 was represented to un-dose condition while cooling 7 is was represented with dosed detergent at 5 mg/l. Table 4.3.2.3 was summary data and percentage removal of weighting.

Table 4.3.2.3 shows the actual weighting result before and after used detergent.

Unit	Chemical (mg/l)	Before dosed (kg)	After dosed (kg)	Fouling Removal (%)
CW#5	0	6.17	6.24	-
CW#7	5	7.02	3.02	57.0%

The actual weighting of fill packing material before and after dosed with detergent can summarized that the detergent can effectively remove fouling matter from fill pack. And figure 4.3.1.4 shows some of visual inspection of fill pack after dosed with detergent. The overall was clean when compared with un-dose condition.

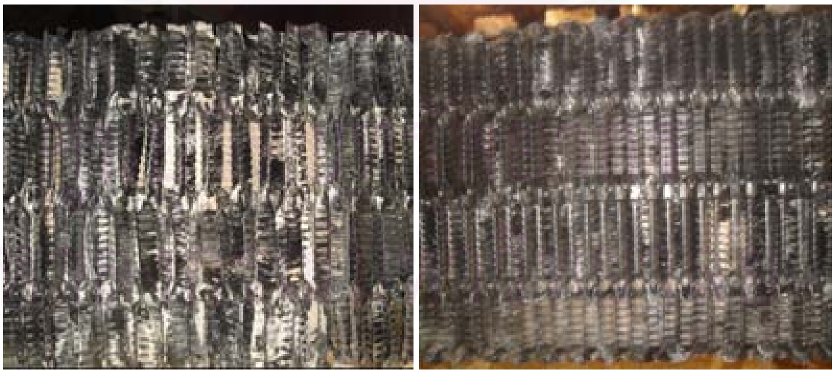


Figure 4.3.1.4 the visual inspection of filled pack of cooling 1 (Left: un-dosed) and cooling 3 (Right: 5 mg/l of detergent

4.3.2.3 Conductivity

The conductivity result can represent the suspended solid remove from tower fill pack. Figure 4.3.2.5 illustrates conductivity after done detergent at 3, 5 and 10 mg/l.

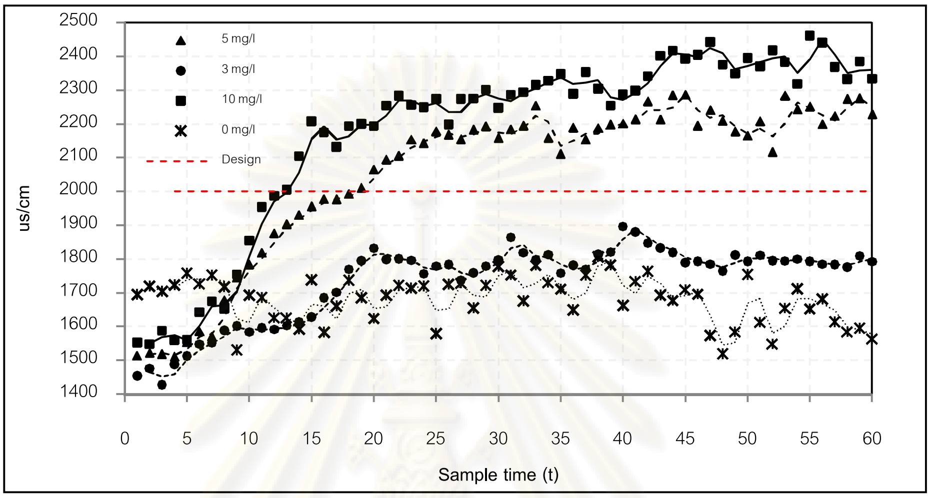


Figure 4.3.2.5 Conductivity results between CW#5 (un-dosed) and CW#6,7 and 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

The conductivity profile at CW#5 (do not dosed), the result maintained during 1<t<45. When 46<t<60 the profile was decreased. CW#6 was dosed at 3 mg/l of detergent. The conductivity trend was not different with CW#5 during 1<t<10 and has a increasing trend when t > 10. CW#7 was dosed detergent at 5 mg/l. It was dramatically increased over target (2500 us/cm) when t > 7 due to turbidity profile was increased. While conductivity profile of CW#8 after performs at 10 mg/l detergent. This was similarly with CW#7.

Because of detergent product can act as the dispersancy. It removes of soft foulant deposits that fouled in fill pack. This is increased turbidity trend and consequently to increase conductivity profile after added detergent chemical.

4.3.2.1.4 Corrosion rate result

The corrosion rate during test was collect by NCM100. It was installed for all cooling units. Figure 4.3.2.6 shows the result after dosed detergent at 3, 5, 10 mg/l.

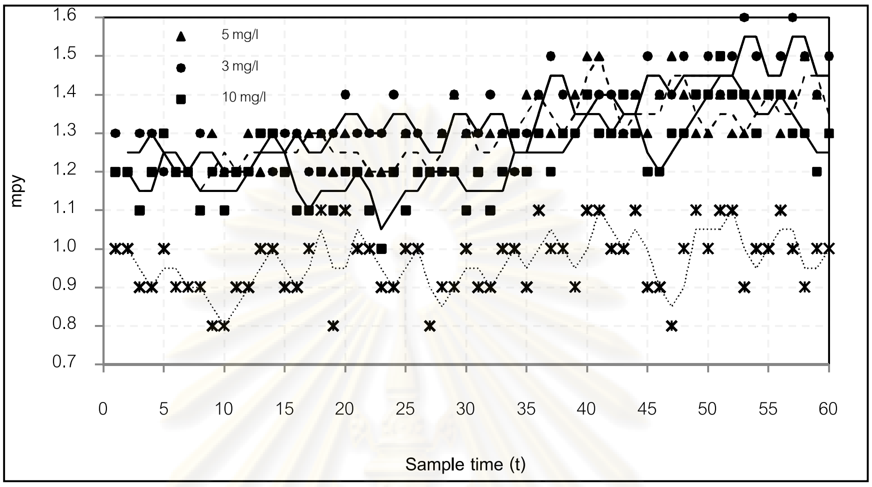


Figure 4.3.2.6 Corrosion rate between CW#5 (un-dosed) and CW#6, 7, and 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

The corrosion rate profile at CW#5 (do not dosed) was not any changed. Because other parameters (such as pH, phosphate, etc) were kept at maintain condition to prevent more corrosivity trend. Corrosion rate at 3 mg/l detergent was not any changed in during 1<t<20 and look increased 0.5% when t > 30. Corrosion rate at 5 and 10 mg/l detergent were similarly trend. In early (0<t<30) was not changed and look a little increased 1% when t > 30. Figure 4.3.2.7 show the result of corrosion coupon after study. The results were within specifying result of lower than 3.0 mpy. These were not found pitting corrosion problem.

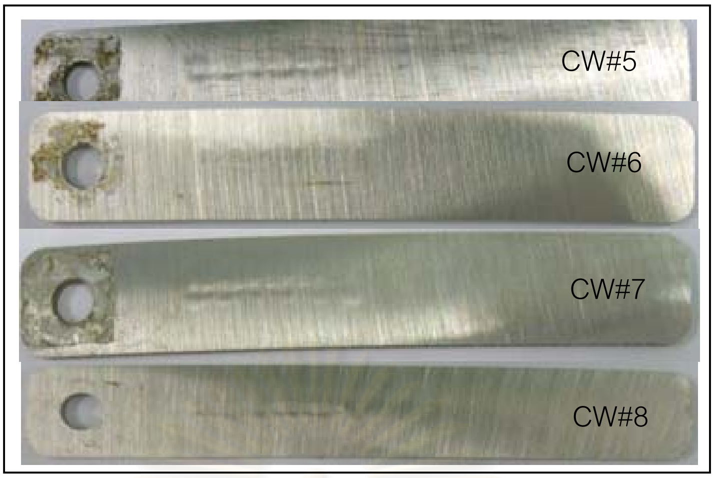


Figure 4.3.2.7 Corrosion coupon after study for cooling system number 5, 6, 7 and 8

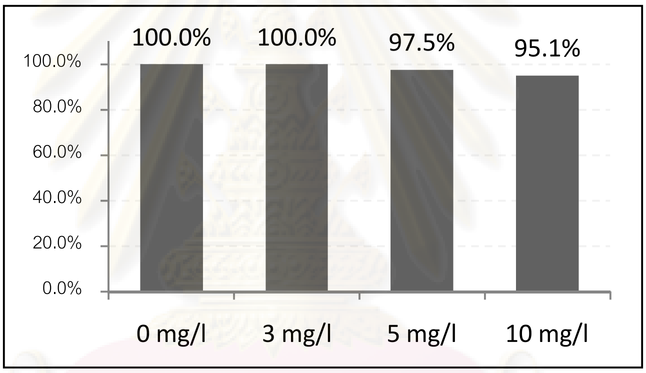


Figure 4.3.2.8 Show percent in control of microbiological analysis between CW#5 (un-dosed) and CW#6,7,8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

Figure 4.3.2.8 shows percent in control of microbial analysis profile after perform detergent at 3 mg/l was 100%. While percent in control of microbial analysis at 5 mg/l detergent was 97.5% increasing and percent in control of microbial analysis at 10 mg/l detergent was 95.1% increasing.

Figure 4.3.2.9 to 4.3.2.16 is summary % in control after dose detergent at 0, 3, 5, and 10 mg/l on cooling water at loading megawatt 50 MW.

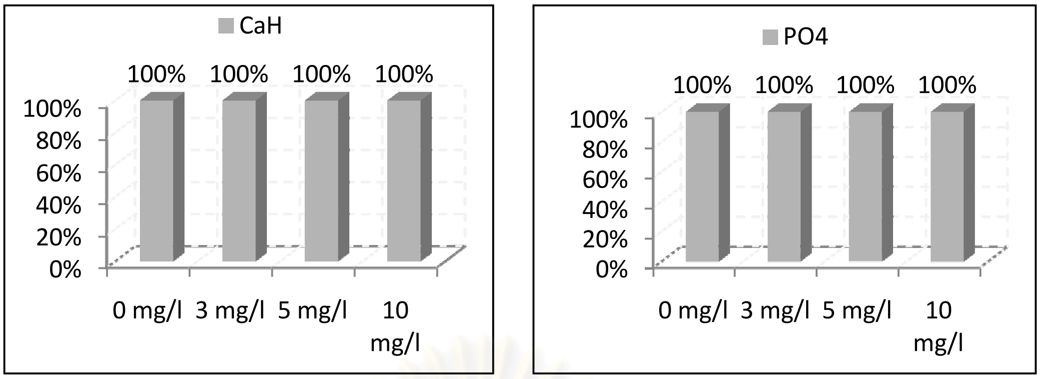


Figure 4.3.2.9 and 4.3.2.10 Summary (% in target) of calcium hardness and ortho phosphate between CW#5 (un-dosed) and CW#6,7,8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

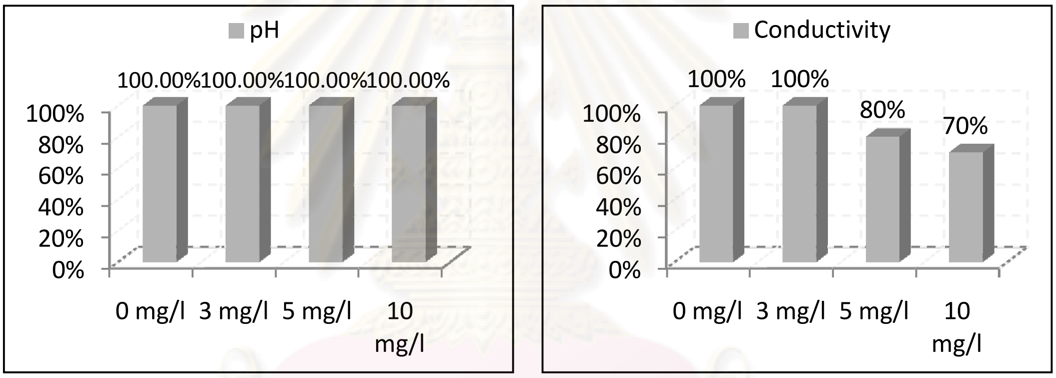


Figure 4.3.2.11 and 4.3.2.12 Summary (% in target) of pH and conductivity between CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

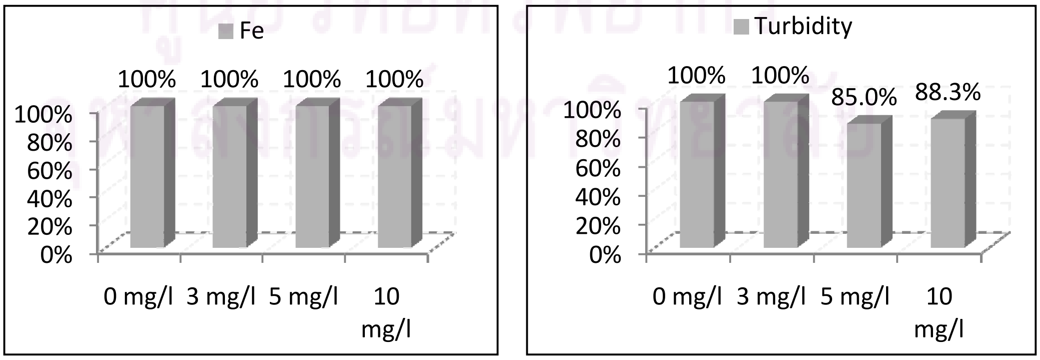


Figure 4.3.2.13 and 4.3.2.14 Summary (% in target) of total iron and turbidity between CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

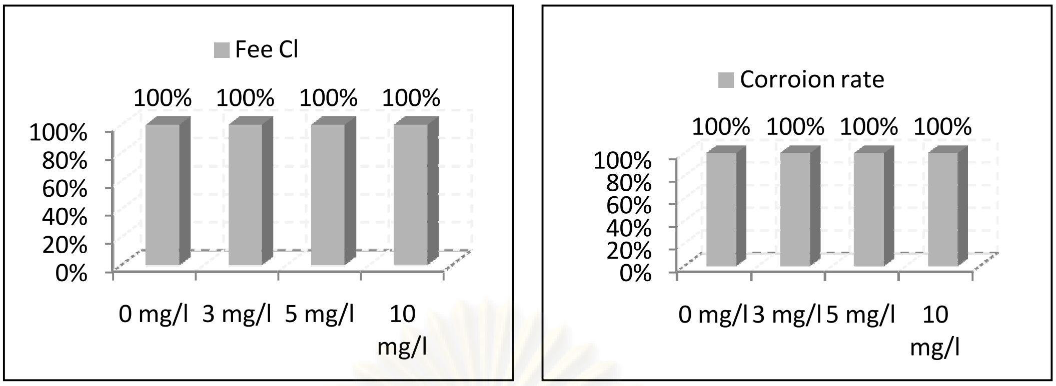


Figure 4.3.2.15 and 4.3.2.16 Summary (% in target) of chlorine and corrosion rate CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) atloading 50 MW.

4.3.2.2 Calculation result after perform detergent at loading 50 MW.

The cooling system 6, 7 and 8 is dosed the detergent chemical at 3, 5,10 mg/l continuous. The cooling efficiency result is compared with the un-dosed condition (CW#5) which is operated with the same conditions of fan speed, recirculation flow rate. During testing period, others chemistry parameters were sustained as normal condition (such as chlorine residual (FRC) to control microbial growth, phosphate to control corrosion rate, synthesis polymer to control scaling from exceed mineral of calcium, magnesium, silica, etc. And cycle of concentration to limit the cooling water concentration).

4.3.2.2.1 Cooling efficiency result

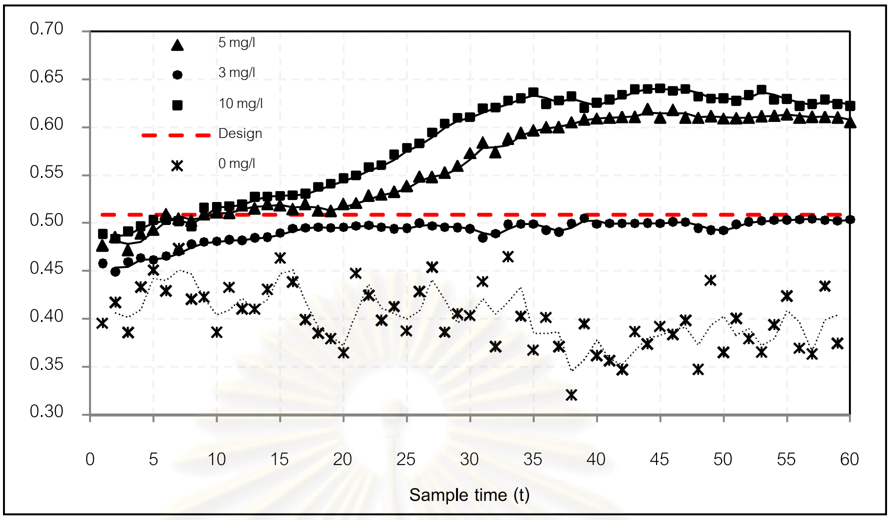


Figure 4.3.2.17 Cooling efficiency between CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

Figure 4.3.2.17 shows cooling efficiency at CW#5 (do not dosed with detergent). The trend was maintained and reduced when t > 30. CW#6 was dosed at 3 mg/l. The overall of cooling efficiency was near with specify design. It was 22.5% increasing (compared with CW#5). Cooling efficiency of CW#7 was dosed at 5 mg/l detergent. This was significant increased trend over specify design when t > 15.

The cooling efficiency after dosed detergent at 5 mg/l was 10.1% increasing (compare with design). Cooling efficiency at CW#8 was dosed at 10 mg/l detergent. It gets significant higher than specify design. The trend was 15.2% increasing with specify design.

The cooling efficiency of CW#7 and CW#8 were improved potential because of detergent has removed the suspended solid fouling in fill packing. Reduced blocking channel of air flow to contract with heated of water droplet in fill pack from suspended solid fouling.

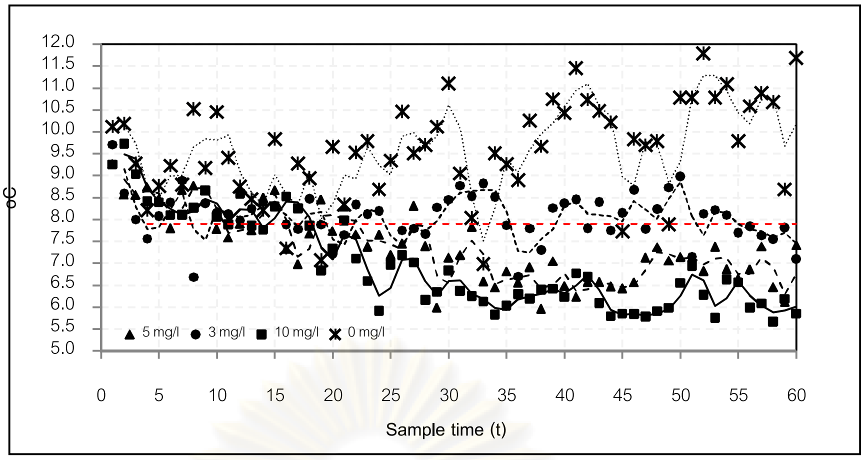


Figure 4.3.2.18 Temperature approach between CW#1 (un-dosed) and CW#2, 3, 4 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

4.3.2.2.2 Approach temperature result

Figure 4.3.2.18 shows the approach on CW#5 (do not dosed detergent) was not changed. CW#6 after performs detergent at 3 mg/l. the overall result of temperature approach shows a decreased trend (3%) and near with to the specify design. The approach of CW#7 which dosed 5 mg/l shows a better result of approach than CW#6. The approach of CW#8 was similar trend with CW#7.

Consequently of decreasing in approach, heat rejection from cooling tower is improved also. Figure 4.3.2.19 shows heat rejection before and after perform detergent.

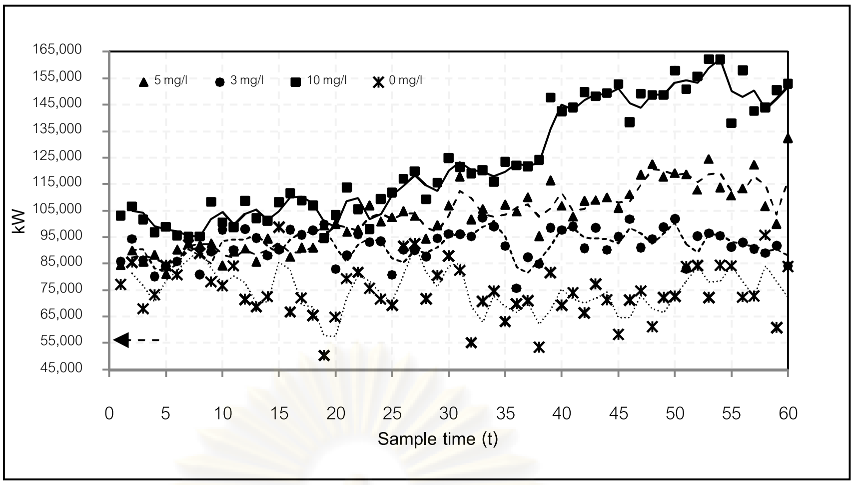


Figure 4.3.2.19 Heat rejection between CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

4.3.2.2.3 Heat rejection

Heat reject on CW#5 (do not dosed detergent) was not changed. CW#6 after dosed with detergent at 3 mg/l. The overall result of heat reject was shown a little increased (3% increasing). The approach of CW#7 which dosed 5 mg/l showed a better result of heat reject than CW#6. Heat reject of CW#8 was similar trend with CW#7; the result line gets a better after dosed.

Table 4.3.2.4 Summary the result test of CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

Cooling Tower Performance Summary
At load megawatt : 50 MW

Items	Design	Average result				Totalize Variance (%)
		0 mg/l (ppm)	3 mg/l (ppm)	5 mg/l (ppm)	10 mg/l (ppm)	
Water circ.rate (m3/hr.)	10,338	10,129	10,024	10,040	10,018	-
Cold Water Temperature (^{o}C)	36	37.65	36.09	35.71	35.34	-
Hot Water Temperature (^{o}C)	44.18	46.08	45.87	46.50	46.87	-
Range (^{o}C)	8.18	8.41	9.80	11.00	11.36	-
Wet Bulk Temperature (^{o}C)	28.1	28.05	28.03	28.02	28.05	-
Approach (^{o}C)	<7.9	9.61	8.05	7.69	7.48	-
Variance Design (%)	-	-57%	-1.9%	2.7%	7.1%	**2.6%**
Heat Reject (kW)	>98,349	75,026	93,120	102,723	103,894	-
Cooling Efficiency	> 0.509	0.40	0.49	0.56	0.53	-
Variance with CW#5 (%)	-	-	22.5%	40.0%	46.5%	**36.3%**
Variance with Design (%)	-	-	-3.7%	10.1%	15.2%	**7.2%**

Table 4.3.2.4 shows that water circulated rate was kept at constant 10,000-10,300 m3/hr. The averaged of inlet wet-bulk temperature was not significant differential during testing.

Cold water temperature, approach was decreased after dosed with detergent due to fouling in tower fill pack was improved. This can increase the retention time of heat and mass transfer between water and air flow.

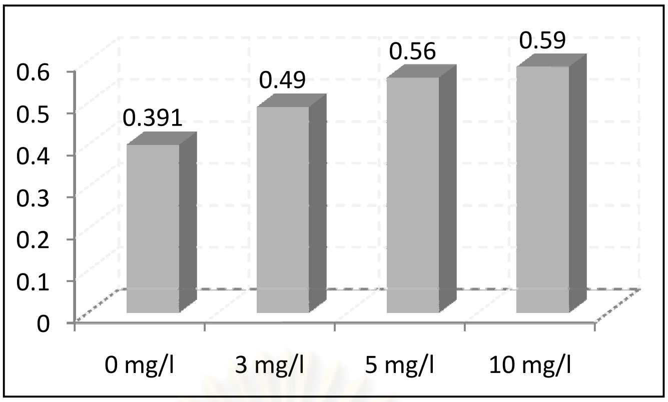


Figure 4.3.2.20 average of cooling efficiency between CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) at loading 50 MW.

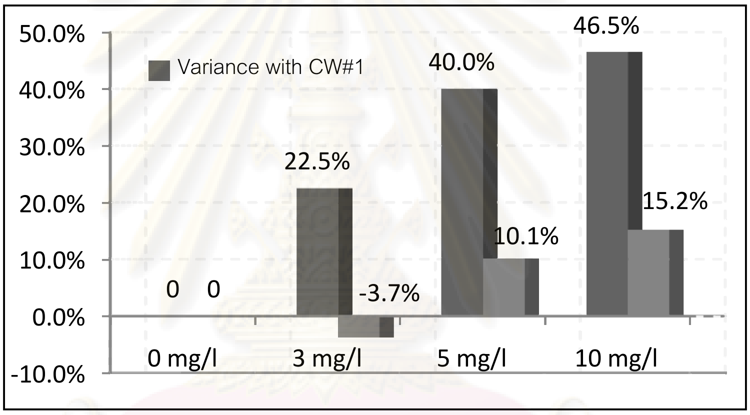


Figure 4.3.2.21 Deviation of cooling efficiency with CW#5 (un-dosed) and CW#6, 7, 8 (Dosed 3, 5, 10 mg/l respectively) and specify design at loading 50 MW.

4.3.2.3 Discussion on loading megawatt 50 MW.

The conclusion for loading megawatt 50 MW. The average of hot water temperature was 46.41oC. The suitable range of detergent should be 5 mg/l. Because of dosing 5mg/l can increase the cooling efficiency from under specify design to upper design (10.1% increases). The approach and heat reject are better than Cooling tower with no detergent.

The suspended solid in bulk water increase when detergent was dosed into cooling system. Because detergent chemical will remove suspended solid from filled pack and disperse it in bulk water. The dosage 5 mg/l can show a better of removing suspended solid into bulk water.

The overall water chemistry (pH, phosphate, total iron, microbial) are not different with pre-test. The corrosion rate and conductivity was not much high. Although at detergent 10 mg/l is get better of cooling efficiency (15.2%). But if compare the chemical cost, conductivity and corrosion profile between 5 and 10 mg/l. because conductivity and corrosion trend of 10 mg/l detergent is higher than 5 mg/l detergent. The suggestion dosage of detergent at loading megawatt should be 5 mg/l.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study has enabled to investigate the effect of the cooling efficiency and suspended solid removing after dose detergent chemical by a counter flow cooling tower filled pack type. The result obtained during the investigation within a range of experimental conditions of 40 & 50 loading megawatt with constant of fan speed, cooling water recirculation flow rate. The conclusion can be summarized as follows.

When inlet air wet-bulb temperature does not significantly different (vary between 1-1.5°C with average value). The cooling efficiency increased when detergent chemical is dosed at 3 mg/l at plan loading megawatt 40 MW. It increases with increase the detergent chemical dosing to 5 mg/l. At plant load megawatt 50 MW. The cooling efficiency increased when detergent chemical is dosed at 5 mg/l. It increases with increase the detergent chemical dosing to 10 mg/l.

Suspended solid (fouling matter) which accumulate in cooling system will removed into bulk water when increase detergent chemical is dosed between 5-10 mg/l. It represents that the fouling matter in filled pack can be removed from filled pack into bulk water when detergent is applied. And the result of manual weighting and visual inspection were clearly proofed that fouling matter in filled pack is reduced when detergent is used.

The optimize dosage of detergent chemical to increase cooling efficiency and remove suspended solid in which fouled in filled pack should be 3-5 mg/l.

Detergent can effect to water chemistry by increasing on turbidity, conductivity and corrosion rate. Because detergent can disperse the suspended solid from filled pack material into bulk water. This cause increasing of turbidity and conductivity in bulk water. Corrosion rate is a chemical reaction. The reaction rate can depend on total dissolved solid (or conductivity) in water.

Recommendations

5.1 It is interesting to note that increasing of detergent chemical can increase the cooing efficiency and a removing potential of suspended solid from filled pack. But it should be considered carefully especially in commercial part when increase chemical dosing. Because of increasing detergent chemical will increase potential of corrosion rate on surface heat material heat exchanger; increase make-up water to dilute the suspended solid concentration in system and especially chemical price is increase also.

5.2 Due to the major root cause of serious fouling in filled pack come from poor quality of make-up water, especially for turbidity. To enhance a fouling problem in filled pack material. The pre-treatment of make-up water source should be improved.

5.3 Install a Side-stream filtration which is an effective method of minimizing problems caused by suspended matter. The use of a side-stream filter results not only in better operating efficiency, but also in reduced chemical costs. The loss of water treatment chemicals through adsorption on suspended matter may be reduced by use of a side-stream filter.

5.4 Due to the cooling efficiency is increase into specify design. And cold water temperature is decreased as well. This can reduce turbine exhaust steam backpressure, thus maximizing efficiency of the turbine. The steam condenser efficiency monitoring study is a recommended to implement to check the heat transfer rate and efficiency of steam condenser.

5.5 Routine cleans the suspended solid matter that foul in strainer of recirculation pump and cooling water basin. Because this suspended solid is removed from filed pack material by using detergent chemical, to prevent it’s picked up in filled pack again. The routine cleaning is recommended.

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APPENDICES

APPENDIX A

COOLING TOWER MASS BALANCE CALCULATIONS

1.1 Mass balance equations of recirculation cooling system

1.1.1 Range temperature: can be measured by taking the temperature of the tower return water (TR) and subtracting the temperature of the basin supply water (TS). This difference can be used to calculate the approximate amount of evaporation that has occurred in the cooling tower. The range temperature can be expressed as follows.

$$\Delta \mathrm{T} = \mathrm{T_R} - \mathrm{T_S} \tag{14}$$

Where: ΔT = Range temperature in degrees Celsius
T_R = Hot water temperature in degrees Celsius
T_S = Cold water temperature in degrees Celsius

1.1.2 Evaporation: The method by which heat is removed from an open recirculating cooling water system is evaporation of some of the water over a tower The recirculation rate and the temperature drop across the cooling tower are the two pieces of data needed to calculate the amount of water lost from the open recirculating cooling system (due to evaporation). Evaporation losses will vary depending upon temperature and humidity, but a general rule is that for every 5.5°C temperature drop across the tower, approximately 0.85% of the recirculation rate will be evaporated. The evaporation can be expressed as follows.

$$Evaporation\ rate = \frac{\Delta T\ x\ RR\ x\ 0.85\%}{5.5} \tag{15}$$

By arrangement, find that.

$$Evaporation\ rate = \ \Delta T\ x\ RR\ x\ 0.00153 \tag{16}$$

Where: RR = Recirculation flow rate

1.1.3 Cycle of concentration: The concentration ratio (CR) of an ion carried in a recirculating system is merely the concentration of that ion in the recirculating water divided by the concentration of the ion in the makeup water. Concentration ratio is also referred to as follows.

$$\text{Cycle} = \frac{\text{Specify ion concentration in cooling water}}{\text{Specify ion concentration in makeup water}} \qquad (17)$$

1.1.4 Makeup water: The water that must be added to replace water lost from the recirculating system by evaporation and bleed-off (or blowdown) is called makeup water. The amount of water entering the system must be equal to the amount leaving the system

$$\text{Makeup water} = \text{Blow down} + \text{Evaporation} \qquad (18)$$

If the temperature drop across the tower and the recirculation rates are known, the amounts of water lost through evaporation can be calculated. If the concentration ratio is also known, then the makeup water requirements can be calculated using

$$\text{Makeup water} = \frac{\text{Evaporation x Cycle}}{(\text{Cycle}-1)} \qquad (19)$$

1.1.5 Blow down water: all of these water losses, except for evaporation, are generally considered together and called tower water blowdown System. Blowdown (BD) rate can be calculated from the following expression.

$$\text{Blow down water} = \frac{\text{Evaporation}}{(\text{Cycle}-1)} \qquad (20)$$

2.2 Summary of calculation of cooling tower.

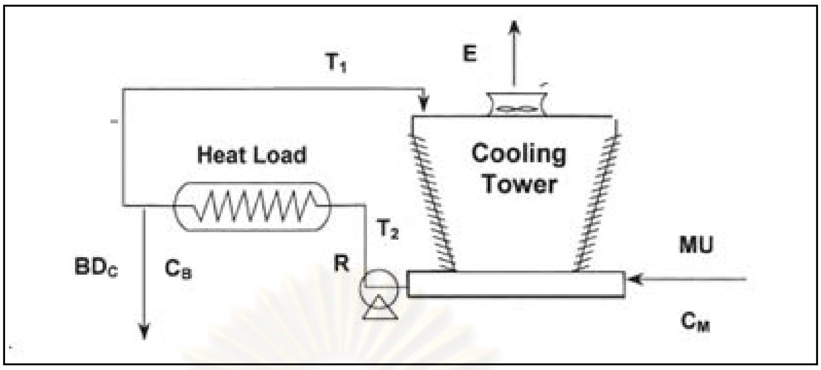

Figure A1 Summary the mass balance of cooling water and calculation.

2.2.1 Nomenclatures and Calculation results of specify design

2.2.1.1 CR=Cycle of concentration

= Calcium concentration in cooling water / Calcium concentration in makeup

= C_M/C_B = 226 / 30 = 7.51

2.2.1.2 T1=Cold water temperature (^{o}C) = 35.6^{o}C

2.2.1.3 T2=Hot water temperature (^{o}C) = 44.3^{o}C

2.2.1.4 R= Recirculation flow rate (m^3/hr) = 10,013 m^3/hr

2.2.1.5 E=Evaporation rate (m^3/hr) = R x (T1-T2) x 0.00153

= 10013 x (44.3-35.6) x 0.00153

= 133 m^3/hr

2.2.1.6 MU=Makeup water required (m^3/hr) = E x CR / (CR-1)

= 133.3 x 7.5 / (7.5-1) = 153.8 m^3/hr

2.2.1.7 BDc=Blow down water (m3/hr) = E / (CR-1) = 20.5 m3/hr

APPENDIX B

CALCULATIONS FOR HEAT PENALTY ACROSS COOLING TOWER

2.1 Definite of Heat rate penalty

Typically, a change in condenser backpressure (increase or decrease) will have an impact on the efficiency of the unit. If backpressure increases, more fuel is required to produce the same amount of energy and the percent efficiency of the unit decreases. In some regions, this efficiency is described as the heat rate of the unit. The unit gross heat rate is defined as the ratio of the total energy input (fuel) to the energy output (electricity). The energy input (Btu/h or MJ/h) is the product of the heat content of the fuel in Btu/lb (MJ/kg), and the total fuel consumed in lb/h (kg/h). The energy output is the measured gross electrical energy (MW). Heat rate is expressed as Btu/MWh (MJ/MWh), and is essentially an inverse of percent efficiency for the unit. Important rules of thumb for condenser-turbine sets are as follows:

- Heat rate is defined as fuel usage in Btu (MJ) per gross amount of electricity generated in MWh
- The higher the heat rate, the less efficient the process
- In fossil-fuel plants, fuel consumption or heat rate (Btu/MWh, MJ/MWh) will increase about 1-2% per inch Hg increase in backpressure (0.3-0.7% per kPa increase) Conversely, the percent efficiency will decrease by 1-2% per inch Hg decrease in backpressure (0.3-0.7% per kPa decrease) in fossil-fuel plants
- The heat rate penalty or loss of efficiency will be a greater percentage as unit load deceases

- Each 0.3% of heat rate penalty ~ 1 kPA of back pressure increase

- Whereas 0.19% of heat rate penalty = 14.25 - 15.2 kJ/kWH losses.

- 0.5% of heat rate penalty or 1.5°C increase of hot water temperature mean = 37.5-40 kJ/kWH losses.

This percent increase in heat rate due to backpressure increase is also called the heat rate penalty. The added fuel cost due to the heat rate penalty from an increase in backpressure can be calculated with a simple equation. The first step is to determine the current unit load, current backpressure loss, design heat rate penalty, design heat rate, and fuel cost of the unit. Obtain the heat rate from the plant and determine if it is the gross or net unit heat rate.

2.2 Finance impact of heat rate and Efficiency calculation from Electrical utility condenser pressure.

2.1 Conceptual of Calculations

High cold water temperature results in turbine backpressure increase (lower vacuum in condenser).

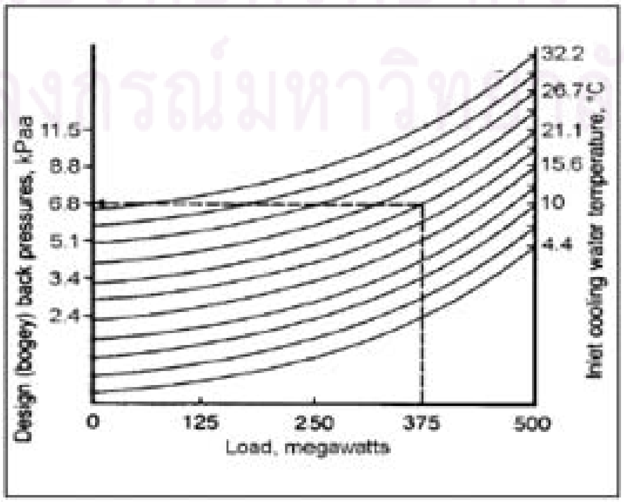

Figure A2 Relation of Loading, Cold Temperature & Back Pressure. (Nalco company, 2005:43-366, 2007:1)

Change in condenser backpressure will have a serious impact on the efficiency of the power plant. As backpressure increases,

- More fuel is required to produce the same amount of energy
- The percent of efficiency of the unit decrease.

Power plant efficiency is typically described in the heat rate of the unit. The unit gross heat rate is defined as the ratio of the total energy input (fuel) to the energy output.

The percent increase in heat rate due to backpressure increase is called heat rate penalty. Following is the typical heat rate of different power plant type and the heat rate penalty.

Table A1 Heat rate penalty from 1.0 kPaa change in backpressure. (Nalco company, 2005:43-266, 2007:1)

Unit Heat Rate				Heat Rate Penalty of 1 kPas change in backpressure
Type of unit	**Pressure, bar**	**Fuel**	**Typical Heat Rate, kJ/KWh**	
Combined cycle	124	gas	7400-8400	0.30%

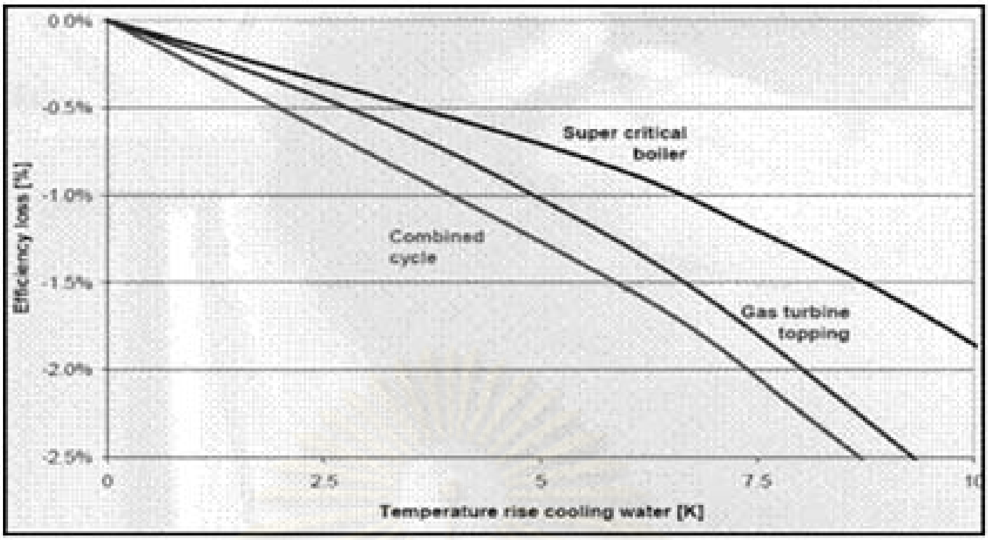

Figure A3 Graph of impact cold water temperature on efficiency loss(available online from www.kema.com).

Figure A3 shows the efficiency loss because of higher cooling water temperature. The added fuel cost due to the heat rate penalty from an increase in back pressure can be calculated with this.

2.2 Actual calculation the impact of cold temperature on plant efficiency

Table A2 is summary cold temperature and differential with CW#5 (no dosed condition), heat rate penalty and fuel increase price at detergent condition.

Table A2 summary cold water temperature after dosed at 3, 5, 10 mg/l and heat rate penalty (%) value.

Items	Value	Deviation	Heat rate penalty (%)
Cold temperature design	36.00	-	-
Cold Temperature at 0 mg/l detergent	37.65	1.65	0.35% (Heat loss)
Cold Temperature at 3 mg/l detergent	36.09	0.09	0.02% (Heat loss)
Cold Temperature at 5 mg/l detergent	35.41	-0.59	-0.20% (Potential saving)
Cold Temperature at 10 mg/l detergent	35.17	-0.83	-0.25% (Potential saving)

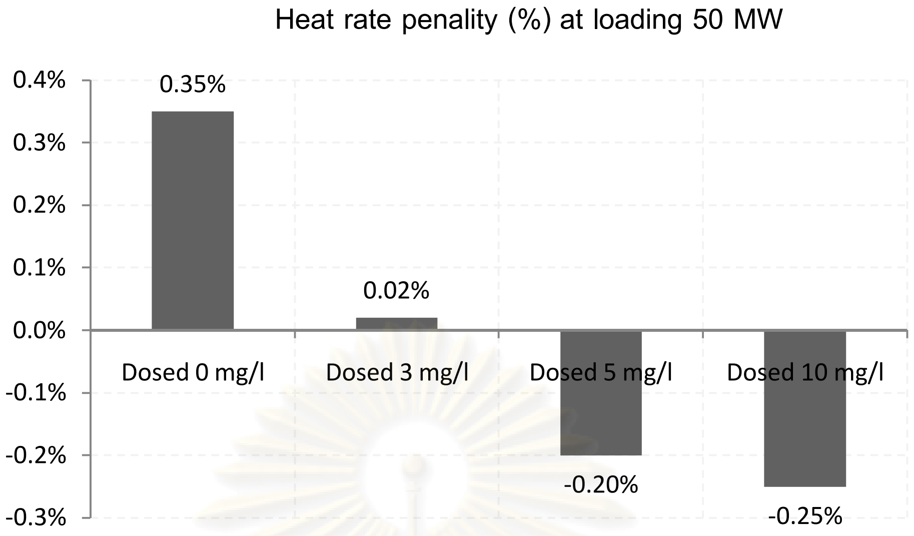

Figure A4 summary graph of heat rate penalty (%) value for each of detergent condition of 3, 5, 10 mg/l.

Figure A4 shows a benefit of lowest cold water temperature from better cooling tower at loading megawatt 50 MW. No detergent will give the 0.35% of heat rate penalty. The dosage of detergent at 3 mg/l will give 0.02% of heat rate penalty. While dosage of detergent at 5 mg/l will give the saving potential (0.2%). Same with dosage of 10 mg/l will give the saving potential (0.25%).

By compare the cold water temperature between cooling tower without using detergent and cooling tower where used detergent. Use the concept in item 2.1. Total calculation of saving price after study was 242,000 THB per month.

BIOGRAPHY

Prakasit Juangpanich was a single son of Mr. Raychai and Piyanee Juangpanich. Prakasit was born at Bangkok on 25 June 1981 B.C. Prakasit was completed the bachalar degree of chemical techonolgy from Chulalongkorn university since 2004 B.C. Now a days, Prakasit has work with engineering positions of Nalco industrial services (Thailand) Company by office based at Maptaphu Rayong province. Prakasit has experienced with utility power plant especially for application of cooling tower system, clarifier system, boiler system and reverse osmosis system.