RECLAMATION OF INDUSTRY WASTEWATER AS A RENEWABLE SOURCE FOR COOLING WATER SYSTEM: A CASE STUDY FOR A SEMICONDUCTOR PLANT

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ABSTRACT

Deionized water is generally used to rinse the integrated circuit (IC) crystal chips in semiconductor manufacturing. Wastewater generated in the semiconductor manufacturing need to be collected and treated as regulated by Department of Environment (DOE) Malaysia. On the other hand, cooling systems are major water consumers in the industry. The treated industry wastewater from semiconductor usually contains less inorganic and has the potential to be reused as make-up water in the cooling tower water system. The aim of this study is to determine the critical parameters of the make-up water for cooling water tank and create a baseline of recommended water quality for cooling water if reclaimed water from treated semiconductor effluent is used as alternative water source of make-up water for cooling water. Comparison of reclaimed water characteristic was reviewed and to evaluate the appropriateness and effectiveness of the reclaimed water to be reused as cooling water. The related mass balance data of used water quantities in the whole plant indicated the reuse and recovery of used water could be appropriately carried out in the plant.

A representative semiconductor plant was selected as this case study which this plant has installed a wastewater recycling system that draws over 382 cubic meter/day treated industrial wastewater before discharge to environment. Total amount of collected reclaimed wastewater used in wastewater recycling system for cooling make-up water need to have close monitoring and nine critical parameters were identified which affects cooling water system's efficiency; pH, conductivity, total hardness, total calcium hardness, total alkalinity, free chlorine, total silica, total iron and total bacteria count. This wastewater recycling system was operated since January 2017 and without any major breakdown. Total reclaimed wastewater has reached 1990 cubic meter/year in the past one year and cost saving reached about RM 202k per year.

Keywords: sustainable water management, wastewater recycling, zero discharge concept

ABSTRAK

"Air deionized" biasanya digunakan untuk membilas cip kristal litar bersepadu (IC) dalam pembuatan semikonduktor di mana air kumbahan akan dihasilkan. Air sisa kumbahan yang dihasilkan dalam pembuatan semikonduktor perlu dikumpulkan dan dirawat dalam sistem rawatan efluen industri seperti yang diseliakan dalam peraturan yang dikuatkuasa oleh Jabatan Alam Sekitar Malaysia. Sistem penyejukan adalah pengguna air utama dalam industri, oleh itu, air kumbahan industri yang dirawat biasanya mengandungi jumlah bahan bukan organik yang sedikit dan sesuai dipakai semula dalam sistem air menara penyejuk.

Tujuan kajian ini adalah untuk menentukan paramater-parameter kritikal untuk tangki air untuk air penyejuk dan mewujudkan kajian asas kualiti air yang disyorkan jika air sisa kumbahan yang dipakaisemula dari efluen industri sebagai sumber air alternatif untuk kegunaan air penyejuk. Kajian tentang perbandingan laporan ciri air yang dipakaisemula dan kemudian menilaikan kesesuaian dan keberkesanan air kumbahan yang dipakaisemula untuk digunakan semula sistem pendingin menara air. Selain itu, data baki massa berkaitan kuantiti air yang digunakan di seluruh kilang menunjukkan penggunaan semula dan pemulihan air yang digunakan boleh dilakukan dengan sewajarnya di kilang. Sebuah wakil kilang semikonduktor telah dipilih sebagai kajian kes ini yang telah berinisiatif memasang sistem kitar semula air kumbahan untuk mengumpulkan semula lepasan industri effluent yang dirawat secara proses kimia-fizikal yang lebih daripada 382 meter padu air sehari sebelum dilepaskan ke alam sekitar. Jumlah lepasan industri effluen yang dikumpulkan untuk dikitarsemula sebagai air kumbahan yang dipakaisemula perlu dipantaukan untuk kecekapan sistem pendingin menara air dimana sembilan parameter yang kritikal telah dikenalpasti seperti pH, konduktiviti, jumlah kekerasan air, jumlah kekerasan air kalsium, jumlah alkaliniti, klorin bebas, jumlah silika, jumlah besi and jumlah bilangan bakteria. Jumlah air sisa kumbahan ini telah dikumpulkan ke dalam

sistem kitar semula air kumbahan sebagai air yang dipakaisemula untuk sistem menara penyejuk. Sistem kitar semula air kumbahan ini telah beroperasi sejak Januari 2017 dan tanpa sebarang masalah. Jumlah air kumbahan yang telah dipakaisemula mencapai 1990 meter padu dalam tempoh satu tahun dan jumlah penjimatan sebanyak sekitar RM 202k per tahun.

Kata kunci: Pengurusan air lestari, Kitar semula efluen industry, konsep pembuangan sifar

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LIST OF SYMBOLS AND ABBREVIATIONS

AWN	:	Acid Waste Neutralization
BOD_5	:	Biological Oxygen Demand 5-day test
Ca	:	Calcium
$CaCO_3$	:	Calcium carbonate
Cl^-	:	Free Chlorine
COD	:	Chemical Oxygen Demand
H_2S	:	Hydrogen Sulfide
LEDs	:	Light-Emitting Diodes
mg/l	:	Milligrams per liter
MLD	:	Million liters per day
MPCBs	:	Polychlorinated biphenyls
NO_3^--N	:	Nitrate-Nitrogen
NO_2—N	:	Nitrite-Nitrogen
NH_4^+-N	:	Ammonium-Nitrogen
ORP	:	Oxidation and Reduction Potential
PBA	:	Pulau Pinang Bekalan Air
RO	:	Reverse Osmosis
RRS	:	Resource Recovery Systems
SPAN	:	Suruhanjaya Perkhimatan Air Negara
SiO_2		Free Silica
SO_4^{2-}		Sulphate
SS	:	Suspended Solid
TDS	:	Total Dissolved Solid
TOC	:	Total Organic Carbon

UF	:	Ultrafiltration
UNEP	:	United Nations Environment Programme
US EPA	:	United State's Environment Protection Agency
μS/cm	:	Micro Siemens / Centimeter

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The growth of semiconductor industry continues to spearhead the expansion of the Electrical & Electronic industry in Malaysia and has benefited from the worldwide demand such as the usage of mobile devices (smartphones, tablets), storage devices (cloud computing, data information centres), optoelectronics (photonics, fibre-optics, LEDs) and embedded technology (integrated circuits, PCBs, LEDs). Generally in the semiconductor industry, electronic-grade deionized water is needed to rinse integrated circuit (IC) crystal chips. The reject deionized water was channeled into industry wastewater treatment system plant for treatment before release to inlands waters. The discharge effluent shall comply as stipulated in Environmental Quality (Industrial Effluent) Regulations 2009 (Department of Environment Malaysia, 2009).

Many countries around the world are facing increasing difficulty of fresh water supply to satisfy various water demand. As water scarcity is growing, reclamation of water is a good practice towards sustainability in water resource management (Lyu, et al., 2016). Reclaimed water is "pipe-to-pipe" treated effluent where the intended water reuse application dictates the appropriate treated quality. Reclaimed water used for potable use need further treatment technology to meet the drinking water quality requirement. Instead of discharging to inland water, the intention for most wastewater reclamation and reuse projects is to produce water with certain qualities to be used for all the potential uses that do not require potable water quality standards, such as agricultural and landscape irrigation, industrial uses, and non-potable urban uses (L. Sara & M. Serra, 2004). Reclaimed water can also be used for non-potable use such as in the agricultural irrigation systems, industries, urban, recreational and environment uses and combination from above (Michael-Kordatou, et al., 2015 ; Asano & D. Levine, 1996). This study offers an opportunity to investigate the use of treated industry efflent as renewable source as parts of resource recovery systems (RRS) where conceptual transformation would allow the perceived impact of industrial effluent on communities to become net positive.

A representative semiconductor plant was selected for this case study. The selected plant is located in Penang state and this semiconductor industry manufactures motherboard chipsets, network interface controllers and integrated circuits, flash memory, graphics chips, embedded processors and other devices related to communications and computing. The plant is accredited with internationally recognized ISO 9001 (Quality management system), ISO 50001 (Energy management system) and OHSAS 18001 (Environmental, Health & Environmental management system).

The purposes of this case study were mainly interested in evaluating the appropriateness and effectiveness of reusing the treated industry wastewater from the manufacturing process as the plant has put the plan wastewater recovery and reuse into practice as to convert the reclaimed wastewater as make-up non-potable water source for cooling water system. This study include data collection of treated waste water quality analysis and water analysis in cooling water system as well include the field investigation.

1.2 SEMICONDUCTOR MANUFACTURING DESCRIPTION

Figure 1.1 presents the relevant industry wastewater treatment performance and mass balance data of effluent in this selected plant. Wastewater contributions into the wastewater treatment system are mainly from about 70% production discharge and 30% from facilities equipment wastewater such as reverse osmosis (RO) reject water and multi-media polypropylene (MMP) filtration backwash. The wastewater generation is estimated around 70 gallons per minutes (usgpm) / 458 cubic meter/day (m^3pd) / 167,281 cubic meter/year (m^3py). It is treated to comply with the Environmental Quality (Industrial Effluent) Regulations 2009 before discharge into Malaysia inland water.

In this wastewater reclamation project, the MMP backwash and RO reject is recovered and collected in the equalization tank. Thereafter, this wastewater is channeled into wastewater treatment system which is mainly from plating process where deionized water is used to rinse or clean the plating electrolyte. The generated wastewater is treated by acid waste neutralization (AWN) and chemical coagulation method as in Figure 1.1.

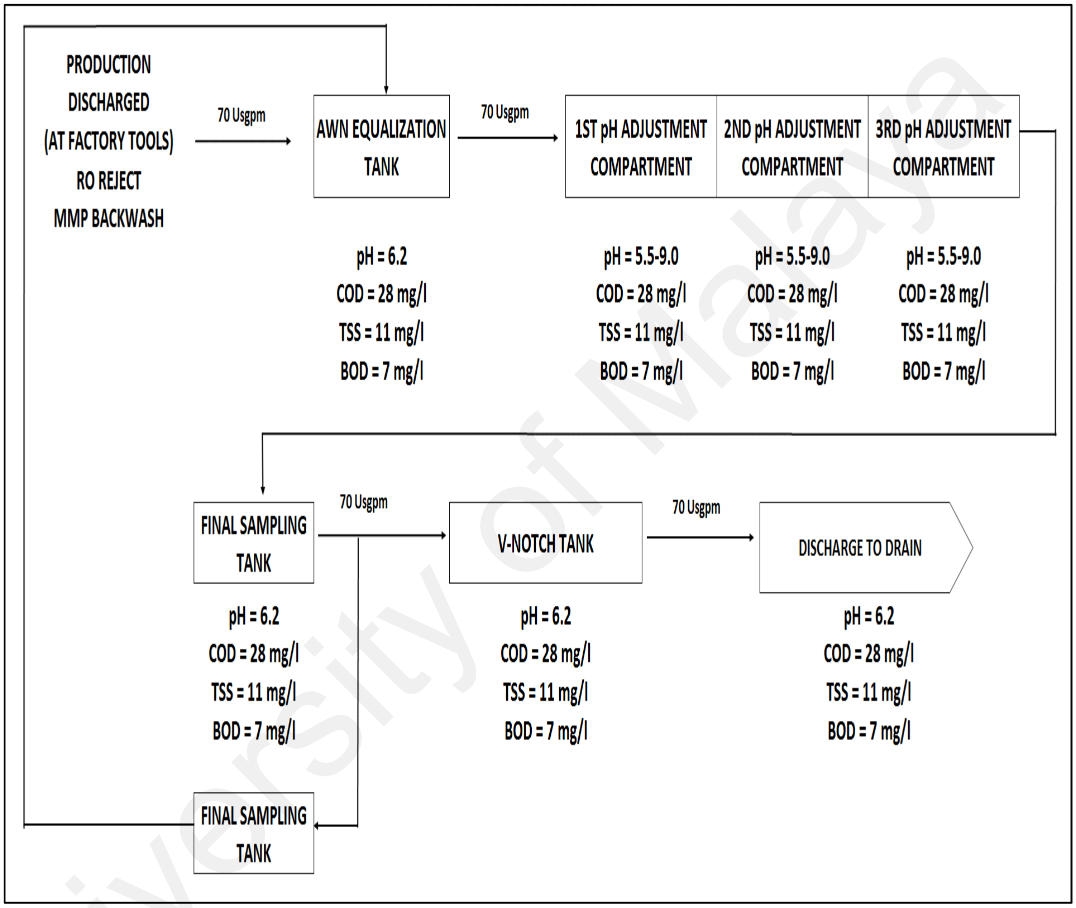

Figure 1.1: Flow diagram of Industry Wastewater Treatment System in the selected plant

In the plant, the cooling water system contains open recirculating counter-flow type where the air moves upward and directly opposed to the downward flow of water. Headers and spray nozzles are usually used to distribute the water in counter-flow towers. This design provides a good heat exchange as the cold air is indirect contact with the coolest water.

1.3 PROBLEM STATEMENT

Availability of technologies to recover resources from industrial effluent have undergone accelerated development but become barrier for successful implementation of resources recover as there is lack of agreed-upon sustainability goals and targets, management commitment and sociological factor such as the absence of a holistic design in the planning and design process of resources recovery (Saha, et al., 2005). Many reputable companies have adopted the concept of sustainability development, recognizing that environmental protection and social responsibility are important. However, despite their increased awareness and commitment, most companies find it difficult to translate broad goals and policies into daily decisions (Fiksel, 2003).

Secondly, treated industry wastewater is discharged to inland waters as water tariff in Malaysia is relatively low especially in Penang state at RM1.45 / m^3 compared to others Malaysia states as shown in Figure 1.2 (Suruhanjaya Perkhimatan Air Negara (National Water Services Commision), 2011).

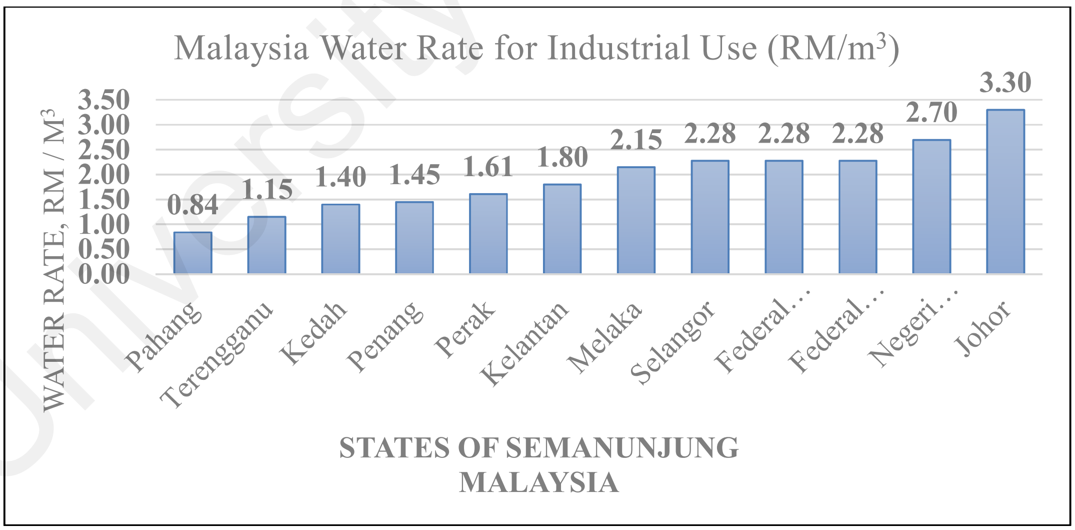

Figure 1.2: Malaysia's Water Rate for Industrial Use (Suruhanjaya Perkhimatan Air Negara (National Water Services Commision), 2011)

Example in Singapore where (Ong, 2010) had explained Singapore had adopted policy of to charge the water bill and metering within country based on formula with components water tariffs, water conservation tax and legal charged called waterborne fee and sanitary appliance fee every year. According to (Siddiqi & Anadon, 2011), in Middle East and

North Affrica, the expansion of semiconductor production is restricted due to a limited water supply. The cost of water and surcharges for excessive consumption per capita water resources were abundant and therefore cause economic sensitivites to variation are not well understood. Due to rapid urbanization, population growth, imbalance water cycle and climate change cause there is a need for integrate the planning and design of energy and water systems efficiently and effectively. Water extraction, treatment, distribution and disposal process consume energy and water-energy nexus had been progresively highlighted as a critical issue for future and also strategic policy planning. These common shortfalls suggest that the underlying problem on lack of proper planning and appropriate provision of water conservation or alternative source of non-potable water in case there is any water crisis.

Thirdly, there is no resources recovery emergency plan during water crisis where water supply is limited. Besides that, there is no other water supply provider and the only sole dependency from Pulau Pinang Bekalan Air (PBA) in Pulau Pinang. A press had release from Penang local authority on water crisis where phenomenon of “Super El-nino” had caused water supply interruption, prolonged drought and reduced rainfall in the northern region of Malaysia in April 2016. This cause more than 80% Penang’s raw water sourced from Sungai Muda dam to drop to below 40%. (Perbadanan Bekalan Air Pulau Pinang Media Report, 2016). Climate change and water availability are also expected to further raise security concerns in international river basins and claiming that increased rainfall intensity and variability were projected to increase the risk of floods and droughts in many areas (Nordas & Gleditsch, 2007). (IPCC , 2015) also reported there is predicted increase of global mean surface temperature about + 0.3^0C-0.7^0C in year 2016-2035 and the rise of sea level about +0.2-0.6m by the year 2100 which increasing the likelihood of a severe, widespread and irreversible impact on the people and the ecosystem. A paper presented by (Ding, et al., 2011) suggested that a company that adopts water stewardship strategies should be able to anticipate, manage and mitigate emergency such as water costing, changing regulatory or disruption of physical supplier. Therefore, having good emergency response on water recovery emergency plan can minimize the impact during emergency crisis.

Lastly, there is a lack of environmental and ecological assessment available. Accordingly to (Sala & Serra, 2004), industrial effluents are in larger quantities and contribute to nutrient imbalances in the ecosystem and a host of environmental detriments such as concentrations of organic carbon (cause depletion of dissolved oxygen), nitrogen and phosphorus (cause eutrophication). The loading and cycle of these main pollutants and the adequacy of their actual fate from an ecological point of view are being placed in the ecological compartment and they should with the lowest adverse impact to the environment.

1.3.1 HYPOTHESIS

In this paper study, to test the hypothesis, all the information was gathered, read and all the relevant research paper was analyzed. To ensure the hypothesis is testable, evidence needed to collect to reject the null hypothesis. Question, hypothesis and prediction was discussed as below:

Question	Hypothesis	Prediction
Can industry wastewater be reclaimed as make-up water tank for cooling water system?	Discharged industry wastewater meet the cooling water system's operating specification can be reclaimed as industry reuse in cooling water system	If the parameters are all within the cooling water system's operating specifications, then it can used as alternative source of non-potable water for cooling water system and vice-versa

1.4 AIM

To identify framework on sustainability project in semiconductor industry by identifying the opportunity for water reuse, to exploit the current facility system for potential of water reuse and to evaluate the suitability of reusing reclaimed effluent for efficient operation of the cooling system. While water reuse is a wise resource option, consideration should be made regarding the quality of the water and how that will impact the efficient operation of the cooling system, and the system's ability to meet the required cooling demand.

1.5 OBJECTIVES

The objectives of this study are to:

1. To determine critical parameters of the make-up water used for cooling water operation.
2. To evaluate the suitability of reclaimed wastewater for cooling water make-up.
3. To calculate potential total water saving from reusing of treated industrial wastewater as cooling water.

1.6 SCOPE OF STUDY

This reclaimed wastewater project is applicable to only semiconductor industry where the deionized water is used to rinse the electronic products in the processes. The wastewater generated undergo physical-chemical process to meet the standard B parameter as compliance with Environmental Quality (Industrial Effluent) Regulations 2009 before discharge into Malaysia inlands water. Make-up for cooling water supply from public water provider was analyzed on the quality water for cooling tower performance. From the baseline study, water quality of 30:70 ratio mixture of reclaimed wastewater and raw water was study whether it is suitable used for cooling water in cooling tower system.

1.7 SIGNIFICANCE OF STUDY

This study offers an opportunity of treated industry efflent as renewable source for other potential use or described as resource recovery systems (RRS) where conceptual transformation could allow the perceived impact of industrial effluent on communities to become net positive.

CHAPTER 2: LITERATURE REVIEW

2.1 THE HYDROLOGICAL CYCLE AND WASTEWATER RECYCLING

The natural hydrological cycle is not only a circulation of water among the ocean, atmosphere, land, surface and subterranean water bodies but is a process of water purification through natural actions as shown in Figure 2.1. Following the natural principles, the concept of water cycle management is proposed to design urban water systems and wastewater in new ways that provide fresh water supply, reclamation and reuse of water and urban water environment integrated into a water cycle to maximize the efficiency of water use and natural resources. The main route of water reuse is shown by a violet line in Figure 2.1 and includes refilling of underground water, irrigation, resident use, industrial use and surface water replenishment. Surface water replenishment and underground water flow are occur naturally through drainage through hydrological cycles and through irrigation infiltration and rainwater runoff. The potential usage of reclaimed wastewater for potable water is also shown.

The amount of water transferred through each path in the Figure 2.1 depends on the climate condition, watershed attribute, geographical hydrological factor, degree of water utilization for various purpose use and the degree of direct and indirect water reuse (Asano & D. Levine, 1996). The cradle to cradle from the recycling of conventional sewage water and the concept of eco efficiency is beyond the tools and conventional sustainability approaches that mainly create a negative impact on the environment (Mcdonough, et al., 2003).

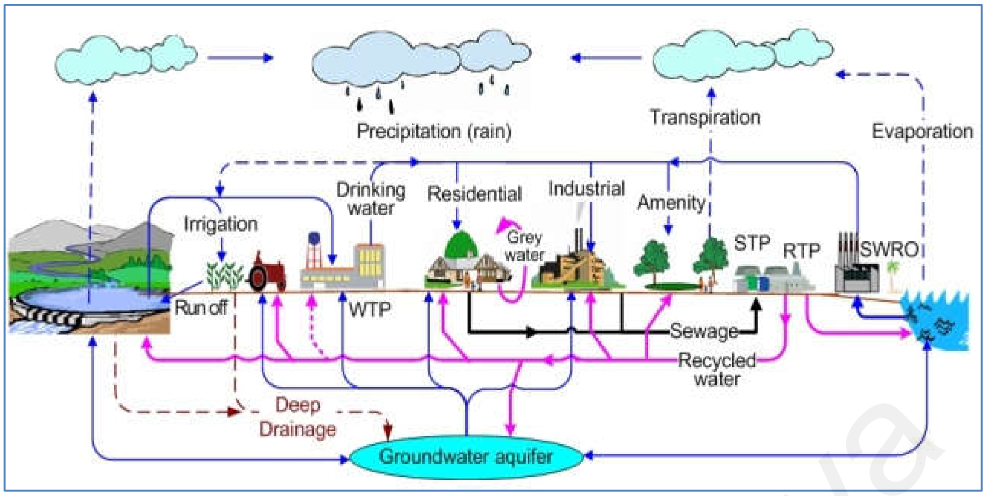

Figure 2.1: Water Resource Management in the Cycling Water Through Hydrologic Cycle [Typical water cycle (blue line) including recycled water (violet line) and sewage (black line)] (Asano & D. Levine, 1996)

Remarks: WTP = Water Treatment Plant; STP = Sewage Treatment Plant; RTP = Recycled Water Treatment Plant; SWRO = Seawater Reverse Osmosis (desalination plant).

Generally industrial reclaimed wastewater use is used for a diversity of industries with high consumption rate of water. The degree of treatment required in individual water treatment and wastewater reclamation treatment facilities is according to the specific reuse application and associated water quality requirements as shown in Figure 2.2 on water quality changes in time sequence. The treatment varies from simple solid / liquid separation such as filtration, reverse osmosis to the complex treatment systems involving single or combination of biological, chemical biological processes.

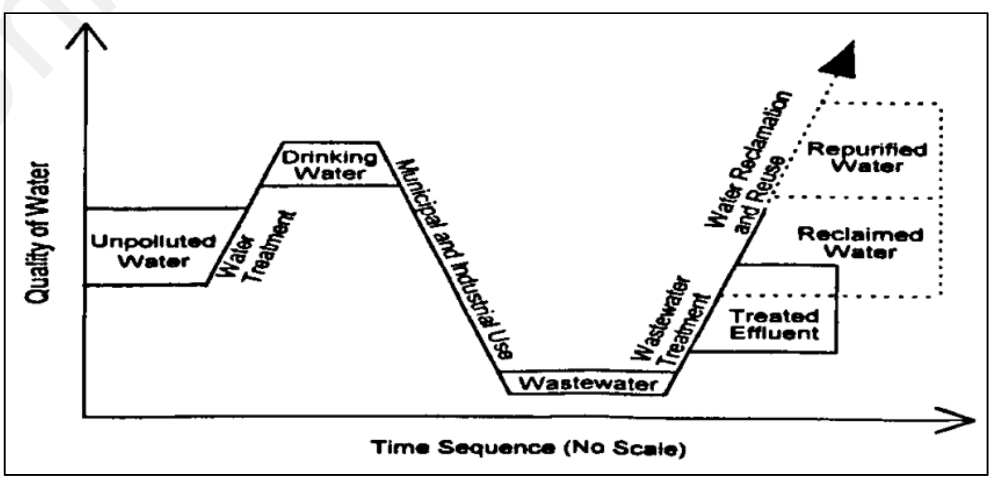

Figure 2.2: Water Quality Changes in a Time Sequence (Mujeriego & Asano, 1999)

Inadequate water management is accelerates the surface water and groundwater resources. Water needs has been increased steadily due to world population growth, industrial development and proliferation of irrigated agriculture (United Nations Environment Programme (UNEP), 2005). Many parts of the world are facing changes in climatic conditions, such as rainfall patterns, pollutants loading, flood cycles and droughts which affect the hydrological cycle (Huntington, 2006). Water availability in Africa and Asia have very low or catastrophically low as shown in Figure 2.3. This is to explain there is an urgent need to improve the efficiency of water use of supplement existing water resources with a more sustainable alternative.

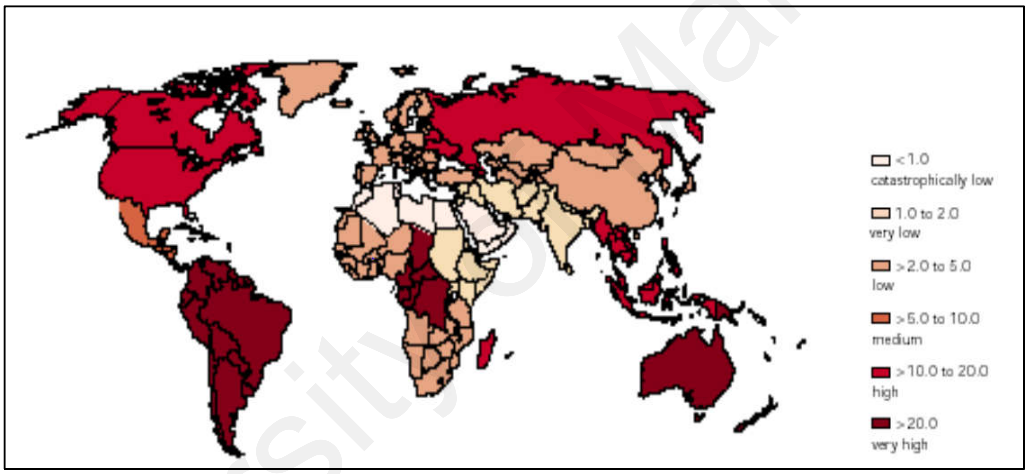

Figure 2.3: Water Availability in 2000 (Measured in terms of 1000m^3 per capita/year) (United Nations Environment Programme (UNEP), 2005)

2.2 INTERNATIONAL EXPERIENCE ASSOCIATED TO WASTEWATER RECLAIMATION

An international survey was done showing the highest ranked countries for total wastewater re-use in United States, Mexico, Mediterranean countries, the Middle East, South Africa, Australia, Japan, China, and Singapore on per capita wastewater reuse. In Asian countries excluding Singapore, the reclaimed water use still ranked lowest especially in Malaysia where is only 28% treated wastewater compare total wastewater generation (Sato, et al., 2013). Figure 2.4 shows the ratio of treated wastewater to total generated wastewater (expressed as a proportion) in selected countries. Wastewater recycling in Asia is low and the most common barriers in Asia including Malaysia are the lack of financial resources, followed by the lack of clear government policies and the lack of competent person in waste water management (United Nations (UN), 2000).

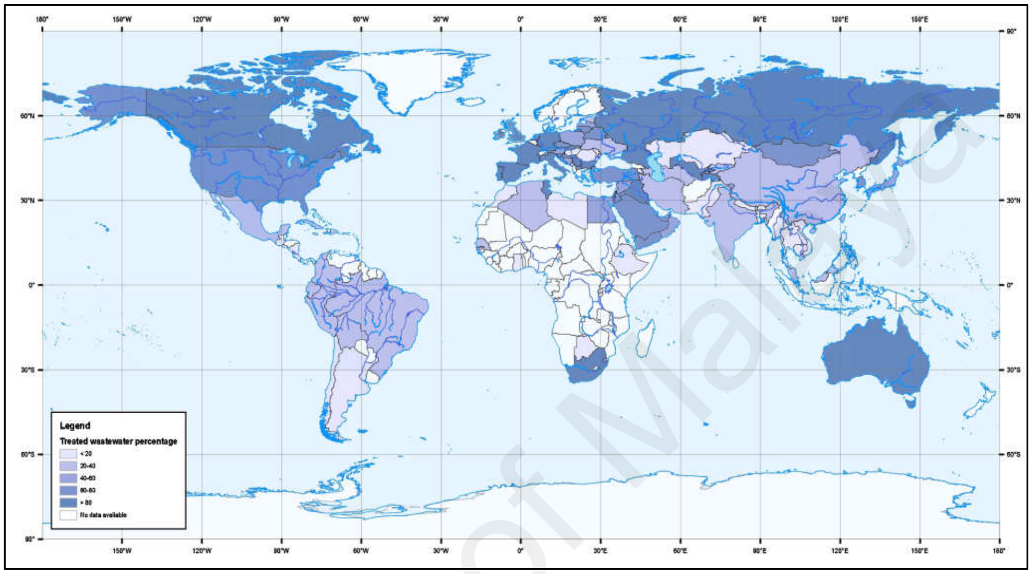

Figure 2.4: The Ratio of Treated Wastewater to Total Generated Wastewater (expressed as a proportion) in Selected Countries (Sato, Qadir, Yamamoto, Endo, & Zahoor, 2013)

Green engineering approaches focus on sustainability through science and technology (Fiksel, 2003). Innovations on reclaimed industry wastewater as non-potable use water for cooling water system was found in various studies around the world and is a popular program as water quantity supply to cooling water system is significant in water use in the plant.

In Taiwan, one of semiconductor industry are directly using the rejected water from deionizing water as cooling water make-up had been reported which only required further chemical treatment to control the biological fouling and corrosion control. Total savings of 200 m^3 per day was achieved by just directly channeling the rejected deionized water into cooling water make-up tank (You, et al., 2001). In Albuquerque site, New Mexico, United stated, company called Philips semiconductors has initiated a pro-active plan to reduce water use at their semiconductor facility. This is also in align with Albuquerque local council Water Resources Management strategy where they set a goal to reduce residential and industrial water use by 30 percent by year of 2004. The study found that reverse osmosis from deionized water plant, reject water and fabrication-process rinse industrial effluent are good opportunities for reuse for their current system of acid scrubbers, chemical wet sink aspiration, corrosive chemical bottle and waste washing, landscape irrigation as well as cooling tower system. A total saving of 20% reduction for incoming water supply was achieved at approximately 104 million gallons of water per year (Chavez, 1997). Another study in Japan was conducted where wastewater recycling system was only two process steps of chemical precipitation followed by ultrafiltration (UF). Redeemed water can be used for non-process purposes such as cooling towers, scrubbers, and air compressor systems. This reclaimed water project was operated for 2 years without issue and total reclaimed water reached 1,225,000 m^3 savings in the past 2 years (Okazaki, et al., 2000). Ministry of Environment Qatar issued a directive that requires energy and industry sectors in Qatar to work towards Zero Liquid Discharge (ZLD) of process wastewater by December 2016. ORYX GTL, one of the gases for fluid technology operators in Qatar had re-used about 1.38 million m^3 of treated industrial wastewater for landscape irrigation, make up cooling towers and fire extinction in 2012 (Jasim, et al., 2016).

Besides example of experiences in industry, reclaimed water project was practiced in airport industry example Kingsford Smith Airport, Sydney, Australia. The wastewater treatment plant treats raw sewage from the International and surrounding Terminals, including multi-storey carpark, Ulm Building (Sydney Airport Corporate Office) and Customs House. The treatment plant produces two recycling water streams where one consists of recycled water that is being disbursed to the International Terminal for use for toilet sprinklers and 526 toilets and 212 urinals connected to this system. The other stream is composed of reverse osmosis water delivered to the facility building and used in air conditioning cooling towers (Carvalho, et al., 2013).

Another example from oil and gas industry in Toledo, United States where a refinery of Sun Oil Company have reused the wastewater generated by using bio-oxidation technology to treat the identified pollutants such as oil and oily sludge, suspended solids, phenol type compounds in wastewater treatment plant. Reclaimed wastewater was used for cooling water extended over 8 years operation and cost savings of $100,000/yrs for water saving in fresh water make-up for cooling towers (Mohler, et al., 1964). Another study showing that reclaimed sewage water effluent in Amarillo city, Texas was used for power plant cooling system where the treated sewage reclaim water was directly supplied from activated-sludge water reclamation and sewage treatment plant of Amarillo city local government (Scherer & Terry, 1971).

For the hotel industry in Eastern Caribbean, reuse of wastewater can meet up 38% of total need in a hotel and resorts and can to reduce the overall cost of water supply and overcome shortages in the dry season. The opportunity of reclaimed wastewater is for irrigation, toilet flushing and cooling tower make-up water too (Peters, 2015).

2.3 CHARACTERISTIC OF WASTEWATER FOR SEMICONDUCTOR MANUFACTURING

Semiconductor process reject wastewater is different compared to semiconductor industrial wastewater. The major contaminants of the process reject wastewater are nano-size and micro-size particles and organic solvents. Nano-size and micro-size particles in the semiconductor wastewater is typically controlled by dosage of coagulation-flocculation in the physical-chemical treatment of wastewater which significantly minimize the turbidity level and concentration of suspended solids of semiconductor's process reject wastewater (Huang et al, 2011).

Process wastewater from semiconductor plant normally consists of silica oxide which is commonly present in chemical mechanical polishing process and generally consists of fluoride where hydrofluoric acid, phosphoric acid, ammonium hydroxide is used in wafer fabrication process. (De Luna et al., 2009) concluded that mixture of wastewater containing fluoride and silica helps the effective chemical precipation in flocculation where enhanced agglomeration of particle in waste water is enhanced. Electrocoagulation has become important physio-chemical reactions in wastewater treatment system and its ability to remove the contaminants are generally more difficult to remove by filtration or chemical treatment especially silica, emulsified oil, particle, suspended solids, and heavy metals (Belongia et al., 1999).

The design of the wastewater treatment plant depends on the raw wastewater quality and flow rate of industrial wastewater generated from the process of the semiconductor industry. The pollutants of critical paramater of the wastewter can easily be achieved by additional physical and chemical treatment (Mohsen & Jaber, 2002). For Malaysian's wastewater final discharge standard, Malaysia Environmental Quality Act 1974 Section 25 which states that "no any person shall emit, discharge or deposit any environmentally hazardous substances, pollutants or wastes into any inland water or Malaysian waters". Under Environmental Quality (Industrial Effluent) Regulations 2009, this industry shall comply to paramaters B as in Table 2.1 in the final discharge wastewater unless the final discharge wastewater is released into any inland waters within the catchment area, and so paramater A need to be complied (Department of Environment Malaysia, 2009).

	Parameter	Unit	Standard	
			A	B
	(1)	(2)	(3)	(4)
(i)	Temperature	°C	40	40
(ii)	pH Value	–	6.0-9.0	5.5-9.0
(iii)	BOD_5 at 20°C	mg/L	20	50
(iv)	Suspended Solids	mg/L	50	100
(v)	Mercury	mg/L	0.005	0.05
(vi)	Cadmium	mg/L	0.01	0.02
(vii)	Chromium, Hexavalent	mg/L	0.05	0.05
(viii)	Chromium, Trivalent	mg/L	0.20	1.0
(ix)	Arsenic	mg/L	0.05	0.10
(x)	Cyanide	mg/L	0.05	0.10
(xi)	Lead	mg/L	0.10	0.5
(xii)	Copper	mg/L	0.20	1.0
(xiii)	Manganese	mg/L	0.20	1.0
(xiv)	Nickel	mg/L	0.20	1.0
(xv)	Tin	mg/L	0.20	1.0
(xvi)	Zinc	mg/L	2.0	2.0
(xvii)	Boron	mg/L	1.0	4.0
(xviii)	Iron (Fe)	mg/L	1.0	5.0
(xix)	Silver	mg/L	0.1	1.0
(xx)	Aluminium	mg/L	10	15
(xxi)	Selenium	mg/L	0.02	0.5
(xxii)	Barium	mg/L	1.0	2.0
(xxiii)	Fluoride	mg/L	2.0	5.0
(xxiv)	Formaldehyde	mg/L	1.0	2.0
(xxv)	Phenol	mg/L	0.001	1.0
(xxvi)	Free Chlorine	mg/L	1.0	2.0
(xxvii)	Sulphide	mg/L	0.50	0.50
(xxviii)	Oil and Grease	mg/L	1.0	10
(xxix)	Ammoniacal Nitrogen	mg/L	10	20
(xxx)	Colour	ADMI*	100	200

*ADMI–American Dye Manufacturers Institute

Table 2.1: Acceptance Conditions for Discharge of Industrial Effluent or Mixed Effluent of Standard A and B (Department of Environment Malaysia, 2009)

2.4 CONTROL OF POLLUTANTS IN COOLING WATER FACILITIES

2.4.1 MICROORGANISMS CONTROL IN COOLING TOWER FACILITIES

Bacteria, algae and fungi growth in cooling tower system are considered health hazard and pose potential infectious waterborne disease. Common diseases in cooling tower water are caused by bacteria like Legionnaires' Disease which infect human's respiration system. Prevention of Legionnaires' Disease in cooling tower suggested (Fields et al., 2002) are maintaining water temperature within 20-50^{0}C and avoid stagnation in the water system, prevent fouling or biofouling where deposit of nutrient can enhanced the bacteria growth, periodic disinfection of circulating water system and frequent cleaning of cooling tower system. Disinfection also can be done with the presence of free chlorine or monochloramine in the waste water as well in the drinking water (Theresa et al., 2010).

An important parameter to be monitored in reclaimed wastewater as make-up water for cooling tower system in controlling the fouling or bio-fouling is total free chlorine. Water chlorination is used to kill certain bacteria and other microbes in the water as chlorine is highly-toxic substance and good in control water-borne disease. Chlorination commonly is done by introducing or adding dilute solutions of Calcium Hypochlorite in water (Holzwarth, et al., 1984).

2.4.2 FOULING CONTROL IN COOLING TOWER FACILITIES

Circulating cooling water system is an important facility especially to reject waste heat to atmosphere and to cool down the water stream to a lower temperature. Fouling is the accumulation or deposition of unwanted materials on solid surface such as cooling tower's piping clogged with organic or inorganic substances or biofouling which consists of living organism. Fouling is a factor that cause inefficiencies of pumps to circulate in the cooling tower causing increase of energy consumption and decreased water's flow rate (Gao & Xiao , 2017).

Calcium and magnesium are present in fresh water and reclaimed wastewater naturally but is higher in wastewater. Calcium and magnesium in water or reclaimed wastewater is important to determine the water hardness and it also functions as a pH buffer and stabilizer. High levels of total hardness in the water could cause serious problems in industrial settings such as abnormal cloudiness and the formation of scale wherein water hardness is typically monitored to prevent costly failures in components like cooling towers, boilers and other equipment that contains or processes water (Rebhun & Engel, 1988).

Another fouling factor is conductivity where conductivity is a measurement of total ions in a solution where is actually measure of the ionic activity of a solution in term of its capacity to transmit current. Conductivity has an approximate relationship with total dissolved solid (TDS). TDS is the combined content of all the organic and organic ingredients contained in the liquid or the form of suspended molecules, ionized or micro granular suspended form. High conductivity or high TDS in reclaimed water can cause fouling or biofouling where deposit of nutrient in the cooling tower's in the tube or piping (Mohler, et al., 1964).

An example of reclaimed water project in Taiwan's semiconductor industry where the directly reuse reverse osmosis water in the industrial cooling systems but it needs further chemical treatment to reduce the fouling matter and heat transfer issue in the cooling towers (You et al., 2001).

2.4.3 CORROSIVITY CONTROL IN COOLING TOWER FACILITIES

(Mohler, et al., 1964) presented removal of sulfur compounds in the water is important for the prevention of atmospheric pollution especially hydrogen sulfide (H_2S) and minimizing corrosiveness of the potential reuse make-up reclaim water supply for cooling towers.

In cooling tower systems, corrosion causes two basic problems where the first and most obvious is the failure of the equipment with the cost of replacement and causing downtime and the second is the reduced the plant efficiency due to the loss of heat transfer due to thickening of the heat exchanger caused by the corrosion product deposition. Corrosion can be controlled effectively by the use of additive or corrosion inhibitors which prevents of corrosive substances coating on the metal (Hsieh, et al., 2010).

Appropriate monitoring of levels of hardness in cooling tower is important where if the total hardness is too high, the scale formation will occur as discussed earlier. If the total hardness is too low, it indicates the water is corrosive and more aggressive (Rebhun & Engel, 1988). To prevent corrosiveness in water, important parameters to monitor are pH and total alkalinity. pH is a very important factor because certain chemical processes can only take place when water has a certain range of pH. The pH is an indication for the acidity of a substance and it is determined by the number of free hydrogen ions (H+) in the water while total alkalinity is the capacity of water to resist changes in pH. These pH of make-up water for cooling water is generally causing general corrosion in the cooling tower system where corrosion rate of metal and metal alloys was significantly influenced by pH where low pH enhanced corrosion as contain more hydrogen ions react with the electrons at the metal and metal alloys cathode site (Choudhury, et al., 2012). Alkalinity measurement is important in identifying the capacity of water to neutralize the acidic and corrosive effects (Rebhun & Engel, 1988). The corrosion rate in the cooling tower is occurs which is directly proportional to both the total alkalinity and pH of the cooling water where the higher values of either one of both parameter will result in an increased rate of corrosion (Choi, et al., 2002).

Poor treatment toward corrosivity may reduce the cooling tower's efficiency and increase the risk of cooling tower system downtime. There are three common forms of corrosion relevant to the cooling loop, first is called uniform corrosion also referred as general corrosion and is spatially uniform removal of metal from the surface. A second type of corrosion form is pitting corrosion where a localized attachment of metal surface can lead to water leaks with typical mean time to failure. A third type is called galvanic corrosion where is arises when two metals that are wide apart in the galvanic series are in contact with electrical and immersed in the same water environment. Electrons will be forced to flow from the less noble to the more noble metal, the less noble metal surface, corrosion will occurs by giving off the electrons that are consumed on the more noble metal surface by reduction reaction process (Cortinovis, et al., 2009).

Monitoring total iron in the make-up water for cooling water is to determine the corrosion rate due to the pH, total alkalinity or bacteria growth especially iron bacteria or cultivable aerobic heterotrophic bacteria which might increase the total iron in the cooling tower that causing inefficiency and ineffective in cooling tower's operation (Rao, Sairam, et al., 2000).

2.4.4 SCALING CONTROL IN COOLING TOWER FACILITIES

Scaling is the deposition of solid material and adherent material on the cooling loop surface. Scale formation occurs when the high concentrations of solubility of salt in water or due to increases of temperature (Wu, et al., 2004). There are two common type of scales found in the cooling tower system. In the first scale that is those dissolved solids and minerals are introduced to the cooling water system called mineral scales such as calcium carbonate, calcium sulfate, calcium phosphate, magnesium silicate, silica compounds and this mixtures. The second type of scale is normally introduced through influent water or airborne impurities in the sludge and organics such as silt and windblown debris, biological deposits, metallic oxides, corrosion products, oil, organics, and process contaminants. Scaling inhibitors are added in the water treatment to reduce the scaling formation in the cooling tower system (Morse & Knudsen, 1977).

High value of total hardness water is the most common and is responsible for the deposition of calcium carbonate scale in pipes and equipment meanwhile high concentration of total calcium hardness in the make-up water tank is the primary cause of mineral scale deposits that form on heat transfer surfaces causing loss in heat transfer efficiency. For this reason, cooling water chemistry is controlled to prevent the precipitation of calcium salts (Kim, et al., 2001).

2.5 RECLAIMED WATER QUALITY POLICY AND REGULATION

Some countries have adopted their own reclaimed wastewater quality policy and regulations for the intended water reuse application (Asano & D. Levine, 1996). However, there is lack of appropriate water quality standards or guidelines for wastewater reclamation (Okun, 1996). In Asia, especially in Malaysia, there is no policy or regulations relevant to reclaimed wastewater. This is a reason why reclamation of wastewater is not popular and recycle of wastewater is still low among various industries (United Nations (UN), 2000).

In United Stated of America, there is no federal regulation governing the reclaimed wastewater and only several states adopt Guidelines for Water Reuse 2004 from US EPA (United States's Environmental Protection Agency) was published for a variety of reuse application such as urban reuse, industrial reuse (cooling make-up water, boiler make-up water and industrial process water), agricultural reuse, environmental and recreational reuse and groundwater recharge (Crook & Surampalli, 1996).

In EU (European Union) and its member states, Water Framework Directive EU Directive 1991 (Directive 2000/60/EC) was established where it is a framework for Community action in the field of water policy among this region. Europe and Mediterranean countries are lagging behind compared to California, Japan, and Australia in the context of reuse where this re-use concepts is difficult for regulators and the public to understand and accept (Bixio, et al., 2006).

In China, the central government has great vision to expand wastewater reuse and the overall wastewater reuse is encouraging. Many policies, regulations and standards on reclaimed water had been established, example a technical guideline for municipal wastewater reclamation and reuse was issued by Ministry of Housing and Urban-Rural Development China which covers planning, construction, operation, maintenance and risk management during industry and ends users to promote reclaimed wastewater. However, China is at still a primary stage of wastewater reclamation and reuse as it is limited to industry development, lack of public awareness and lack of cooperation among stakeholders (Lyu, et al., 2016).

In Taiwan, semiconductor industry generally discharged industrial effluent contains high turbidity and conductivity. In this pilot-scale study, three stages system using membrane systems, ultrafiltration and reverse osmosis membrane was been developed for semiconductor wastewater reclamation. The main criteria in this pilot-scale study is to ensure 14 important parameters consisting of conductivity, turbidity, Total Dissolved Solid (TDS), Suspended Solid (SS), Total Organic Carbon (TOC), Chemical Oxygen Demand (COD), Nitrate-Nitrogen (NO_3^--N), Nitric-Nitrogen (NO_2^--N), Ammonium (NH_4^+-N), Free Silica (SiO_2), Sulphate (SO_4^{2-}), Free Chlorine (Cl^-), Alkalinity, Calcium (Ca) Harness and Total Bacteria Count for reclamation of wastewater on the water reuse standard developed by industrial park (Huang et al., 2011).

In most of countries that do not have any reclaimed water standard adapt United of Stated Environmental Protection Agency reuse standard (United States Environmental Protection Agency, 2012). Although most of the published reuse water guidelines are applied for the industry wastewater and these guidelines can be used for industrial reuse application especially make-up for cooling water system as tabulated in Table 2.2.

Indexes / Sources	(Lyu, at al., 2016)	(Mohler, et al., 1964)	(Rebhun & Engel, 1988)	(Huang, et al., 2011)	(United States Environmental Protection Agency, 2012)
pH	6.5-8.5	6.5-7.7	7.9	7.4	6.0–9.0
Conductivity (µS/cm)	≤1000	736-1,075	-	<300	-
Total Hardness (mg/l as $CaCO_3$)	-	126-155	<250	<500	-
Calcium Hardness (mg/l as $CaCO_3$)	-	-	-	<198.6	-
Total Alkalinity (as $CaCO_3$, mg/l)	-	116-172	<300	<35	-
Free chlorine (mg/l as Cl)	-	96-162	<500	<100	1
Silica (mg/l)	-	4.8-6.8	-	<3.0	-
Total Iron (mg/l as Fe)	<0.3	1.19-3.38	-	-	-
Total Bacteria Count (cfu/ml)	-	-	-	<2.38x106	-
Reuse application	Industrial use (Cooling)	Industrial use (Cooling)	Industrial use (Cooling)	Industrial use (Cooling)	Industrial use (Cooling)

Table 2.2: Wastewater Reuse Standard from Different Countries

CHAPTER 3: METHODOLOGY

3.1 PROCESS FLOW

In this study, a semiconductor company was chosen to study whether the industry wastewater can be reclaimed water as make-up tank for cooling tower system. Semiconductor plant wastewater discharge generally must comply to standard B as regulated in Environmental Quality Environmental Quality (Industrial Effluent) Regulations 2009 (Department of Environment Malaysia, 2009). Literature review of international experience on reuse of industry wastewater for cooling tower system were compiled. Concerned parameters from various literature review were compiled and then is compare with cooling tower standard operating specification. Collection of discharged industry effluent is channeled to make-up water tank for cooling water system which contribute 30% of total capacity of this make-up water tank and 70% was filled up by raw water supplied by local water supply provider. Monitoring on those concerned parameters in the make-up water tank was done weekly by chemical supply provider, Nalco company which appointed by this semiconductor company. Sampling of data collection was discussed in Chapter 3.4. Data collection was analyzed and compared with cooling tower standard operating specification. Hypothesis of reclaimed industry wastewater was discussed and is accepted if all concerned parameters in the make-up water tank was met the cooling tower standard operating specification while hypothesis is rejected if all concerned parameters in the make-up water tank was not met the cooling tower standard operating specification. Cost-benefit was analyzed to be further reported if the hypothesis was accepted and the total cost saving of water consumption and total cost saving was reported in this paper study. The overall project methodology is shown in Figure 3.1.

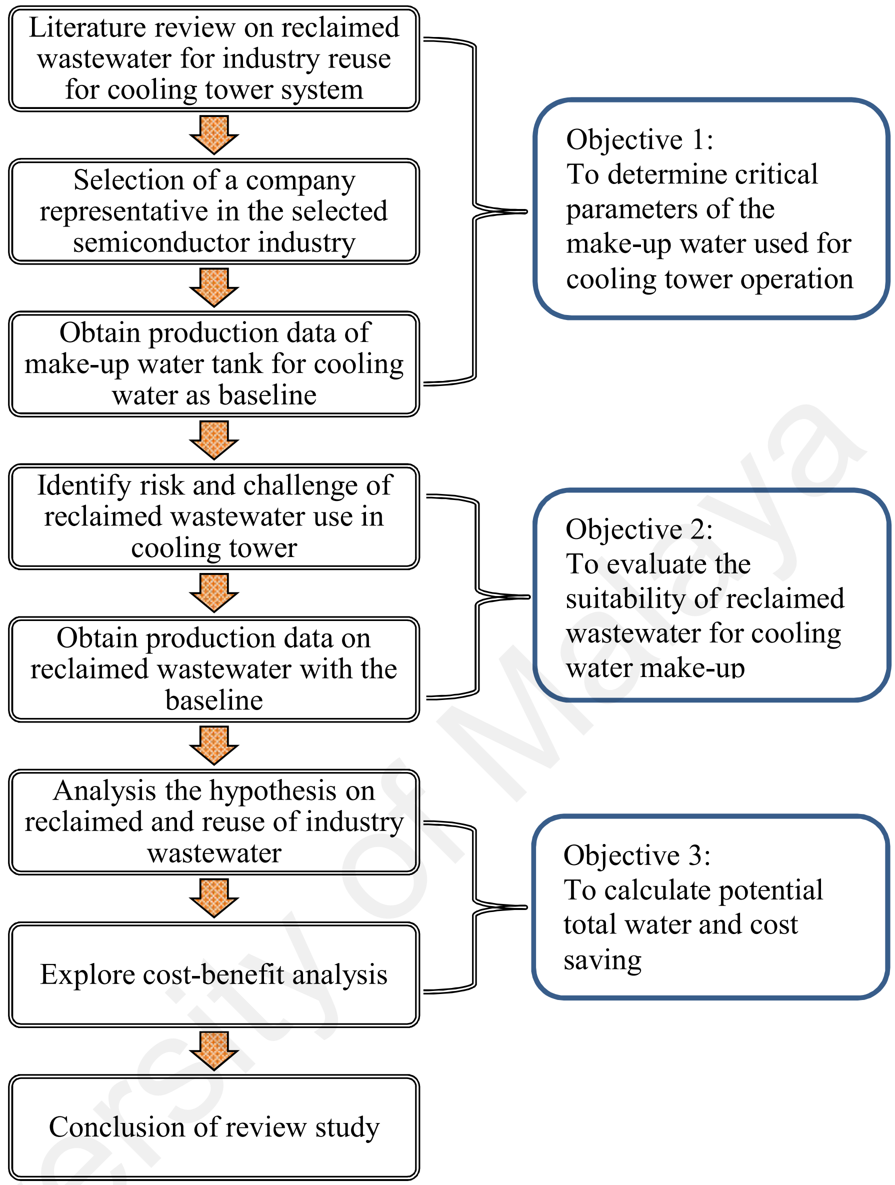

Figure 3.1: Project methodology

3.2 PILOT-SCALE PLANT

Wastewater reuse network was designed to connect the current industry wastewater part of the make-up water used for cooling tower system instead of the previous wastewater network where it is directly discharge to inlands water as shown in Figure 3.2. The reclaimed water was collected and stored in the final sampling tank. 30:70 mixing ratio of reclaimed wastewater and raw water is set at any time in the final sampling tank. Final sampling tank was installed with temperature sensor to monitor the incoming wastewater's temperature. Besides that, a level sensor was also installed where high level overflow wastewater will directly channel to v-notch. During emergency off spec wastewater, it will be transferred to off-spec tank and channeled back to equalization tank in the wastewater treatment plant for re-treatment.

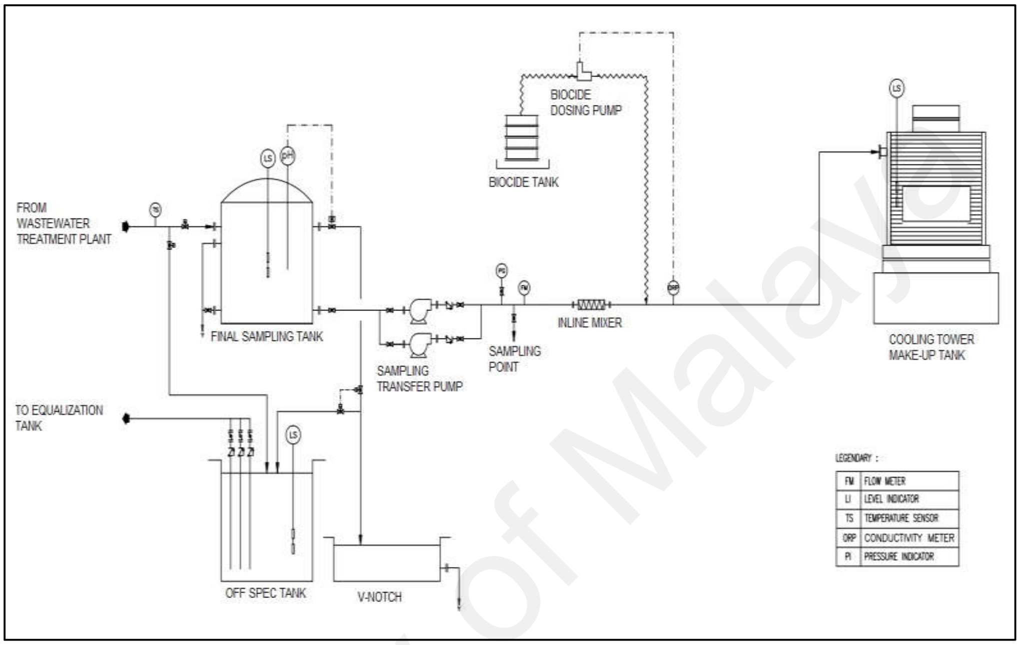

Figure 3.2: Schematics of Pilot-Scale Reclaim Water System

The actuator valve is controlled by pH meter where out of range pH will remained close and within spec pH, it will be channeled to cooling tower make-up tank directly. Water sampling point is available to monitor those critical cooling tower's operating specification. Along the pipeline toward to cooling tower make-up tank, flow meter and pressure indicator were installed to monitor the flow rate to cooling tower make–up tank. Besides that, conductivity sensor was installed also and will trigger biocide tank to pump the biocide when the reclaim wastewater's conductivity is high concentration detection is done with conductivity meter or oxidation / reduction potential (ORP) meter. Sampling points are available to ensure the reclaim water meets the cooling tower quality requirements. Reclaim wastewater for cooling tower make up water's sample was taken in the sampling point weekly. Cooling tower operation performance using reclaimed wastewater is also monitored based on the critical parameters are discussed in Table 2.2.

3.3 DETERMINATION OF OPTIMUM RECLAIMED WATER CHARACTERISTIC FOR MAKE-UP WATER FOR COOLING WATER SYSTEM

Based on the studies by (Lyu, et al., 2016; Mohler, et al., 1964; Rebhun & Engel, 1988; Huang, et al., 2011 and US EPA, 2012) as discussed earlier in Table 2.2, most of standards use was developed by their own country legislation or real case study on those critical parameter that impact the cooling water system. The important consideration is to identify the key ingredients in the recycled water to determine if any will impact the cooling water contacted equipment in an adverse manner. Cooling tower system needs to review their recycled water and their system for a more accurate determination of any adverse or beneficial impact.

Hence, from the above various studies, a total nine of concerned parameters were identified and need to be monitored for the reclaimed make-up water for cooling water system. Those nine parameters are pH, Conductivity, Total Hardness, Total Calcium Hardness, m-Alkalinity, Free Chlorine, Total Silica, Total Iron and Total Bacteria Count. Obviously the reclaimed wastewater has lower water quality compare to the raw water.

To develop the baseline for make-up water tank for cooling water on the nine concerned parameters, the optimum range of each parameters was provided by in-house water treatment chemical provider, Nalco Malaysia benchmarking their patent right (United States of America Patent No. US 6,315,909 B1, 2001). For conductivity, total hardness and total silica, due to each water quality supplied in each country is different where the given optimum range value is based on the data collection in the raw water supplied in the make-up water tank. Data given for parameter conductivity, total hardness, total silica, total silica and the cycle are based on raw water local supply into make-up water tank for cooling water which without mixture of any industry reclaimed wastewater.

This proposed recommend baseline water quality for cooling tower is guideline developed by Nalco Malaysia for semiconductor plant and this is an ideal quality of water as make-up water for cooling water which this quality of make-up water can run up 6 to 8 cycles circulating in the cooling tower system before it was blow down to external.

Indexes / Parameter in make-up water tank with 100% raw water supply	(United States of America Patent No. US 6,315,909 B1, 2001)
pH	6.8 – 8.0
Conductivity (μS/cm)	50 – 800*
Total Hardness (mg/l as $CaCO_3$)	<500*
Calcium Hardness (mg/l as $CaCO_3$)	15 - 1500
m-Alkalinity (as $CaCO_3$, mg/l)	15 - 200
Free chlorine (mg/l as Cl)	0.2 – 0.5
Total Silica (mg/l)	< 150*
Total Iron (mg/l as Fe)	< 8
Total Bacteria Count (cfu/ml)	<10,000
Cycles	6 – 8*
Reuse application	Industrial use (Cooling)

Table 3.1: The Proposed Recommend Baseline Water Quality for Cooling Water

Remarks: * value given from the monitoring of incoming raw water supply in the make-up water tank for cooling water

Protection of the cooling water equipment most often is equal to or better than with fresh water. This means proper protection will increased life span and less maintenance for the cooling water contacted equipment. As ideal stage for make-up water tank, the cooling water as shown in Table 3.1 can be recirculating in the cooling tower system for 6 to 8 cycles before the water is discharged out from the cooling tower system with condition all nine parameters are within the limit. The improvement can be attributed to several factors: perhaps the most important is that greater attention and control is exercised with reclaimed wastewater versus fresh water. The increase in monitoring and chemical feed control also is a major factor in showing improved performance of the water treatment program (Lin & Yang, 2004).

3.4 EXTERNAL LAB ANALYSIS – POLLUTION IN INDUSTRIAL FINAL DISCHARGED WASTEWATER

Final discharge wastewater samples from this selected semiconductor's waste water treatment plant were collected monthly at the designated final discharge point. Wastewater analysis was done ex-situ analysis where the wastewater is transferred from the site to the appointed external accredited third party lab. Pollutants in the wastewater was analyzed in compliance with parameter B as stated in Environmental Quality Environmental Quality (Industrial Effluent) Regulations 2009 that indicating 31 parameters quality including Chemical Oxygen Demand (COD), Temperature, pH, BOD_5, Suspended Solids, Mercury, Cadmium, Chromium Hexavalent, Chromium Trivalent, Arsenic, Cyanide, Lead, Copper, Manganese, Nickel, Tin, Zinc, Boron, Iron, Silver, Aluminum, Selenium, Barium, Fluoride, Formaldehyde, Phenol, Free Chlorine, Sulphide, Oil & Grease, Ammoniacal Nitrogen and color.

All parameters were analyzed following the standard methods for examination of water and wastewater published by American Water Works Association and Water Environment Federation of United States of America or code of federal regulations, Title 40, Chapter 1, Subchapter D, part 136 published by Office of Federal Register, National Achieves and Records Administration, United States of America as tabulated in Table 3.2 as stated in Environmental Quality Environmental Quality (Industrial Effluent) Regulations 2009 sub-regulation 16 (2) on "Methods of Analysis of Industrial Effluent or Mixed Effluent" (Department of Environment Malaysia, 2009).

To minimize the biological, chemical and physical changes that may occur that alter the sample's composition, wastewater samples are handled in a manner that store the sample in ice box and within 4 hours to reach the external lab for the analysis.

Test Description	UOM	Results(s)	Method or Equipment Used
COD- Chemical Oxygen Demand	mg/L	ND < 2	APHA 5220 D (2005)
Temperature	°C	28.0	APHA 2550 B (2005)
pH		7.1	APHA 4500-H+ B (2005)
BOD-5 days test @ 20'C	mg/L	ND < 2	APHA 5210 B (2005)
Suspended Solid	mg/L	ND < 1	APHA 2540 D (2005)
Mercury	mg/L	ND < 0.001	APHA 3112 B (2005)
Cadmium	mg/L	ND < 0.003	APHA 3111 B (2005)
Chromium Hexavalent	mg/L	ND < 0.02	APHA 3500-Cr B (2005)
Chromium Trivalent	mg/L	ND < 0.02	APHA 3111 B & APHA 3500-Cr B (2005)
Arsenic	mg/L	ND < 0.001	APHA 3500-As B (2005)
Cyanide	mg/L	ND < 0.02	APHA 4500 CN E (2005)
Lead	mg/L	0.05	APHA 3111 B (2005)
Copper	mg/L	ND < 0.01	APHA 3111 B (2005)
Manganese	mg/L	ND < 0.01	APHA 3111 B (2005)
Nickel	mg/L	ND < 0.02	APHA 3111 B (2005)
Tin	mg/L	ND < 0.05	In house method MY/STP/225 based on APHA 3120 B (2005)
Zinc	mg/L	0.04	APHA 3111 B (2005)
Boron	mg/L	ND < 0.1	APHA 4500-B C (2005)
Iron	mg/L	ND < 0.02	APHA 3111 B (2005)
Silver	mg/L	ND < 0.01	APHA 3120 B (2005)
Aluminium	mg/L	ND < 0.01	APHA 3500-Al B (2005)
Selenium	mg/L	ND < 0.001	APHA 3120 B (2005)
Barium	mg/L	ND < 0.01	APHA 3120 B (2005)
Fluoride	mg/L	0.8	APHA 4500 F-D (2005)
Formaldehyde	mg/L	ND < 0.01	US EPA 8315A (Rev.1) 1996
Phenol	mg/L	ND < 0.001	In house method MY/STP/069 based on Manual UDK 126D & APHA 5530 D (2005)
Free Chlorine	mg/L	ND < 0.02	APHA 4500 Cl G (2005)
Sulphide	mg/L	ND < 0.1	APHA 4500-S2-D (2005)
Oil & Grease	mg/L	ND < 0.2	APHA 5520 B (2005)
Ammoniacal Nitrogen	mg/L	0.1	APHA 4500 NH3 B & C (2005)
Colour (ADMI)	ADMI	< 5	APHA 2120 F (2005)

Table 3.2: Standard Methods for Examination of Water and Wastewater Published by American Water Works Association and Water Environment Federation of United States of America (Department of Environment Malaysia, 2009)

3.5 DIRECT MEASURING DEVICE – MAKE-UP FOR COOLING WATER TANK SAMPLE

Reclaimed wastewater quality monitoring and control are taken to ensure the critical parameters were determined to ensure smooth operation of cooling tower and it efficient performance. Hence, reclaimed wastewater were taken at the sampling point where the reclaimed wastewater sample was collected once a week at the sampling point. Total nine critical parameters were monitored such are pH, Conductivity, Total Hardness, Total Calcium Hardness, m-Alkalinity, Free Chlorine, Total Silica, Total Iron and Total Bacteria Count.

Measurement of data sampling for reclaim wastewater's total conductivity used a calibrated direct reading handheld portable instrument (brand Eutech, model name PC450) while reclaimed wastewater for parameters pH, free chlorine, silica, total hardness and total iron were using calibrated direct reading handheld portable instrument (brand Hach, model name DR900 Multiparameter Colorimeter) as illustrated in Figure 3.2.

Eutech PC450

Hach R900 MultiparamaterColorimeter

Figure 3.3: **Portable Handheld Instrument Eutech CON400 and DR900 in Monitoring pH, Total Conductivity, Free Chlorine, Silica and Total Iron**

Measurement of data sampling for reclaimed wastewater's total alkalinity and total calcium hardness was used titration method done in-house lab with approved method proposed by Hach Company/Hach Lange GmbH. Measurement of data sampling for reclaimed wastewater's total bacteria count used Dip Slide comparison chart to compare the bacteria forming unit.

3.5.1 CONDUCTIVITY MEASUREMENT

In this study, Eutech CON400 portable handheld portable meter was used to measure conductivity of the sample Eutech Instrument proposed follow proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.2 pH MEASUREMENT

In this study, Hach DR900 Colorimeter portable handheld portable meter to measure pH range of the sample, Hach company proposed Phenol Red Colorimetric method (method 10076) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.3 FREE CHLORINE MEASUREMENT

In this paper study, Hach DR900 Colorimeter portable handheld portable meter to measure free chlorine concentration of the sample, Hach company proposed DPD (N,N-diethyl-p-phenylenediamine) method (method 10069) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.4 TOTAL SILICA MEASUREMENT

In this paper study, Hach DR900 Colorimeter portable handheld portable meter to measure total silica concentration of the sample, Hach company proposed Silicomolybdate method (method 8185) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.5 TOTAL IRON MEASUREMENT

In this paper study, Hach DR900 Colorimeter portable handheld portable meter to measure total iron concentration of the sample, Hach company proposed FerroVer method (method 8008) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.6 TOTAL HARDNESS MEASUREMENT

In this paper study, Hach DR900 Colorimeter portable handheld portable meter to measure total harness concentration of the sample, Hach company proposed Calmagite method (method 8030) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.7 TOTAL CALCIUM HARDNESS MEASUREMENT

In this paper study, titration method was used to measure total calcium harness concentration of the sample. Hach company proposed Titration with EDTA—Digital Titrator method (method 8329) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.8 TOTAL ALKALINITY MEASUREMENT

In this paper study, titration method was used to measure total alkalinity concentration of the sample. Hach company proposed Titration Buret Titration method (method 8221) on proper instruction or procedures in calibrating, rinsing and measuring as per instruction manual. The weekly sampling result of conductivity was captured and logged in the log book.

3.5.9 TOTAL BACTERIA COUNT MEASUREMENT

In this paper study, quantitative measurement using Dip Slide comparison chart was used to measure total bacteria count concentration of the sample. Proper instruction or procedures in calibrating, rinsing and measuring referring the to Dip Slide comparison chart. The weekly sampling result of conductivity was captured and logged in the log book.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 SAMPLING ANALYSIS

Result of data sampling for all the data collections based on nine concerned parameter as baseline of make-up water tank for cooling water are summarized in Appendix A and all the descriptive summary statistics data is available in Appendix B.

4.1.1 pH

he data collection for parameter pH in the make-up tank for cooling water is shown in Figure 4.1. The proposed recommended baseline for cooling water, the pH in the make-up tank shall within 6.8 to 8.0 as cooling water. Results of data collection for parameter show the minimum and maximum pH detected in the make-up tank for cooling water are 6.8 and 7.3 respectively. The overall mean for pH is 7.03. As discussed in the literature review, good control pH can reduce the corrosivity in the water and prevent of corrosion sign to the cooling tower equipment, pipeline and other accessories. The pH data collection in the make-up tank for cooling water shows the overall performance for parameter pH are met and accepted.

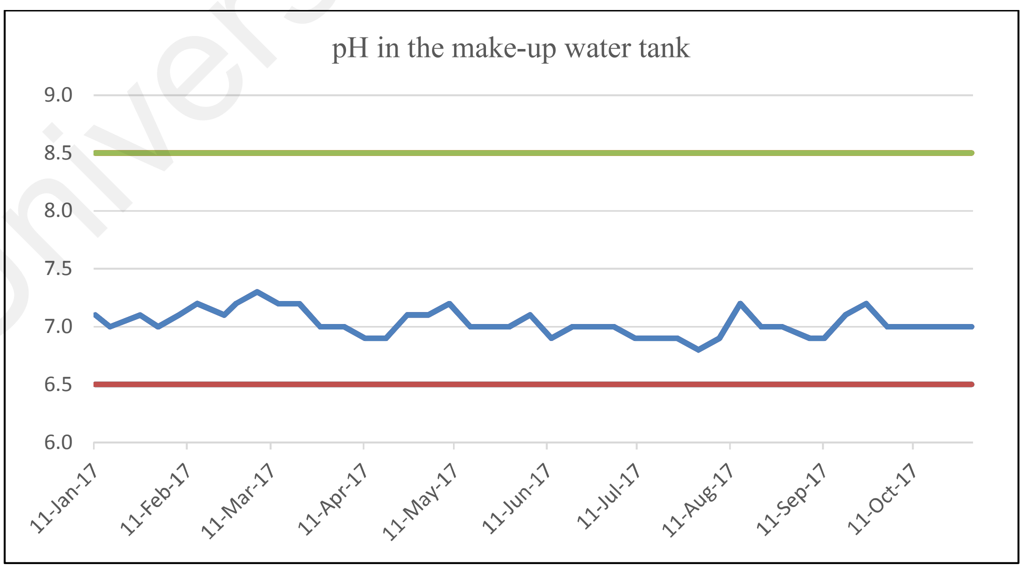

Figure 4.1: Data Collection for pH in Make-up Water Tank

4.1.2 CONDUCTIVITY

The data collection for conductivity in the make-up tank for cooling water is shown in Figure 4.2. The proposed recommended baseline for cooling water, the conductivity in the make-up tank shall be within 50-800 µS/cm as cooling water. Results of data collection for parameter show the minimum and maximum conductivity detected in the make-up tank for cooling water are 68 µS/cm and 91 µS/cm respectively. The overall mean for conductivity is 81.8 µS/cm. As discussed in the literature review, good control conductivity can reduce the scaling to the cooling tower system where too high conductivity in water indicate high dissolved mineral in the water and too low conductivity will cause water usage high as the make-up water to continue add in to achieve the set limit. From the conductivity data collection in the make-up tank for cooling water shows the overall performance for parameter conductivity are met and accepted.

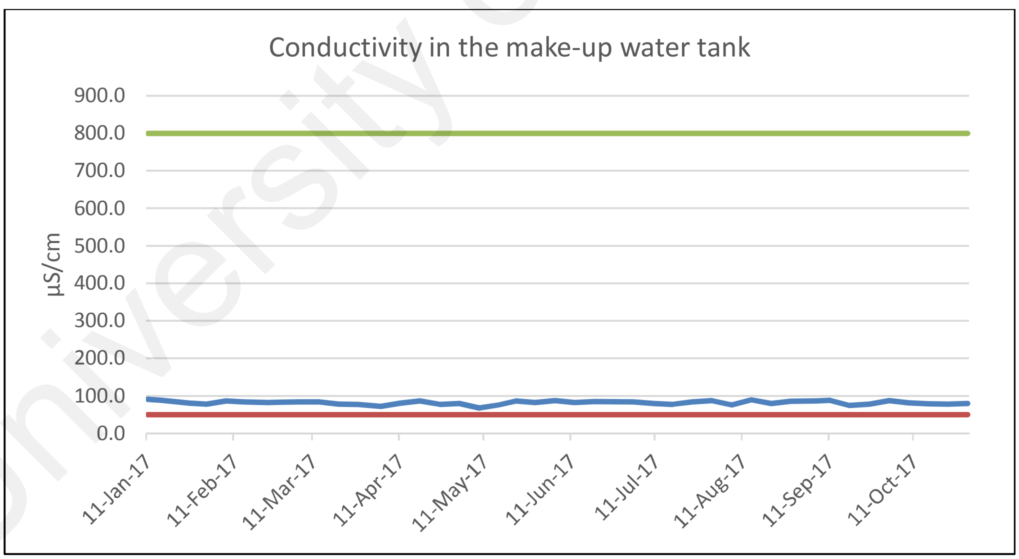

Figure 4.2: Data Collection for Conductivity in Make-up Water Tank

4.1.3 TOTAL HARDNESS

The data collection for parameter total hardness in the make-up tank for cooling water is as shown in Figure 4.1. The proposed recommended baseline for cooling water, the total hardness in the make-up tank shall be within <500 mg/l as $CaCO_3$ as cooling water. Results of data collection for parameter show the minimum and maximum total hardness detected in the make-up tank for cooling water are 20 mg/l as $CaCO_3$and 34 mg/l as $CaCO_3$ respectively. The overall mean for total hardness is 28.7 mg/l as $CaCO_3$. As discussed in the literature review, good control total hardness can reduce the scaling and corrosivity in the cooling tower system where too high total hardness will cause scaling as it contain mineral and low total hardness will cause the corrosion to the cooling tower system. The total hardness data collection in the make-up tank for cooling water shows the overall performance for parameter total hardness are met and accepted.

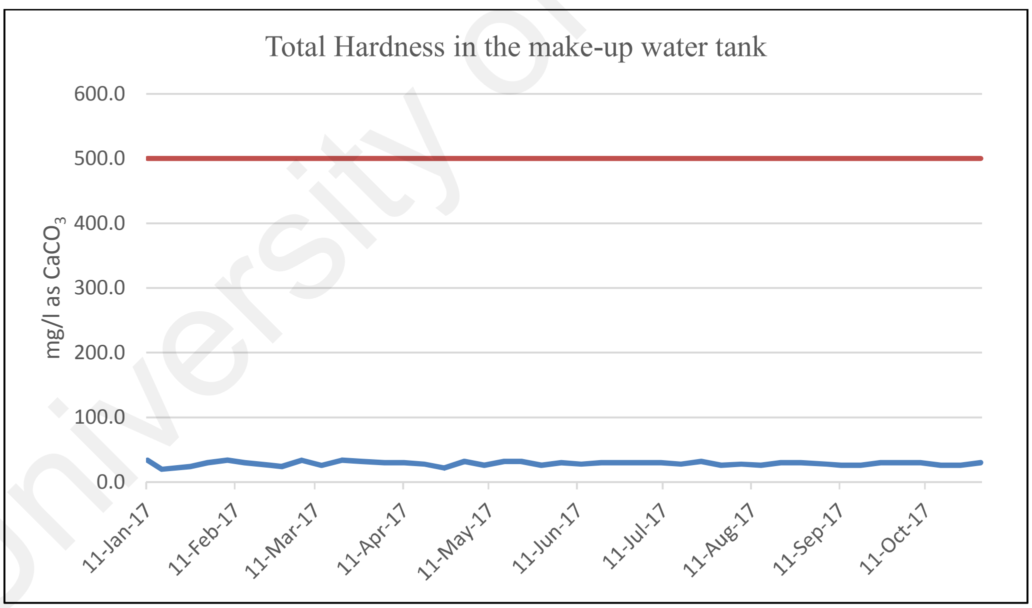

Figure 4.3: Data Collection for Total Hardness in Make-up Water Tank

4.1.4 TOTAL CALCIUM HARDNESS

The data collection for parameter total calcium hardness in the make-up tank for cooling water is as shown in Figure 4.1. The proposed recommended baseline for cooling water, the total calcium hardness in the make-up tank shall be within 15 mg/l as $CaCO_3$ to 1500 mg/l as $CaCO_3$ as cooling water. Results of data collection for parameter show the minimum and maximum pH detected in the make-up tank for cooling water are 18 mg/l as $CaCO_3$ and 30 mg/l as $CaCO_3$ respectively. The overall mean for total calcium hardness is 23.6 mg/l as $CaCO_3$. As discussed in the literature review, good control total calcium hardness can reduce the scaling in the water and prevent of corrosion sign to the cooling tower equipment, pipeline and other accessories where too high total calcium will cause deposit of dissolved calcium and others dissolved mineral in the cooling tower system while too low total calcium hardness will cause corrosivity where low total calcium hardness indicate low pH in the water. The total calcium hardness data collection in the make-up tank for cooling water shows the overall performance for parameter total calcium hardness are met and accepted.

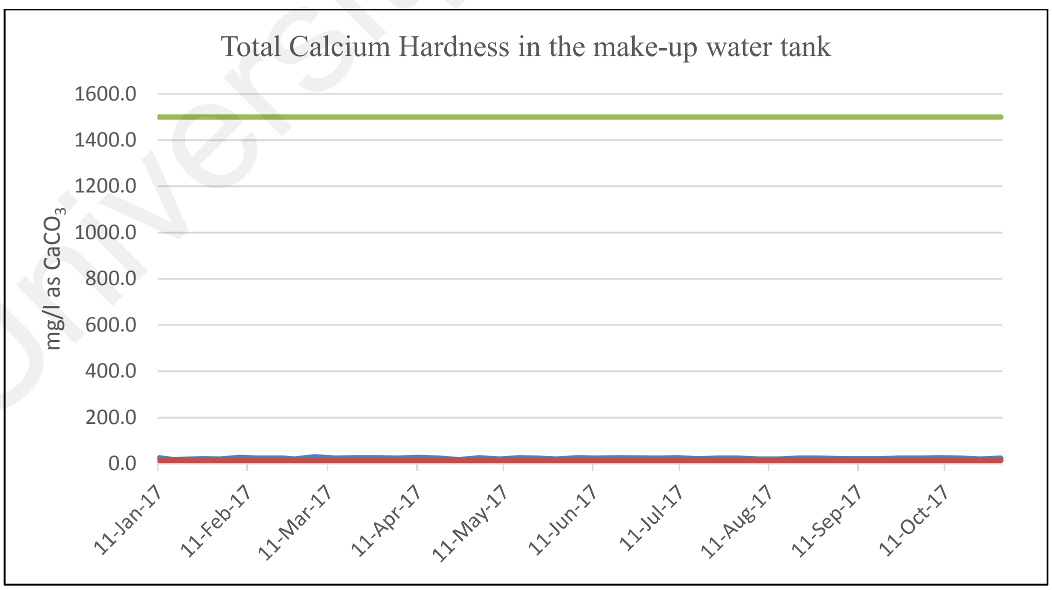

Figure 4.4: Data Collection for Total Calcium Hardness in Make-up Water Tank

4.1.5 TOTAL ALKANILITY

The data collection for parameter total alkalinity in the make-up tank for cooling water is as shown in Figure 4.1. The proposed recommended baseline for cooling water, the total alkalinity in the make-up tank shall be within 15 mg/l as $CaCO_3$ to 200 mg/l as $CaCO_3$ as cooling water. Results of data collection for parameter show the minimum and maximum total alkalinity detected in the make-up tank for cooling water are 10 mg/l as $CaCO_3$ and 28 mg/l as $CaCO_3$ respectively. The overall mean for total alkalinity is 18.6 mg/l as $CaCO_3$. As discussed in the literature review, good control total calcium hardness can reduce the scaling in the water and prevent of corrosion sign in the cooling tower equipment, pipeline and other accessories where too high alkalinity will cause scaling and fouling and too high alkalinity will cause general corrosion to the cooling tower system. The total alkalinity data collection in the make-up tank for cooling water shows the overall performance for parameter total alkalinity are met and accepted.

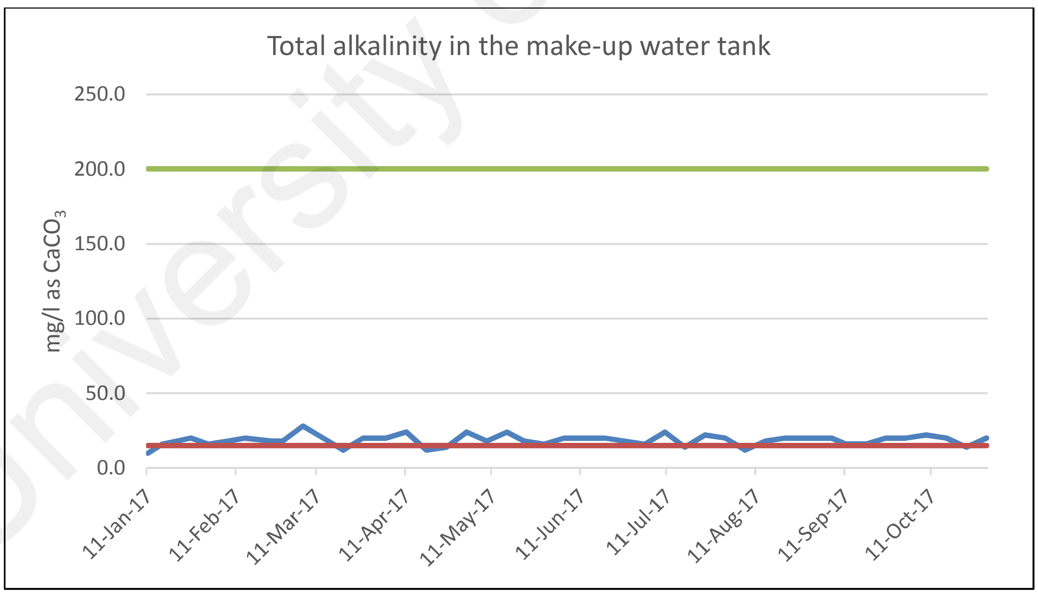

Figure 4.5: Data Collection for Total Alkalinity in Make-up Water Tank

4.1.6 TOTAL FREE CHLORINE

The data collection for parameter total free chlorine in the make-up tank for cooling water is as shown in Figure 4.1. The proposed recommended baseline for cooling water, the total free chlorine in the make-up tank shall be within 0.2 mg/l as Cl to 0.5 mg/l as Cl as cooling water. Results of data collection for parameter show the minimum and maximum total free chlorine detected in the make-up tank for cooling water are 0.02 mg/l as Cl and 0.43 mg/l as Cl respectively. The overall mean for total free chlorine is 0.1 mg/l as Cl. As discussed in the literature review, good control total free chlorine can reduce the corrosivity in the water and prevent of bacteria growth or fouling to the cooling tower equipment, pipeline and other accessories where too high total chlorine will cause corrosion while too low total free chlorine will encourage the growth of bacteria in the cooling water. The total free chlorine data collection in the make-up tank for cooling water shows the overall performance for parameter total free chlorine are partially met and accepted.

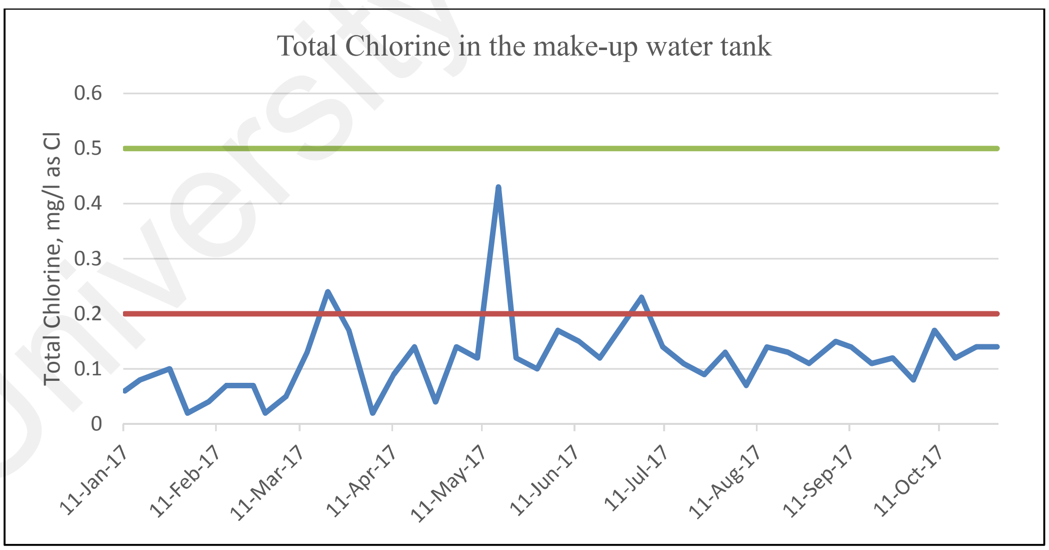

Figure 4.6: Data Collection for Total Free Chlorine in Make-up Water Tank

4.1.7 TOTAL SILICA

The data collection for parameter total silica in the make-up tank for cooling water is as shown in Figure 4.1. The proposed recommended baseline for cooling water, the total silica in the make-up tank shall be within < 150 mg/l as cooling water. Results of data collection for parameter show the minimum and maximum total silica detected in the make-up tank for cooling water are 5 mg/l and 12 mg/l respectively. The overall mean for total silica is 9.5 mg/l. As discussed in the literature review, good control total silica can reduce the scaling to the cooling tower system where too high total silica in water indicate high dissolved mineral in the water and too low total silica will cause water usage high as the make-up water to continue add in to achieve the set limit. The total silica data collection in the make-up tank for cooling water shows the overall performance for parameter total silica are met and accepted.

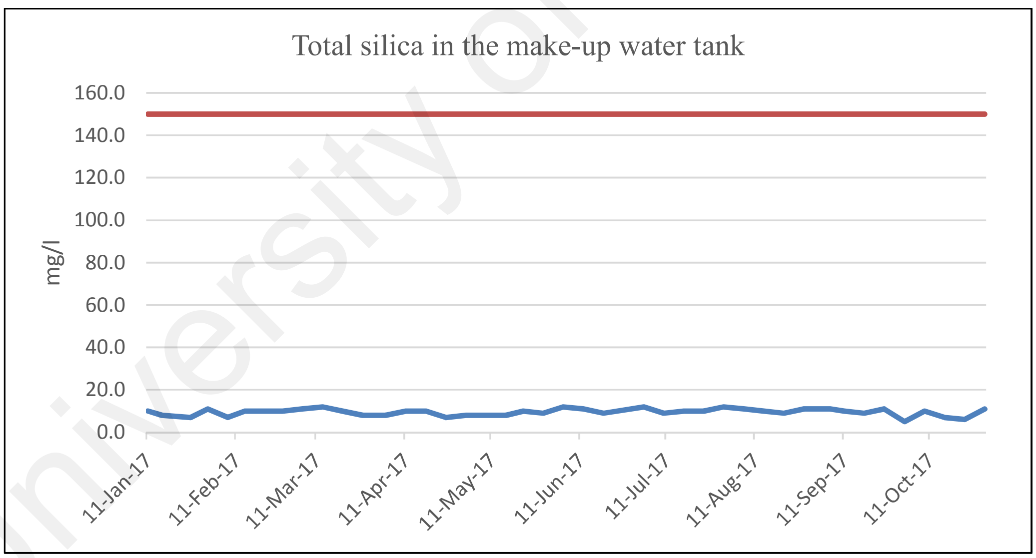

Figure 4.7: Data Collection for Total Silica in Make-up Water Tank

4.1.8 TOTAL BACTERIA COUNT

The data collection for parameter total bacteria count in the make-up tank for cooling water is as shown in Figure 4.1. The proposed recommended baseline for cooling water, the total bacteria count in the make-up tank shall be within <10,000 cfu/ml as cooling water. Results of data collection for parameter show the minimum and maximum total bacteria count detected in the make-up tank for cooling water are 100 cfu/ml and 10,000 cfu/ml respectively. The overall mean for total bacteria count is 8221.4 cfu/ml. As discussed in the literature review, good control total bacteria count can reduce the fouling in the water to the cooling tower equipment, pipeline and other accessories. The total bacteria count data collection in the make-up tank for cooling water shows the overall performance for parameter total bacteria count are partially met and accepted.

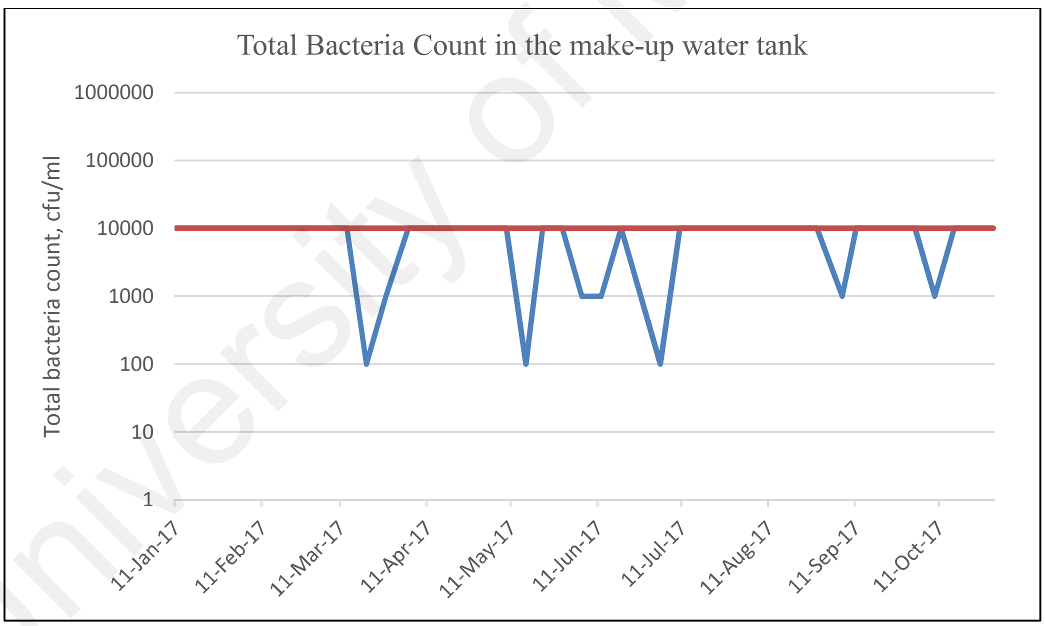

Figure 4.8: Data Collection for Total Bacteria Count in Make-up Water Tank

4.1.9 TOTAL IRON

The data collection for parameter total iron in the make-up tank for cooling water is as shown in Figure 4.1. As in the proposed recommended baseline for cooling water, the total iron in the make-up tank shall be within <8 mg/l as Fe as cooling water. Results of data collection for parameter show the minimum and maximum total iron detected in the make-up tank for cooling water are 0.04 mg/l as Fe and 0.31 mg/l as Fe respectively. The overall mean for total iron is 0.2 mg/l as Fe. As discussed in the literature review, good control total iron can reduce the corrosivity in the water and prevent of corrosion sign of the cooling tower equipment, pipeline and other accessories where high iron in the water indicate the corrosion rate is high to the cooling tower system. The total iron data collection in the make-up tank for cooling water shows the overall performance for parameter total iron are met and accepted.

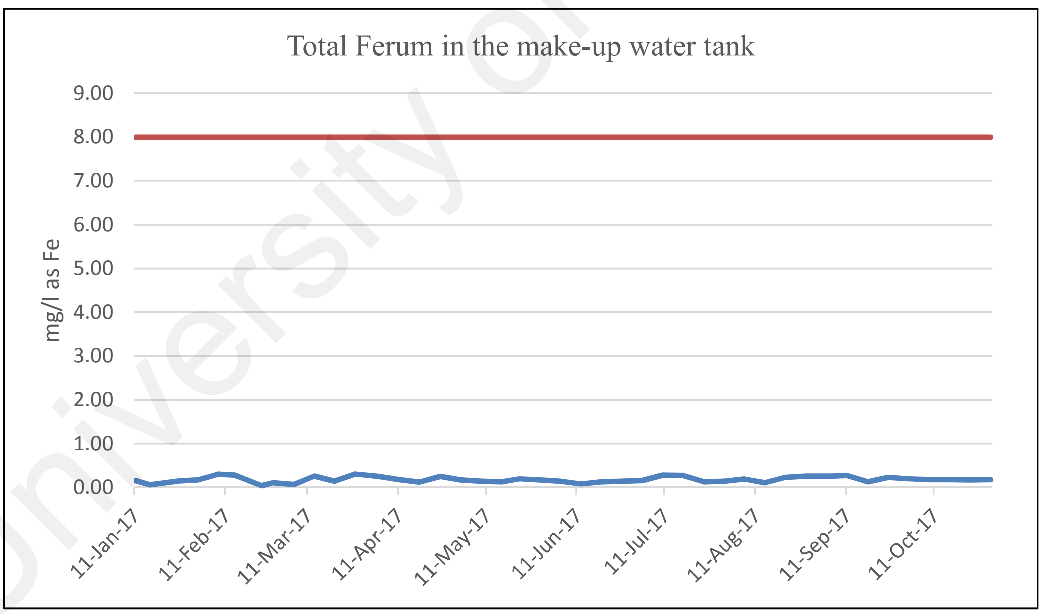

Figure 4.9: Data Collection for Total Iron in Make-up Water Tank

4.2 DISCUSSION

Summary of characteristics and average concentration of major water quality parameters collected from the make-up water tank for cooling water which are the mixture of 30% industry wastewater and 70% incoming raw water are summarized in Table 4.1.

Parameter	Unit	Range	Mean data	Proposed baseline
pH	-	6.8-7.3	7.0	6.8 – 8.0
Conductivity	μS/cm	68-91	81.8	50 – 800*
Total Hardness	mg/l as $CaCO_3$	20-34	28.7	<500*
Calcium Hardness	mg/l as $CaCO_3$	18-30	23.6	15 - 1500
Total Alkalinity	mg/l as $CaCO_3$	10-28	18.6	15 - 200
Free chlorine	mg/l as Cl	0.02-0.43	0.1	0.2 – 0.5
Silica	mg/l	5-12	9.5	< 150*
Total Iron	mg/l as Fe	0.04-0.31	0.2	< 8
Total Bacteria Count	cfu/ml	100-10000	8221.4	<10,000

Table 4.1: Characteristics and average concentration of major water quality parameters collected from the make-up water tank for cooling water

The data collection of samples point in the 30:70 mixing ratio make-up tank for cooling water, pH for was detected in range of 6.8 to 7.3 with mean, 7.0, total alkalinity was detected in range of 68 mg/l as $CaCO_3$ to 91 mg/l as $CaCO_3$ with mean value, 18.6 mg/l as $CaCO_3$ and total iron was detected in range of 0.04 mg/l to 0.31 mg/l with mean 0.2 mg/l as Fe were matched and within the proposed recommend baseline of make-up cooling water. These three quality parameters are important as those parameters are relevant in the corrosiveness control for cooling tower operation. Low pH indicates the environment is in acidic situation where it can cause the corrosion of the pipeline, tubing or the cooling tower system while total alkalinity is proportional with pH where high alkalinity will cause corrosion as same effect with low pH (Choudhury, et al., 2012). Monitoring of total iron is to check overall system corrosion rate. If the total iron content in make-up water tank is high, it indicates the cooling tower system corrosion rate is high and vise versa (Rao, et al., 2000).

Besides that, parameter for conductivity was detected in range of 68-91 μS/cm with mean value, 81.8 μS/cm, silica was detected in range of 5 mg/l to 12 mg/l with mean value, 9.5 mg/l, total hardness was detected in range of 20 mg/l as $CaCO_3$ to 34 mg/l as $CaCO_3$ with mean value, 28.7 mg/l as $CaCO_3$ and total calcium hardness were detected in range of 18 mg/l as $CaCO_3$ to 30 mg/l as $CaCO_3$ with mean value, 23.6 mg/l as $CaCO_3$ respectively were matched and within the proposed recommended baseline of make-up cooling water. These four parameters are important and relevant in the scaling and fouling control as high conductivity represents total dissolved mineral ion is high in the make-up water where the chance of fouling of mineral inside the tubing, pipeline or cooling tower system might happen will be high. Total hardness represents that the dissolved magnesium and calcium in the make-up tank for cooling water while total calcium hardness is indicate the concentration of calcium precipitate (Webb & Li, 2000). Deposition of silica on cooling systems surfaces significantly reduces system performance, cause unscheduled costly shutdowns and chemical or mechanical cleaning operations.

As shown in Table 4.1, total free chlorine was not within the recommended baseline water quality for cooling water. Total free chlorine was detected in range of 0.02 mg/l as Cl to 0.43 mg/l as Cl with mean value 0.1 mg/l as Cl and total bacteria count was detected in range of 100 cfu/ml to 10000 cfu/ml with mean value, 2050 cfu/ml respectively were not matched and was not within proposed recommend baseline of make-up cooling water. Basically, this two parameters monitoring is to reduce the microorganism growth and reduce the bio-fouling where mitigation of biofouling is important as microorganism are very fast in adjust the environment, introduce of adequate free chlorine in the make-up water tank will propagation delay microoganism growth (Kim, et al., 2001). The average for free chlorine is relatively low if compare 0.1 mg/l as Cl to the proposed recommend baseline of make-up cooling water which recommend the ideal range is within 0.2 mg/l as Cl to 0.5 mg/l as Cl. The correlation between total chlorine and total bacteria count is shown in Figure 4.10 where the concentration of free chlorine in the make-up water tank indicate low while the total bacteria count is high and vise-versa as show in Figure 4.10.

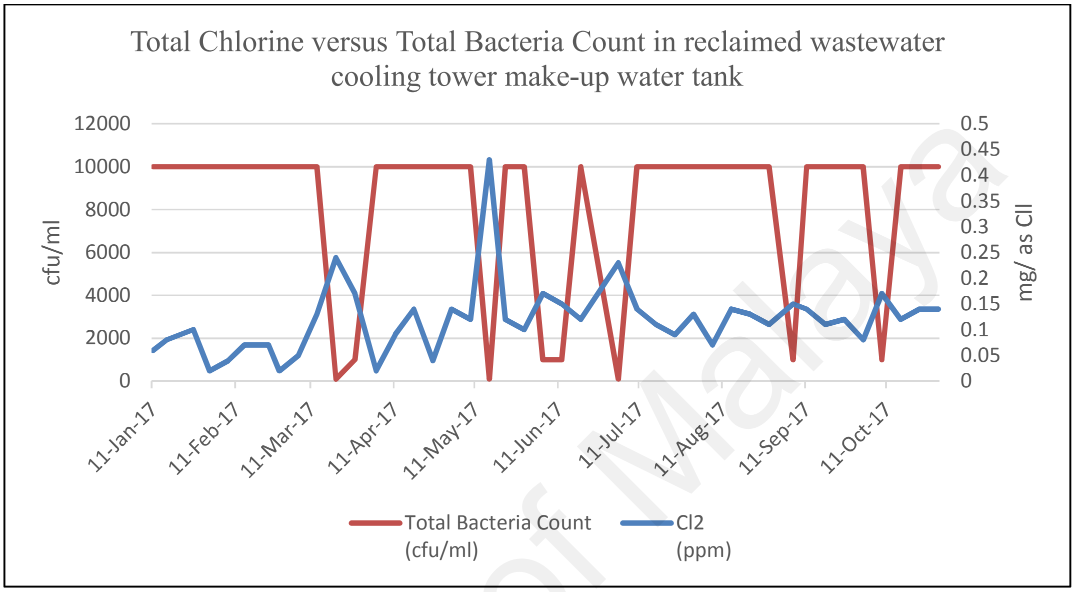

Figure 4.10: Total Chlorine versus Total Bacteria Count in Make-up Water Tank

Although these two parameters are not within the baseline, it can still be used as make-up for cooling water although there is risk and internal control need to be considered. Average the total bacteria count meet the proposed recommend baseline water quality for cooling water, but in the data collection, the total bacteria can increase to the limiting border value. For long term operation with this type of water quality, the biofouling can occurs as growth of bacteria in the cooling tower that might cause hygiene issue such as Legionella disease or any water-borne disease as discussed in Chapter 2. This project then initiate a study, to mitigate the free chlorine and total bacteria count. Biocide tank containing sodium hyperchloride was installed after the collection of industry wastewater shown Figure 3.1. Dosing of sodium hyperchloride will increased the free chlorine concentration in the industry wastewater before channeled to make-up water for cooling water. This relatively will control the bacteria growth by introduce the sodium hyperchloride as chemical treatment in the make-up tank for cooling water.

For total water saving, the output of wastewater discharge of the selected semiconductor plant is about 458 cubic meter / day (m^3pd) and the water tariff for Penang state is as discussed in Figure 1.2 is RM 1.45 / m^3. Estimated the total cost saving for this semiconductor plant is about RM 242k per year.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Through water reclamation and reuse, we can maintain control of the quantity and quality of reclaimed water and prioritize its use (Levine & Asano, 2004). In this study, as discussed in the first objective was achieved where reclamation of industry wastewater as make-up water for cooling water, a proposed recommend baseline of make-up cooling water quality had developed where the make-up water characteristic shall follow pH in range of 6.8-8.0, conductivity in range of 50 mg/l as $CaCO_3$-800 mg/l as $CaCO_3$, total hardness with less than 500 mg/l as $CaCO_3$, total calcium hardness in range of 15 mg/l as $CaCO_3$ to 1500 mg/l as $CaCO_3$, total alkalinity in range of 15 mg/l as $CaCO_3$ to 200 mg/l as $CaCO_3$, free chlorine in range of 0.2 mg/l as Cl to 0.5 mg/l as Cl, silica with less 150 mg/l, total iron with less than 8 mg/l as Fe and total bacteria count with less than 10,000 cfu/ml.

The second proposed objective in this paper is also achieved where reclaimed wastewater had been successfully reused as make-up water for cooling tower system. A mixture of 30:70 ratio of wastewater and raw water proved the water quality meets the first objective where the quality of reclaimed wastewater can be reuse as make-up water for cooling water.

A third objective is also achieved in this study where the plant can save up to 10-30% of water costs when switching from fresh raw water to industry reclaimed wastewater for use in cooling tower. Total reclaimed wastewater saving reached 167,281 cubic meter/year in past one year and cost saving reached about RM 242k per year. This selected semiconductor plant is already operating for 2 years reclaimed wastewater as make-up water for cooling tower system and has proven that this reclaimed activity is economically viable in the solution of prevention of pollution, resources and cost minimization and zero-discharge concept.

5.2 RECOMMENDATION

In this paper study, proposal to establish framework of water reuse legal standard to promote recycling of wastewater shall be implemented especially in Malaysia which there is no any legal framework of reuse water standard or any guideline to reclaim wastewater to various application. Legislation on reclaimed of wastewater is vary from region to region because of financial means, health protection, public acceptance, water scarcity level, legal permit requirements and variety of intended use (Michael-Kordatou, et al., 2015).

Secondly, suggestion to have expertise or skilled workers to handle the recycling wastewater plant where this field still lacks recourse and is dependent on chemical experts in Malaysia. Besides that, there is lack of expertize especially managing in cooling tower management. Selection of supplier based on some knowledge of the chemistry and controls needed will increase the probability of obtaining reliable cooling equipment with maximum heat transfer efficiency at the lowest total cost.

Lastly, government should launch some incentive program or any reward system to be implemented to encourage industry to reuse the wastewater. Water conservation and water reuse produce substantial environmental benefits, arising from reductions in water diversions, reductions in the impacts of wastewater discharges on environmental water quality, reduced demand on the municipal supply and improve water resources such as improve wetlands and water catchment area (Mohsen & Jaber, 2002).

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APPENDIX

APPENDIX A: DATA COLLECTION FROM MAKE-UP WATER TANK FOR COOLING TOWER

	M/up water tank								
Date	pH	Cond (µS/cm)	Total H (ppm)	H (Ca) (ppm)	M (alk) (ppm)	Cl2 (ppm)	Si (ppm)	Total Bacteria Count (cfu/ml)	Fe (ppm)
11-Jan-17	7.1	91.0	34.0	26.0	10.0	0.06	10.0	10000	0.16
16-Jan-17	7.0	88.0	20.0	18.0	16.0	0.08	8.0	10000	0.06
26-Jan-17	7.1	81.0	24.0	22.0	20.0	0.10	7.0	10000	0.15
1-Feb-17	7.0	78.6	30.0	20.0	16.0	0.02	11.0	10000	0.17
8-Feb-17	7.1	86.0	34.0	28.0	18.0	0.04	7.0	10000	0.30
14-Feb-17	7.2	84.0	30.0	24.0	20.0	0.07	10.0	10000	0.28
23-Feb-17	7.1	82.4	26.0	24.0	18.0	0.07	10.0	10000	0.04
27-Feb-17	7.2	83.2	24.0	20.0	18.0	0.02	10.0	10000	0.11
6-Mar-17	7.3	84.0	34.0	30.0	28.0	0.05	11.0	10000	0.07
13-Mar-17	7.2	84.0	26.0	24.0	20.0	0.13	12.0	10000	0.26
20-Mar-17	7.2	78.0	34.0	26.0	12.0	0.24	10.0	100	0.14
27-Mar-17	7.0	77.0	32.0	26.0	20.0	0.17	8.0	1000	0.31
4-Apr-17	7.0	72.0	30.0	24.0	20.0	0.02	8.0	10000	0.25
11-Apr-17	6.9	81.0	30.0	28.0	24.0	0.09	10.0	10000	0.18
18-Apr-17	6.9	86.0	28.0	24.0	12.0	0.14	10.0	10000	0.12
25-Apr-17	7.1	77.5	22.0	18.0	14.0	0.04	7.0	10000	0.25
2-May-17	7.1	80.0	32.0	26.0	24.0	0.14	8.0	10000	0.17
9-May-17	7.2	68.0	26.0	20.0	18.0	0.12	8.0	10000	0.14
16-May-17	7.0	76.0	32.0	26.0	24.0	0.43	8.0	100	0.13
22-May-17	7.0	86.0	32.0	24.0	18.0	0.12	10.0	10000	0.20
29-May-17	7.0	82.3	26.0	20.0	16.0	0.10	9.0	10000	0.17
5-Jun-17	7.1	87.0	30.0	26.0	20.0	0.17	12.0	1000	0.14
12-Jun-17	6.9	82.0	28.0	24.0	20.0	0.15	11.0	1000	0.08
19-Jun-17	7.0	85.0	30.0	26.0	20.0	0.12	9.0	10000	0.13
3-Jul-17	7.0	84.0	30.0	24.0	16.0	0.23	12.0	100	0.16
10-Jul-17	6.9	80.0	30.0	26.0	24.0	0.14	9.0	10000	0.28
17-Jul-17	6.9	77.5	28.0	22.0	14.0	0.11	10.0	10000	0.27
24-Jul-17	6.9	84.0	32.0	24.0	22.0	0.09	10.0	10000	0.13
31-Jul-17	6.8	87.0	26.0	24.0	20.0	0.13	12.0	10000	0.14
7-Aug-17	6.9	76.0	28.0	20.0	12.0	0.07	11.0	10000	0.19
14-Aug-17	7.2	89.3	26.0	20.0	18.0	0.14	10.0	10000	0.11
21-Aug-17	7.0	80.0	30.0	24.0	20.0	0.13	9.0	10000	0.23
28-Aug-17	7.0	85.3	30.0	24.0	20.0	0.11	11.0	10000	0.26
6-Sep-17	6.9	86.0	28.0	22.0	20.0	0.15	11.0	1000	0.26
11-Sep-17	6.9	88.0	26.0	22.0	16.0	0.14	10.0	10000	0.27
18-Sep-17	7.1	74.0	26.0	22.0	16.0	0.11	9.0	10000	0.13
25-Sep-17	7.2	78.0	30.0	24.0	20.0	0.12	11.0	10000	0.23
2-Oct-17	7.0	87.0	30.0	24.0	20.0	0.08	5.0	10000	0.20
9-Oct-17	7.0	81.4	30.0	26.0	22.0	0.17	10.0	1000	0.18
16-Oct-17	7.0	79.0	26.0	24.0	20.0	0.12	7.0	10000	0.18
23-Oct-17	7.0	78.0	26.0	20.0	14.0	0.14	6.0	10000	0.17
30-Oct-17	7.0	80.0	30.0	24.0	20.0	0.14	11.0	10000	0.18

APPENDIX B: STATISCAL SUMMARY FOR EACH MONITORED PARAMETERS

pH	
Mean	7.033333333
Standard Error	0.017598789
Median	7
Mode	7
Standard Deviation	0.11405319
Sample Variance	0.01300813
Kurtosis	-0.48859976
Skewness	0.329889941
Range	0.5
Minimum	6.8
Maximum	7.3
Sum	295.4
Count	42

Conductivity	
Mean	81.77380952
Standard Error	0.750199815
Median	82.15
Mode	84
Standard Deviation	4.861850472
Sample Variance	23.63759001
Kurtosis	0.322691094
Skewness	-0.522319113
Range	23
Minimum	68
Maximum	91
Sum	3434.5
Count	42

Total Hardness	
Mean	28.71428571
Standard Error	0.500041478
Median	30
Mode	30
Standard Deviation	3.240639159
Sample Variance	10.50174216
Kurtosis	0.114688648
Skewness	-0.434921207
Range	14
Minimum	20
Maximum	34
Sum	1206
Count	42

Total Calcium Hardness	
Mean	23.57142857
Standard Error	0.417590646
Median	24
Mode	24
Standard Deviation	2.706296697
Sample Variance	7.324041812
Kurtosis	-0.13374054
Skewness	-0.14808472
Range	12
Minimum	18
Maximum	30
Sum	990
Count	42

Total Alkanility	
Mean	18.57142857
Standard Error	0.575479255
Median	20
Mode	20
Standard Deviation	3.729531829
Sample Variance	13.90940767
Kurtosis	0.311606981
Skewness	-0.131056008
Range	18
Minimum	10
Maximum	28
Sum	780
Count	42

Free Chlorine	
Mean	0.119285714
Standard Error	0.010773741
Median	0.12
Mode	0.14
Standard Deviation	0.069821824
Sample Variance	0.004875087
Kurtosis	8.810074353
Skewness	2.152331419
Range	0.41
Minimum	0.02
Maximum	0.43
Sum	5.01
Count	42

Total Silica	
Mean	9.476190476
Standard Error	0.262300409
Median	10
Mode	10
Standard Deviation	1.699900933
Sample Variance	2.889663182
Kurtosis	-0.07769898
Skewness	-0.61408912
Range	7
Minimum	5
Maximum	12
Sum	398
Count	42

Total Iron	
Mean	0.18047619
Standard Error	0.010514922
Median	0.17
Mode	0.17
Standard Deviation	0.06814448
Sample Variance	0.00464367
Kurtosis	-0.69119335
Skewness	0.088377079
Range	0.27
Minimum	0.04
Maximum	0.31
Sum	7.58
Count	42

Total Bacteria Count	
Mean	8221.428571
Standard Error	573.3992586
Median	10000
Mode	10000
Standard Deviation	3716.051912
Sample Variance	13809041.81
Kurtosis	0.763714938
Skewness	-1.64626321
Range	9900
Minimum	100
Maximum	10000
Sum	345300
Count	42