Technical Reference for Water Conservation in Cooling Towers

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SINGAPORE'S NATIONAL WATER AGENCY

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Preface

In hot and humid Singapore, water-cooled chillers are one of the ways to keep buildings cool for its occupants. The air-conditioning systems rely mostly on wet / evaporative cooling towers (smaller percentage on air cooled towers) that eject heat from the building by evaporating water. Even manufacturing plants and industrial plants adopt these cooling towers to meet the cooling demand of their processes. Although cooling towers are the best available technology to meet cooling demand, competing forces such as drought conditions, growing population and increasing water demand for various uses are diminishing the water availability in Singapore.

Every day a significant amount of energy is also wasted in the form of water and waste heat from air-conditioning and evaporative cooling systems. It is estimated that more than 30 mgd (million gallons per day) of water is used by evaporative cooling towers in Singapore. Reducing that water demand — and saving energy in the process — is a matter of PUB's interest to stem further water losses to the atmosphere and instil water conservation among users.

The aim of this technical guide is to provide cooling tower users, developers, building owners and managing agents with a basic knowledge of cooling tower management, and proper operation and maintenance of these equipment in their premises. By adopting this set of guidelines, PUB hopes to instil discipline and equip users on the technical knowhow for the management of these devises to maximise water savings i.e. optimise the cycles of concentration, while still meeting cooling demands for buildings or industrial processes. The topics covered seek to address concerns on the existing requirements for control of scale, corrosion, deposition and biological fouling associated with the operation of a cooling tower water system. In addition, increased efficiency in the use of energy and control of both makeup water and discharge of residual concentrate will be highlighted as well as health and safety hazards, environmental challenges, and non-chemical systems.

This technical guide should be read in conjunction with the relevant codes of practice and guidelines issued by the National Environment Agency, and the Environmental Public Health (Cooling Towers and Water Fountains) Regulations.

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Terminology

Biocide	A chemical capable of killing or inactivating living microorganisms.
Bleed off (Blowdown)	Water deliberately discharged from a cooling system to control the concentration of dissolved solids.
Cooling tower	Any device in which atmospheric air is passed through sprayed water in order to lower the temperature of the water by evaporative cooling.
Corrosion	An electrochemical process in which metals are oxidized by transferring electrons from an anodic site to a cathodic site.
Corrosion inhibitors	Chemicals that can prevent or slow down the waterside corrosion of metals.
Cycles of concentration	The theoretical number of times water circulates within the cooling system before being discharged via blowdown. This theoretical number can be calculated by various hydraulic and composition means, but should arrive at the same value.
Drift	Water aerosol, which emerges from the airflow outlet of a cooling tower.
Drift eliminator	Any device or physical barriers, designed to minimize the drift emanating from the cooling tower.
Fill	The medium used in cooling towers to increase the surface area of the tower.
Fouling	Organic growth or other deposits on heat transfer surfaces causing loss of efficiency.
Forced Draft Counter Flow	A type of cooling tower that air is forced upward through the water falling from the top of the tower to the basin.
Forced Draft Cross Flow	A type of cooling tower that air is forced across the water falling from the top of the tower to the basin.
Induced Draft Counter Flow	A type of cooling tower that air is drawn or induced in the opposite direction to which the water is falling.
Induced Draft Cross Flow	A type of cooling tower that air is drawn or induced across the water falling from the top of the tower to the basin.
Legionella	A genus of bacterium which is ubiquitous in aqueous environments and found in water systems in the built environment, including cooling systems that are not properly or

	regularly maintained. It comprises numerous species. *Legionella pneumophila* is the most common causative organism of legionnaire's disease.
Makeup water	Water added to cooling tower basin to replace water loss by evaporation, bleed, drift, splash and overflow.
Scale	A hard deposit that is formed on surfaces by the precipitation of mineral particles in water.
Scale inhibitor	Chemicals that prevent scale formation by dispersing the scale forming minerals or modifying the crystal structure of scale.
Splash out	Water leaving the tower via the air intakes and other openings in the tower casing.
Variable speed drive	A way of controlling the speed of a motor, usually electronically using an inverter. The speed can be varied manually, but is more often controlled via a signal from the process, e.g. pressure, flow, level, etc.
Windage	Loss of water from the base of a cooling tower caused by wind of unusual pattern passing through it.

Part 1 General Introduction of Cooling Towers

1.1. Overview

1.1.1. Cooling towers are an integral component of many air-conditioning and refrigeration systems, which function to remove heat through evaporation of water. Wet / evaporative cooling towers are commonly used to provide thermal comfort for large commercial buildings and process cooling for industries such as oil refining, chemical processing, power plants, and many different manufacturing processes.

1.1.2. Cooling towers are engineered and designed based on a specified cooling load, expressed in refrigeration tons[1]. The cooling load is determined by the amount of heat that needs to be extracted from a given process or peak comfort cooling demand. The cooling tower must be adequately sized to reject this same amount of heat to the atmosphere.

1.1.3. A typical cooling tower system consists of cooling tower, chiller condenser/ heat exchanger, water pump, water treatment equipment, makeup water tank, bleed-off and drainage, pipework and fittings, metering devices, etc.

1.2. Cooling Tower Types

1.2.1. Cooling towers can be classified into *natural draft* cooling towers and *mechanical draft* cooling towers.

1.2.2. Based on components' configuration and air draft mechanisms, there are four types of mechanical draft cooling towers: induced draft counter flow, induced draft cross flow, forced draft counter flow, and forced draft cross flow.

[1] One ton of refrigeration is equal to 12,000 Btu/hour.

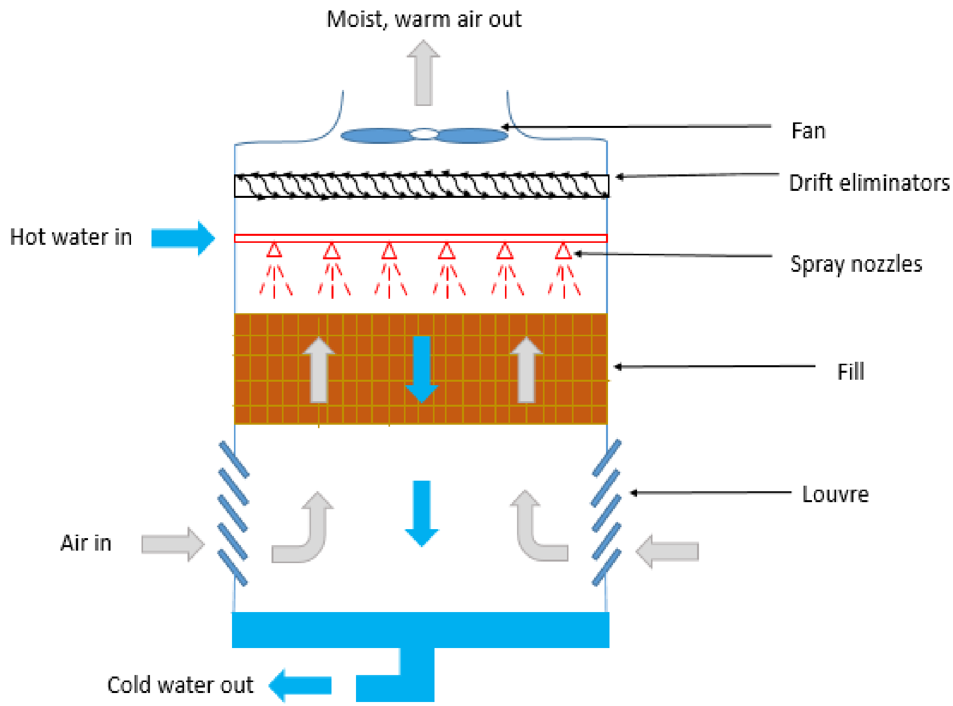


Figure 1. Induced draft counter flow cooling tower

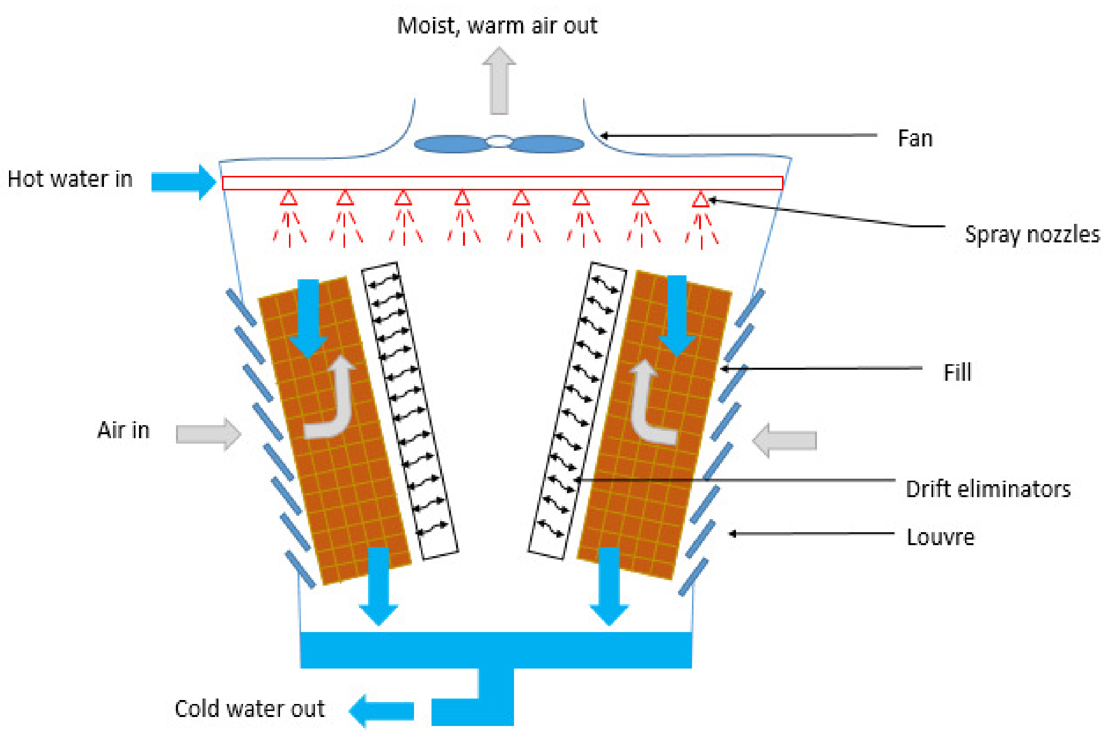


Figure 2. Induced draft cross flow cooling tower

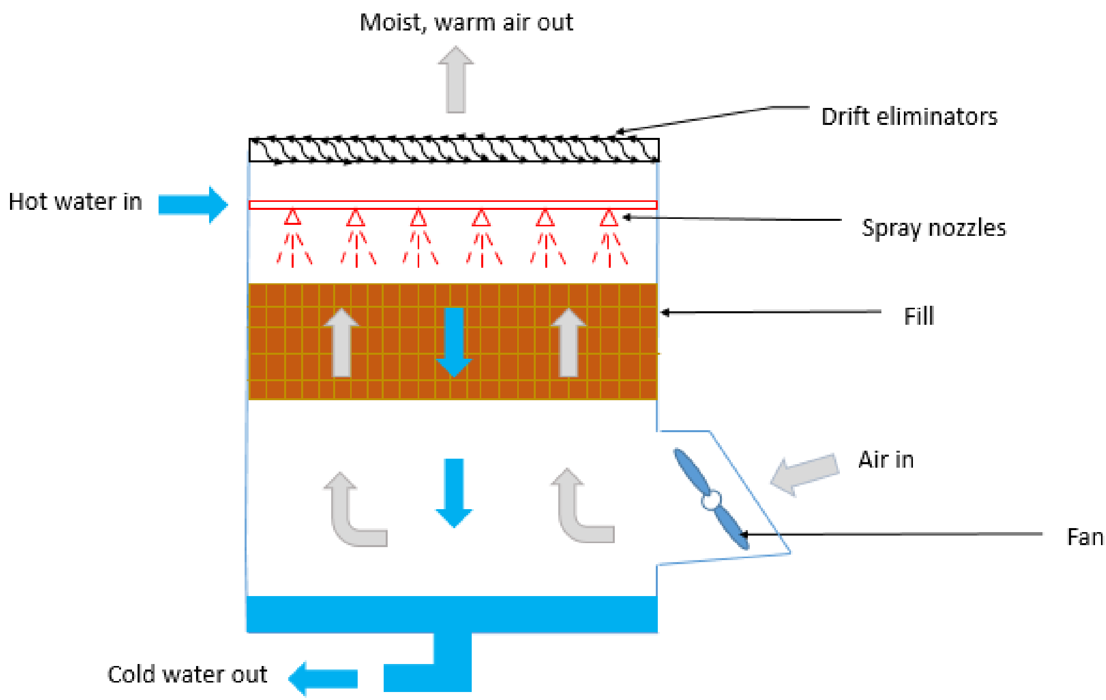


Figure 3. Forced draft counter flow cooling tower

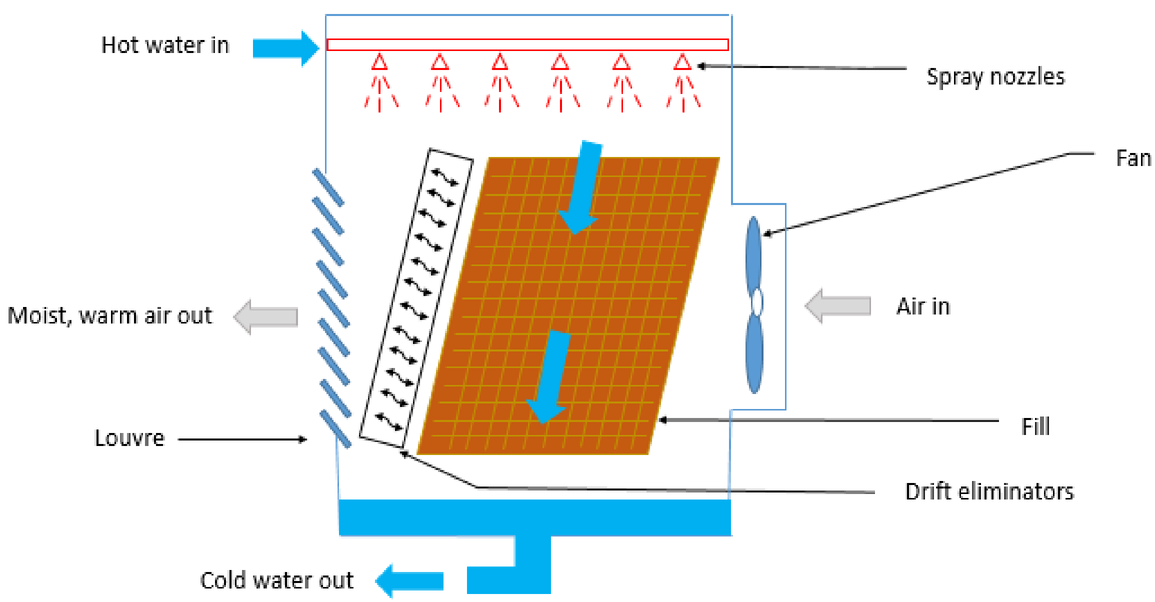


Figure 4. Forced draft cross flow cooling tower

1.2.3. Majority of the cooling towers installed in Singapore are induced draft cross flow cooling towers.

Typical water requirement of cooling systems is around 0.5 to 4 $m^3/h/MW_{th}$.

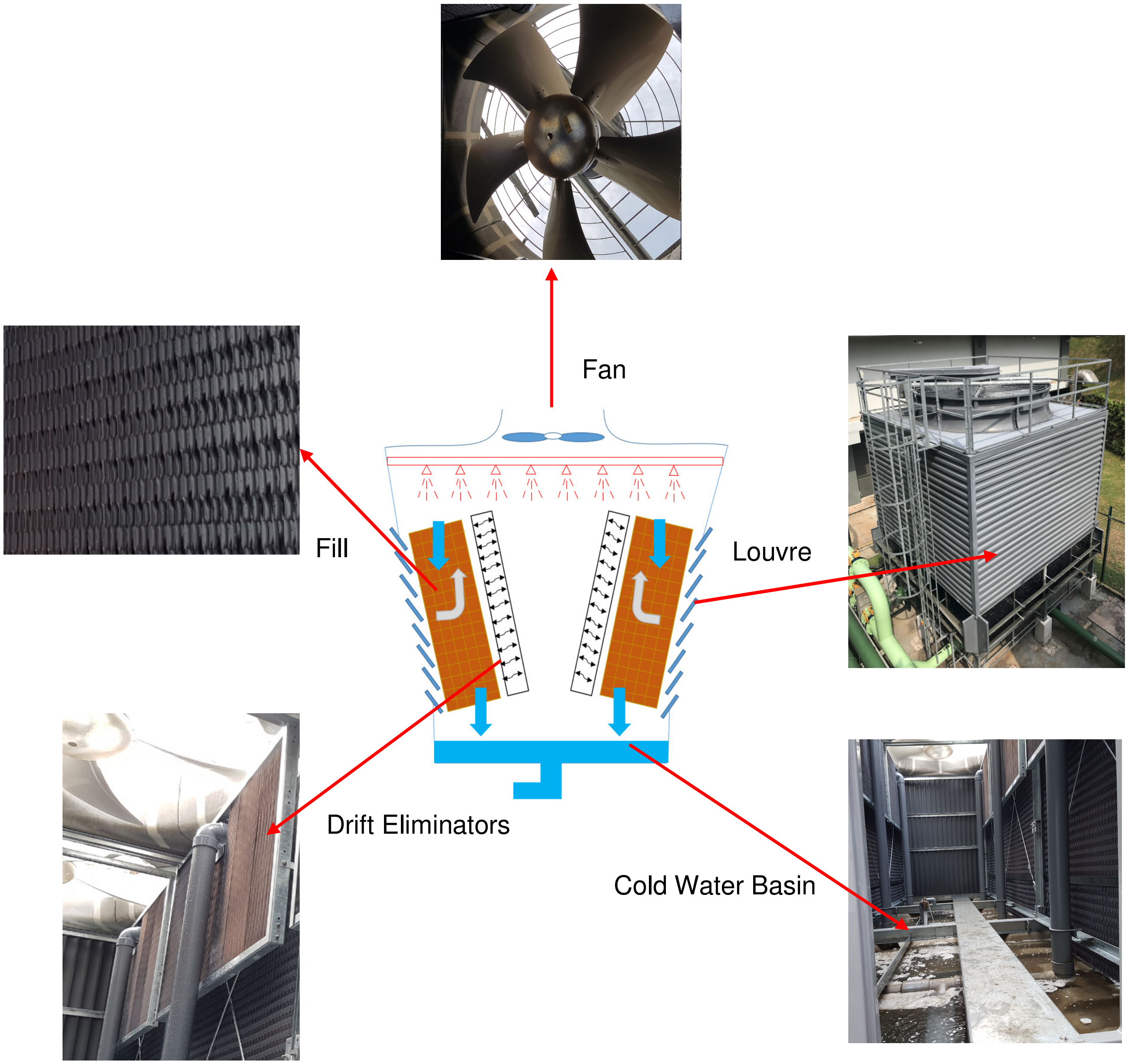


Figure 5. Photos of cooling tower components

1.3. Guidelines and Regulatory Requirements of Cooling Towers

1.3.1. For guidelines and regulatory requirements relating to design, construction (including location), operation and maintenance of cooling towers, please refer to the following documents:

(a) Environmental Public Health (Cooling Towers and Water Fountains) Regulations - a copy of the document is available from the website:

http://sso.agc.gov.sg/

(b) National Environment Agency's "Code of Practice for the Control of Legionella Bacteria in Cooling Towers" - a copy of the document is available from the website:

http://www.nea.gov.sg/

(c) Circular - Environmental Health Measures for Swimming Pools and Cooling Towers - a copy of the document is available from the website:

http://www.nea.gov.sg/

1.3.2. For new buildings, the Building and Construction Authority (BCA) Green Mark Scheme Standard sets out the requirement for assessing efficiency of the entire cooling system, including cooling tower of a building development. Green Mark Score will be awarded for adoption of cooling tower water treatment system with cycles of concentration (COC) of 7 cycles or more. A copy of the document is available from the website:

https://www.bca.gov.sg/

Part 2 Water Use and Conservation

2.1. Understand the water balance and consumption

2.1.1. A basic understanding of the system water distribution shall be established in order to properly operate and maintain a cooling tower on a water efficient manner. The water balance of the tower and efficiency of the chiller for buildings shall be examined to optimise the water efficiency.

2.1.2. The water balance of a tower involves all of the water inputs and outputs associated with the operation of the system. Water outputs include controlled losses such as evaporation, bleed, and drift and pump gland leakage and uncontrolled losses including leaks, splash out, overflows and windage. All of these losses are replaced by makeup water from the system water supply, and in very small amount, by any rainwater that may ether the cooling tower from the air outlet opening. More details on the water balance can be found in **Annex A**.

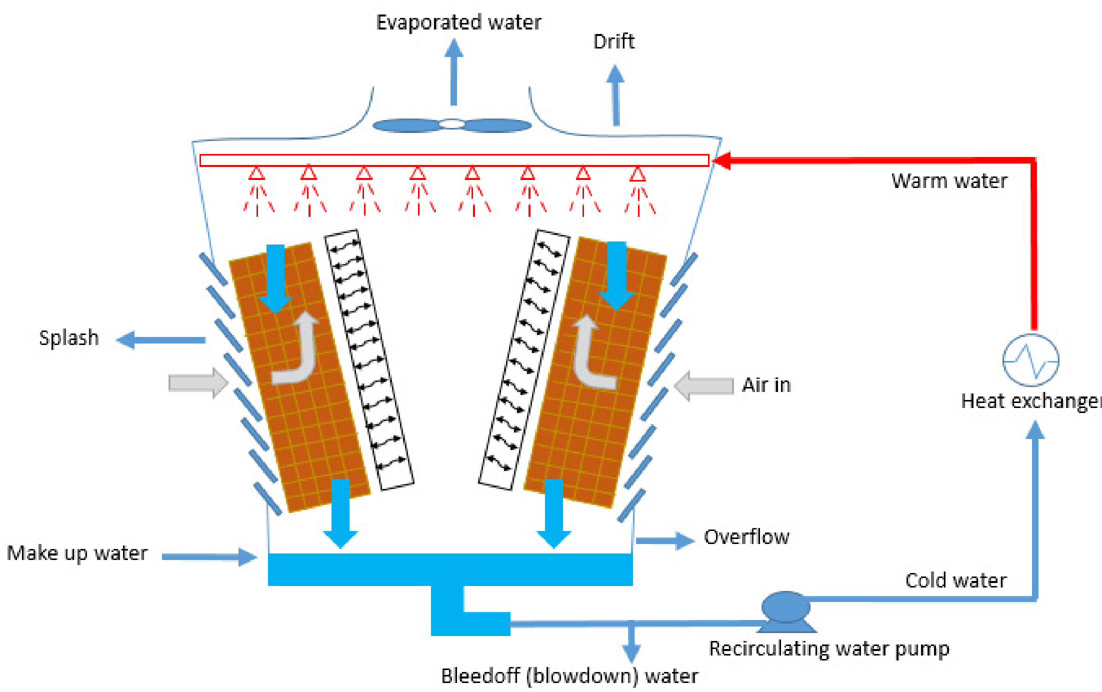


Figure 6. Schematic of water balance in a cooling tower

2.1.3. Evaporation can be reduced by reducing the cooling load, optimising the system operation, and upgrading or redesigning the system. Alternative designs include dry cooling towers, indirect cooling towers, hybrid cooling towers, evaporative condensers or alternative cooling systems.

2.1.4. Bleed volume can be reduced by optimising the Cycles of Concentration (COC), improving the control of the bleed system, maintaining and protecting the bleed valve, maintaining and calibrating the conductivity sensor.

2.1.5. The volume of water saved by increasing the COC can be estimated by the equation

$$V = M \times \left((C2 - C1)/\left(C1 \times (C2 - 1)\right)\right)$$

Where
V = Volume of water saved
M = Initial makeup water volume
C1 = Initial COC number
C2 = Final COC number

Note: the equation does not apply to soft water with low scaling potential
The magnitude of the water savings achievable diminishes with increasing COC, as shown in the Table 1.

Table 1. Water savings achievable at increasing COC

	New COC										
Initial COC		3	4	5	6	7	8	9	10	15	20
	2.0	25%	33%	38%	40%	42%	43%	44%	45%	46%	47%
	3.0	-	11%	17%	20%	22%	24%	25%	26%	29%	30%
	4.0	-	-	6%	10%	13%	14%	16%	17%	20%	21%
	5.0	-	-	-	4%	7%	9%	10%	11%	14%	16%
	6.0	-	-	-	-	3%	5%	6%	7%	11%	12%

2.1.6. COC can have a direct effect on the corrosion/scaling potential of the circulating water. Appropriate materials of construction for the cooling tower with appropriate water treatment methods shall be selected in order to achieve higher COC. More details on water treatment methods are explained in section 2.3.

2.1.7. Drift can be reduced by:
(a) Installing high efficiency drift eliminators;
(b) Checking that drift eliminators are installed correctly throughout the entire section of the air outlet according to supplier's specifications and are not damaged, fouled or blocked;
(c) Checking that the air flow rates are within acceptable manufacturer limits;
(d) Checking that the tower water pressure and flow rate is within the recommended range of manufacturer's specifications;
(e) Using variable frequency drive (VFD);
(f) Protecting the tower from excessive ambient winds.

2.1.8. Pump gland leakage can be reduced by regular pump maintenance and replacing glands with mechanical seals.

2.1.9. Water meter and consumption levels shall be checked regularly to detect changes in usage patterns to minimise leaks.

2.1.10. Splash out can be reduced by:

(a) Installing anti-splash louvres on the tower air intakes;
(b) Checking that anti-splash louvres are installed correctly according to supplier's specifications and are not damaged;
(c) Installing a splash deck above the cold water basin;
(d) Ensuring the water supply pressure is within the manufacturers' limits;
(e) Ensuring that the fan speed and airflow rates are within the manufacturers' limits

2.1.11. Overflow events shall be prevented by:

(a) Checking that the float valve on the makeup line can close preventing uncontrolled inflow;
(b) Checking that the overflow pipe is installed at the correct level and is not leaking;
(c) Checking that water is not being blown out of the overflow pipe during normal operation;
(d) Checking that tower water distribution piping is not oversized or overdesigned with appropriate length
(e) Checking that the operating water levels in multiple tower / cold water basins are equal;
(f) Checking and adjusting the makeup valve setting to ensure overflows do not occur on system shut down.

2.2. Water Efficiency Audits and Reporting

2.2.1. A water audit shall be conducted to optimise the water efficiency of the system. Areas of water use and potential water savings are identified through the audit. The water saving checklist can be found in **Annex B**.

2.2.2. The following items shall be assessed prior to the audit for the first time:

(a) The system used to control the cooling tower blowdown;
(b) The system applied for capacity control of the cooling tower;
(c) The placement and operation of suitable water meters on the cooling tower makeup and bleed lines;
(d) The maximum COC at which the system can operate efficiently.

2.2.3. The results of a water efficiency audit shall be reported.

2.3. Water Quality and Chemical Treatment

2.3.1. Regular monitoring of specific water quality parameters in accordance with the audit checklist shall be performed to identify out-of-range conditions within the system and to optimise water consumption.

2.3.2. The water treatment regime shall prevent or adequately inhibit corrosion, scaling formation and microbial fouling in the system.

Corrosion control

2.3.3. Some of the important factors that contribute to corrosion in cooling water include:

(a) pH level (galvanised steel is susceptible to corrosion with pH levels below 6.5 or above 8.5);
(b) High water conductivity (the upper limit differs according to the type of materials of cooling tower system);
(c) High flow rates (linear velocity should be 1-3m/s);
(d) Ammonia concentration (corrosive to copper alloys as low as 0.3 ppm);
(e) Chloride concentration (a chloride limit of 300 ppm is often used for stainless steel, but limits for other metals may go as high as 1,800 ppm such as for mild steel and carbon steel);
(f) Biofouling, caused by formation of biofilms by micro-organism in the cooling water, may produce acids that are corrosive to metals; and
(g) Poor control of microbiological growth in the system, which promote corrosion of metals and alloys.

Table 2. Corrosion factors for different types of materials

Cooling Tower Materials	Corrosion Factors
Stainless steel	Chloride, sulfate
Galvanized steel	High pH, oxidant, chloride
Copper	Oxidant, ammonia

2.3.4. Monitoring of corrosion shall be in place to ensure corrosion control measures adopted are effective and also detect any abnormal conditions instantaneously.

2.3.5. Corrosion coupon monitor corrosion by a metal coupon of same metallurgy of the system. The coupon shall be placed at a location with continuous and stable water flow.

2.3.6. Corrosion rate meters (corrosometer) is another way of monitoring of corrosion rate. In general, they are classified into two categories namely electrical resistance method and linear polarization methods. The advantage of corrosion rate meter includes measurement of real-time corrosion rates and thus abnormalities can be detected immediately. Incorporating recording devices with the meter enables the retrieval of historical trend of corrosion levels within the cooling water, making diagnosis of causes easier.

Scaling control

2.3.7. Magnesium or calcium carbonates and bicarbonates are the most common types of scale forming salts in cooling water system. Important factors that contribute to formation of scales are:

(a) Low flow rates (linear velocity should be 1-3 m/s);
(b) High water surface temperature (some compounds have inverse solubility above 60℃);

(c) High water hardness (above 400ppm $CaCO_3$); and
(d) Unacceptable level of silica (above 120 ppm) in cooling water, which may form silica scales.

2.3.8. Chemical scale inhibitors delay the rate of precipitation of growing crystalised structure by means of adsorption, blocking the surface of the structure and restricting further growth. Similar to corrosion inhibitors, combination of scale inhibitors will enhance the efficiency of scale removal in cooling water.

2.3.9. Addition of acid to reduce the pH / alkalinity is an easy way to minimise scaling potential for some of the scale forming salts. However, the effect of scale control by creating an acidic environment is compromised by its potential to promote substantial increase in corrosivity. Therefore, proper pH control is essential to inhibit corrosion and scaling at the same time.

2.3.10. Other factors that shall be taken into consideration during selection of appropriate scale control treatment are:
(a) Compatibility of chemicals and treatment technologies selected shall be evaluated beforehand if more than one method / chemical are used concurrently;
(b) Water chemistry of cooling water shall be assessed and monitored regularly to determine the ideal scale control program

Microbial control

2.3.11. Potential sources of micro-organisms in cooling water include micro-organisms scrubbed from the ambient air in open recirculating system as well as those in the makeup water. Common types of micro-organisms that inhabit cooling water are algae, fungi, protozoa and bacteria.

2.3.12. Rapid growth of micro-organisms within the recirculation water will bring about the formation of biofilms and slimes, which trap particles / foulants and eventually lead to microbial fouling and within the system. Other factors that are favourable for microbial growth include:
(a) Presence of sunlight;
(b) Concentration of nutrients in cooling water at high COC;
(c) Elevated dissolved oxygen concentration in cooling water;
(d) Process leak within the cooling system.

2.3.13. Some of the oxidising biocides that commonly used for microbial control are shown in the Table 3.

Table 3. Commonly used oxidising biocides

Oxidising Biocides	Descriptions
Chlorine	Most widely used biocides, usually dosed as sodium hypochlorite or chlorine gas, Advantages: i) Chlorine residual protects the water against risk of microbial attack after treatment and also provides a measure of effectiveness ii) Effective against a wide range of microorganisms iii) One of the most cost effective methods for microbial control iv) Concentration can be readily measured Disadvantages: i) Less effective in alkaline environment (pH 8 and above) and requires constant dosing; Most forms of chlorine are volatile and pose safety concerns ii) Degrades in the presence of sunlight iii) Highly corrosive and some of the by-products are potentially harmful to the environment and humans
Ozone	One of the strongest oxidizing agents, destroy microorganisms on contact by cellular lysis. Advantages: i) About 100-300 times more effective than chlorine as biocide ii) Odourless iii) Effective against most micro-organisms Disadvantages i) High capital and maintenance cost for Ozone generator and absorber compared to chlorine ii) Highly corrosive and unstable iii) Not effective in turbid water or water with high level of hardness iv) No residual effect
Chlorine Dioxide	ClO_2 is a selective oxidizer and as a dissolved gas, which can penetrate biofilms to act directly on causative bacteria and is effective at killing bacteria. Advantages: i) Slow bacterial recovery after disinfection (Chlorite ion)

	ii) Disinfection less dependent on pH (Stability & Economy) iii) Significantly lower corrosion rate compared to chlorine iv) More efficient treatment for macrofouling (algae, mussels) Disadvantages: i) Bigger footprint ii) High cost iii) Safety concern over onsite generation of gas
Electrochlorination	Electrochlorination produces sodium hypochlorite by introducing an electrical current into water containing salt. Advantages: i) Generate fresh hypochlorite ii) Less hazardous chemical handling iii) Provide similar or equivalent disinfection efficacy against micro-organisms. Disadvantages: i) High capital investment compared to chlorine ii) High maintenance cost and power consumption compared to chlorine

2.3.14. Operators shall ensure sufficient concentration and adequate reaction time to ensure effectiveness of non-oxidising biocides. It is also recommended to adopt combination of different types of non-oxidising biocides as well as alternating biocide regime to achieve desired disinfection results.

2.3.15. Other factors that shall be taken into consideration for microbial fouling controls are:
(a) Transfer, storage and dosing of volatile chemicals for microbial treatment must be performed in proper and safe manners to ensure no environmental impact as well as no safety risk posed;
(b) Types of micro-organisms that present in cooling water shall be analysed to determine most suitable / effective microbial treatment methods.

2.4. Non-chemical Treatment

2.4.1. Filtration may be employed to reduce suspended solids in cooling water. The decision to use filters and the selection of the type and configuration of the filtration system will depend on:
(a) The quality of makeup water being added to the system;
(b) The type of contaminants getting into the system;
(c) The type of contaminants being generated within the system;
(d) The type of water treatment being applied;
(e) The COC at which the system is being operated.

2.4.2. Scale control can be achieved by applying electromagnetic waves to stimulate collision of positive and negative dissolved ions that eventually lead to precipitation of ions in the pipework. A filtration system is necessary for removal of precipitation formed during electromagnetic descaling. Compatibility of electromagnetic devices should also be assessed before their use.

2.4.3. Ultraviolet disinfection can be applied as a physical treatment method for microbial fouling prevention. Filter shall be installed at upstream to remove undesirable particles that may obstruct the passage of UV light in the disinfection unit. Routine maintenance and cleaning shall be performed to ensure the performance of the lamps has not deteriorated as well as to remove substances that deposit on the surface of the lamps. Advantages of UV disinfection include:

(a) No chemical required;
(b) Minimal maintenance required;
(c) Lower operating costs compared to chemical disinfectant;
(d) Effective on a wide range of bacteria; and
(e) Continuous operation.

Disadvantages of UV disinfection include:

(a) Insufficient dosages may not effectively inactivate some viruses, spores, and cysts;
(b) Organisms can sometimes repair and reverse the destructive effects of UV through a “repair mechanism,” known as photoreactivation;
(c) A preventive maintenance programme is necessary to control fouling of the tubes;
(d) Turbidity and total suspended solids (TSS) in the wastewater can render UV disinfection ineffective. UV disinfection with low-pressure lamps is not as effective for secondary effluent with TSS levels above 30 mg/L; and
(e) There is no measurable residual to indicate the efficacy of UV disinfection.

2.4.4. Selection of appropriate treatment systems shall be made in conjunction with a specialist supplier or manufacturer and shall be done in consultation with the water treatment service provider.

2.5. Operation and Maintenance

Meters

2.5.1. Water consumption of cooling tower shall be monitored closely by installing water meters at makeup water line and bleed-off line. Under Part IVA of the Public Utilities (Water Supply) Regulations, it is mandatory for premises with annual consumption of 60,000 m^3 or above to install private water meters at cooling tower makeup water line.

2.5.2. Operators shall ensure meters with the correct specifications are installed for accurate measurement of water consumption. Operators shall also ensure water meters are installed at proper locations to capture all the incoming makeup water supply and outgoing blowdown quantity. For bleed off quantity monitoring, meters shall be placed at high pressure side of the system, a filter or strainer shall also be placed in front of the meters.

2.5.3. Read conductivity and flow meters regularly. Check the ratio of makeup flow to blowdown flow and check the ratio of conductivity of blowdown water and the makeup water. These ratios should match the target COC. If both ratios are not about the same, check the tower for leaks or other unauthorized draw-off. If the system is not operating at, or near, the target COC, check the system components including conductivity controller, makeup water fill valve, and blowdown valve.

Monitoring

2.5.4. For more effective water consumption monitoring, it is recommended to install meters with sensoring device. Sensors shall also be integrated with SCADA or BMS (Building Management System) to allow continuous data transmission and real time monitoring continuous data transmission. In addition, such system will also provide information on history water consumption patterns, facilitating identification of abnormalities.

2.5.5. Regular manual logging of water consumption and conductivity data of cooling water system shall be performed for those premises without remote metering system. The data shall also be checked and analysed by a competent person to evaluate performance of the system as well as identify potential problems.

System efficiency optimisation

2.5.6. Optimising system efficiency of cooling system operation can bring about not only reduction in energy usage but also water consumption. The following approaches shall be adopted to improve system efficiency:

(a) Cooling Loads Reduction
The design of cooling loads is often based on highest outdoor air wet bulb temperature of the year. System designers and operators shall re-assess operation setting from time to time by taking into consideration factors such as ambient wet-bulb temperature, heat transmission and solar radiation within the cooling system and the premises. Leaving water temperature of the tower shall be controlled to maintain at the coolest possible temperature.

(b) Variable Speed Drive
Energy consumption can be significantly reduced by using variable speed drive fans for tower airflow control. The fan speed varies in accordance to the actual cooling load of the system and thus chiller operation efficiency can be optimised. Variable feed drive pumps can also bring about energy consumption reduction.

(c) Water Efficient Design
High efficiency drift eliminators, anti-splash louvres or splash mats shall be installed to reduce drift loss, water splashing and the effect of windage.

<u>Maintenance</u>

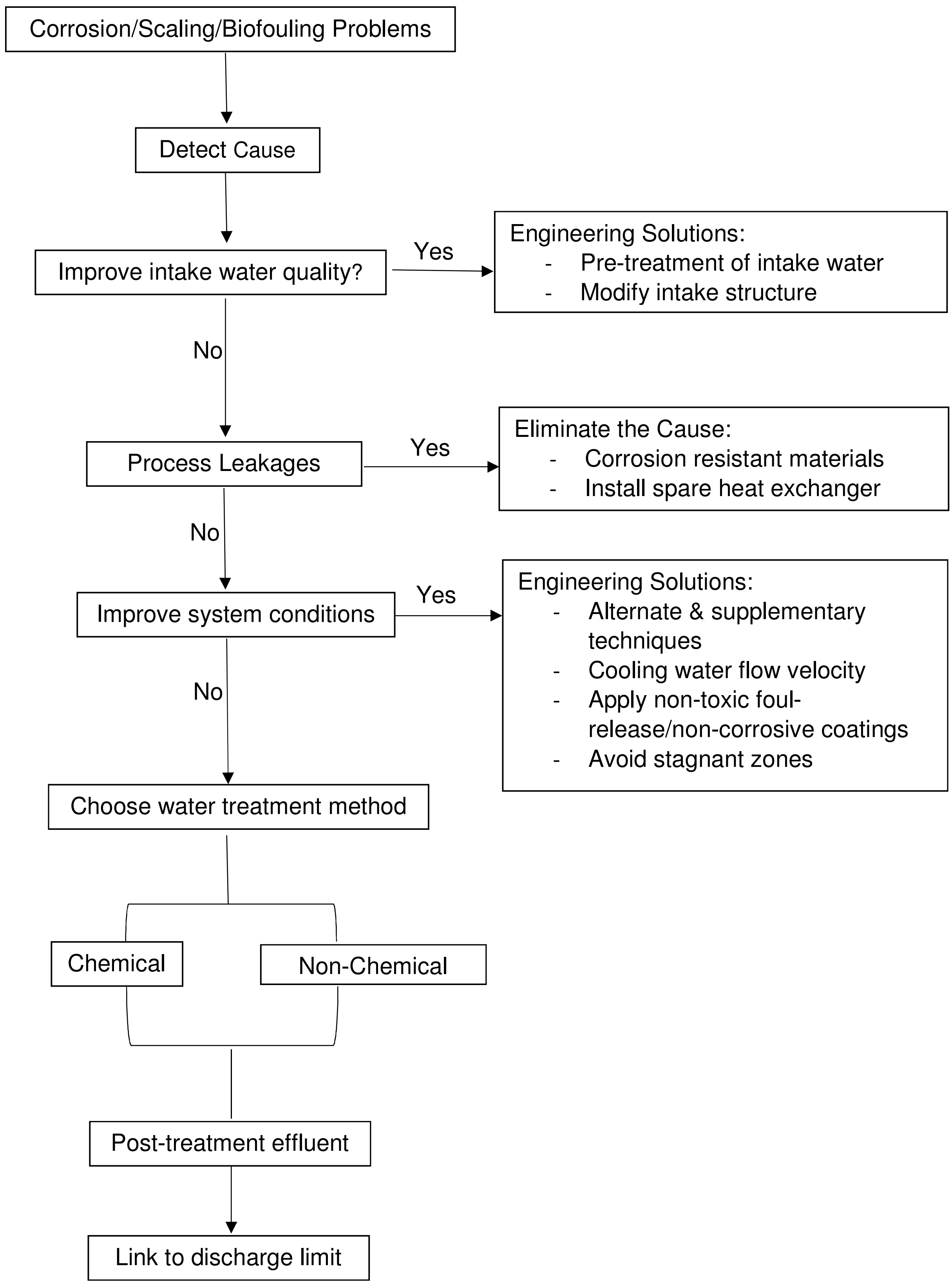
2.5.7. Maintenance of cooling tower shall be performed on a regular basis e.g. once a month by specialist contractor or competent operators to ensure optimal system performance.

2.5.8. The following steps shall be taken to improve operation of cooling tower:
(a) Fix overflow from cooling tower basin – ensure ball float valves in the basin is functioning properly and also water balance in connected tower is correct;
(b) Ensure drift eliminators are correctly placed;
(c) Pipe joints, tower casing, pump seals and flexible connections shall be checked for signs of leakage;
(d) Visual inspection shall be conducted to identify defects on the system;
(e) Conductivity sensors, strainers and filters shall be cleaned regularly.

2.5.9. Maintenance checklists and records shall be kept properly and made available for inspection upon request.

2.5.10. Select a competent water treatment vendor that prioritizes water efficiency. Ask the vendor to estimate the quantities and costs of treatment methods, volumes of blowdown water, and the expected COC.

2.5.11. To troubleshoot problems related to corrosion, scaling and biofouling in the system, the following flowchart can be referred.


Corrosion/Scaling/Biofouling Problems
Detect Cause
Improve intake water quality?
Yes
Engineering Solutions:
- Pre-treatment of intake water
- Modify intake structure
No
Process Leakages
Yes
Eliminate the Cause:
- Corrosion resistant materials
- Install spare heat exchanger
No
Improve system conditions
Yes
Engineering Solutions:
- Alternate & supplementary techniques
- Cooling water flow velocity
- Apply non-toxic foul-release/non-corrosive coatings
- Avoid stagnant zones
No
Choose water treatment method
Chemical
Non-Chemical
Post-treatment effluent
Link to discharge limit

Retrofit Options

2.5.12. Consider installing a side-stream filtration system. These systems filter silt and suspended solids and return the filtered water to the recirculating water. This limits the fouling potential for the tower system.

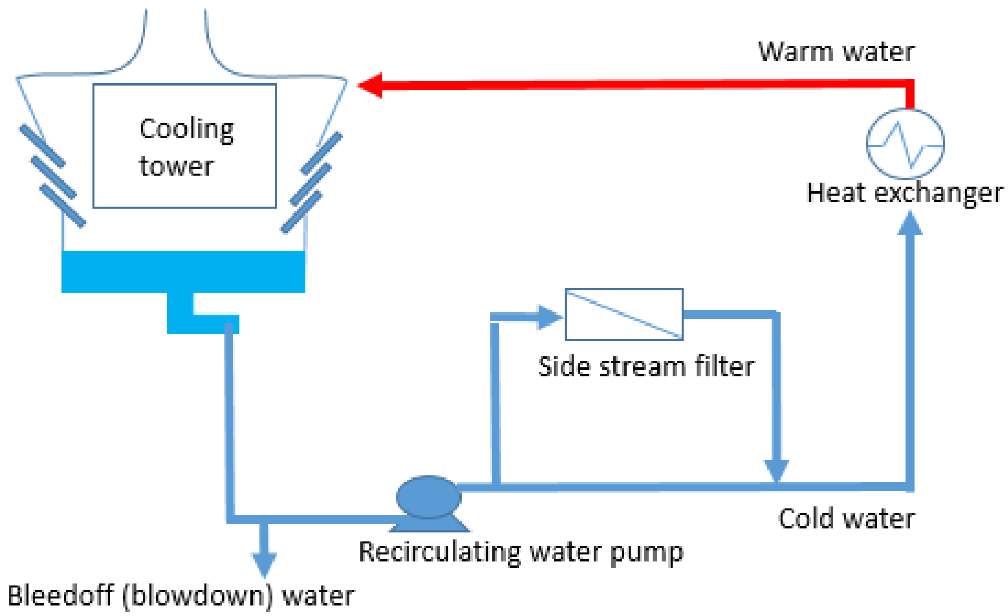


Figure 7. Schematic of side-stream filter

2.5.13. Install covers on open distribution decks on top of the tower. Reducing the amount of sunlight on tower surfaces can significantly reduce biological growth such as algae.

2.5.14. Install automated chemical feed systems on large cooling tower systems (more than 100 RT). The automated feed system should control chemical feed based on makeup water flow or real-time chemical monitoring. These systems minimize chemical use while optimizing control against scale, corrosion, and biological growth.

2.5.15. Install real-time conductivity and pH monitoring system to ensure proper management of the tower operated at high COC.

System fine-tuning and re-commissioning

2.5.16. In order to optimise cooling system efficiency, periodic re-commissioning or fine tuning shall be conducted by contractors or competent operators/engineers.

2.5.17. Actual operational conditions of the system usually differ significantly from designed requirements, hence, system set points and control setting shall be fine-tuned accordingly to reduce water and energy consumption.

De-commissioning of cooling tower system

2.5.18. Proper de-commissioning shall be conducted for cooling tower units that are no longer in operation. Operators shall follow the procedures below for de-commissioning:

(a) Manually shut off the valve of makeup supply to prevent water to flow into the basin;
(b) Drain off all water within the tower basin and piping and then remove the chemical dosing system. De-commissioned cooling towers should also be kept dry.
(c) Power supply shall be disconnected.

2.5.19. Dismantle components of the tower. The dismantled components shall be removed from site in a proper manner.

2.6. Factors Limiting the Increase in COC

2.6.1. Increasing COC will lead to an increased demand for anti-fouling chemicals to allow for higher salt concentrations without the risk of deposition. Proper water treatment programmes designed in particular for operation with higher COC to reduce water requirements and to reduce the blowdown volume. Attention to the chemical and physical factors (e.g. water temperature, pH, water velocity) are important to increase the number of cycles.

Physical Limitations

2.6.2. Three common causes to achieve higher number of COC are windage, drift and leakage.

2.6.3. With new materials and designs, new towers often carry drift guarantees of 0.02% of recirculation rate or less. Newly constructed systems that use towers with highly efficient drift eliminators and have no extraneous losses may be mechanically capable of achieving >10 cycles or more if discharge of the concentrated blowdown is not a limit.

Chemical Limitations

2.6.4. As water's dissolved solids level increases, corrosion and deposition tendencies increase. Because corrosion is an electrochemical reaction, higher conductivity due to higher dissolved solids increases the corrosion rate.

2.6.5. Some salts have inverse temperature solubility that is they are less soluble at higher temperature and thus tend to form deposits on hot exchanger tubes. Many salts also are less soluble at higher pH. As cooling tower water is concentrated and pH increases, the tendency to precipitate scale-forming salts increases.

2.6.6. Calcium carbonate is the least soluble salts and a common scale former in open recirculating cooling systems. Calcium and magnesium silicate, calcium sulphate and other types of scale can also occur.

Scaling Control

2.6.7. There are many contaminants in cooling water that contribute to deposit issues. Three common major types are scaling, general fouling and biological fouling. However, to increase blowdown to limit COC is an effective way to reduce the scaling potential of circulating water but it is not a sustainable solution. High rates of blowdown are not always tolerable and depending on the water quality, cannot always provide complete scale control.

2.6.8. When makeup water sulphate is high and/or the tower is operated at high cycles, sulphuric acid feed can lead to calcium sulphate scaling. Sometimes, hydrochloric acid is used instead of sulphuric acid in such cases. However, this can also result in high chloride levels that can contribute to the increased corrosion rates especially pitting and/or stress cracking of stainless steel.

2.6.9. Injection of CO_2 into circulating water to control pH could be one way to control pH. Such treatment can reduce pH but does not reduce alkalinity. The circulating water is aerated each time it passes over the cooling tower. This reduces the CO_2 concentration in the water to the equilibrium value for the atmospheric conditions, causing the pH to rise. The rapid increase in pH across tower may lead to calcium carbonate scaling on the tower fill. Because of aeration, CO_2 does not cycle and must be fed based on system recirculation rate. It is generally not considered a practical means of controlling pH in open recirculating systems.

2.6.10. Alkaline operation increases the potential to form calcium carbonate and other chemicals such as calcium-magnesium-based scales that can limit COC and necessitate the use of deposit control agents. Apart from that, pH above 8.5 would also reduce the disinfection ability of free chlorine in the cooling tower. This must be taken into consideration while designing the water treatment programme.

2.6.11. Techniques to improve cooling water quality include pre-treatment of cooling water (such as flocculation, precipitation, filtration or membrane technology) can reduce the water requirements, where less blowdown is required to maintain the same concentration factor. Water treatments however will lead to the generation of sludge that will have to dispose of separately.

2.6.12. In Singapore’s context, potable water, NEWater and Industrial water supplied by PUB are used for cooling. The limitation factors for achieving higher COC are listed in the table below.

Table 4 Average COC achievable using PW, NW and IW

Water supply	Average COC achievable	Limitation factor	Remarks
Potable water	6-8 (w/o acid injection); 10-15 (with acid injection)	Discharge pH, calcium hardness, TDS	According to Sewerage and Drainage (Trade Effluent) Regulations, the characteristics of the trade effluent to be discharged into the public sewer shall not exceed the following limits: 1) 6<pH<9 2) TDS<3,000 ppm
NEWater	8-17 (w/o acid injection); 15-20 (with acid injection)	Discharge pH	Ditto.
Industrial Water	2-5	Conductivity and hardness	The conductivity of IW is over 1,000 µs/cm

2.7. Using Alternative Water Sources

2.7.1. Utilising alternative water sources can significantly reduce the potable water/NEWater consumption of the tower. Alternative water sources include such as:

(a) AHU condensate (see Part 4). This reuse is particularly appropriate because the condensate has a low mineral content and is typically generated in greatest quantities when cooling tower loads are the highest;

(b) Pre-treated effluent from other processes provided that any chemicals used are compatible with the cooling tower system;

(c) High-quality industrial wastewater effluent or recycled water;

(d) Rainwater harvesting;

(e) Seawater.

For use of alternative water sources to initially fill up the cooling tower system, and subsequently to top up the water that is lost from the system, owners are required to seek approval from NEA, Director-General of Public Health.

2.7.2. Blowdown water can be reclaimed partially as makeup water using the membrane treatment process.

2.7.3. Treated water shall be delivered to the makeup clear water tank through a network of pipelines which can be similar to the potable water/NEWater distribution system. For good plumbing practice, it is recommended to make reference to the SS CP48- Singapore Standard Code of Practice for Water Services or other acceptable international standards (e.g. BS8525-1:2010) for the design and installation of the treated water reuse distribution pipeworks. Pipes and fittings of equal material, quality and construction for potable water supply system and capable to resist corrosion for the lifetime of the product could be used.

Seawater cooling system

2.7.4. Seawater is currently used in some once-through cooling water systems for petrochemical industries in Singapore.

2.7.5. Polyphosphates and zinc, used in combination or separately, are the corrosion inhibitors most commonly employed in once-through systems.

Part 3 Best Available Technology

3.1 Overview

3.1.1. The proposed implementable techniques have to be proven effective to reduce water consumption. With respect to existing installations, careful considerations must be taken as the assessment could be more varied and options limited depending on process requirements and site availability. For each option chosen, or every change made to a cooling system, careful balance against associated effects and optimisation of the process or cooling capacity must be weighed.

3.1.2. The following techniques presented are considered the best available technology to increase overall energy efficiency, reduction of use of water and of cooling water additives, minimising public health risk, if any.

3.1.3. General options to reduce water in wet cooling towers:

(a) To reduce the need for cooling by optimisation of heat reuse if any;
(b) To reduce the water use, apply recirculating systems to have more closed loops rather than open loops;
(c) Where makeup water is limited during process period or very limited in drought periods, use dry cooling systems but energy penalty will be incurred;
(d) Optimisation of COC which may increase demand on conditioning of water such as water softening of makeup water;
(e) Install automated chemical feed systems to control chemical feed based on makeup water flow or real-time chemical monitoring. These systems minimise chemical use while optimising control against scale, corrosion, and biological growth;
(f) Reusing water purification system reject water as an alternative onsite water source where appropriate and feasible; and
(g) Cooling tower water from the blow down line or from the recirculating water line can be further treated using RO (Reverse Osmosis) membrane technology for purification purpose and re-circulated back to the cooling tower system.

3.1.4. Use of water purification systems to remove contaminants. As no single water purification system is able to remove 100% of all contaminants, it is good practice to implement multiple water purification technologies in sequence or standalone where only a low level of contaminants can be tolerated. The following options can be adopted:

(a) Install a side-stream filtration system to physically filter silt and suspended solids by capturing them on the surface of the media before returning the filtered water to the recirculating water. The filtration unit typically operate at low pressures and do not remove any dissolved solids and a pressure drop indicate that filters requires backwashing to remove contaminants trapped on the media surface;

(b) Install a carbon filtration unit that uses adsorption to attract particles as water passes through the filter. Activated carbon is frequently used depending on the temperature and pH of water; and the amount of time the contaminant is exposed to the activated carbon. Carbon filters can either be disposable cartridges or packed columns (regeneration is required).

(c) Install a deionisation system which is a physical process similar to water softening that exchanges cations and anions present in the untreated water with hydrogen and hydroxide ions. Deionisation is not effective at removing particulates, but because the process is relatively fast, it is commonly used in laboratory applications requiring a low level of water purification. Regeneration of deionisation resins is required.

(d) To further purify water, chlorine based chemicals, or ozone can be used to chemically disinfect water. Chemical disinfection can use additional water if chemicals are added in liquid or slurry form.

(e) Non-chemical based techniques such as electromagnetic waves, heat and extreme mechanical sheer can be used. These technologies might not require backwashing but require regular cleaning.

Part 4 Air–Conditioning Condensate Re-Use

4.1 Introduction

4.1.1. The typical air conditioning system in a commercial building consists of air-handling units (AHU). Fan Coil Units (FCU) are smaller modular versions of AHUs while Makeup Air Unit (MAU) is a type of air handler that conditions only non-recirculated air.

4.1.2. Recirculated air from the space tends to be mixed with incoming fresh air from the outside environment before passing through the AHU. As the mixture of air passes through the AHU, it goes through a cooling coil where its temperature drops. Humidity from both outside air and return air is removed as condensate. The condensate can be collected and re-used at various points-of-use in a building.

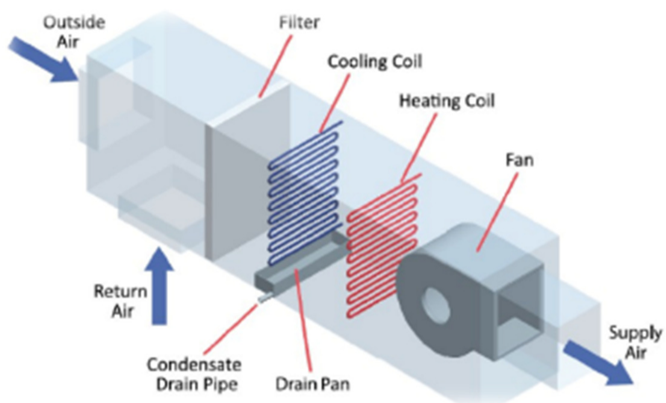


Figure 8. Structure of AHU condensate collection system

4.2 Typical condensate recovery and re-use system

4.2.1. Condensate formed from moisture in the air is relatively high-quality water. They are generally cold with low dissolved mineral content. Therefore, it is recommended to collect condensate for re-use as cooling tower makeup, typically with fairly little treatment required. However, the condensate recovery system must be made of corrosion resistant materials. Otherwise, quality of the condensate will be adversely affected by leaching of the materials, e.g. iron oxides/rust, and this may cause fouling in the cooling tower system and may promote the growth of *Legionella* bacteria.

4.2.2. However, the condensate collected may be contaminated by *Legionella*. Biofilm may also potentially be formed along the piping and storage tanks. Hence, common treatment methods such as sedimentation, neutralization, filtration, disinfection with ozone, ultraviolet radiation, chlorination and adsorption may still be applied to achieve and ensure that the condensate water quality is suitable for use as cooling tower makeup.

4.3 Components required for collection of condensate

4.3.1. A typical condensate recovery and reuse system consists of drain pipes, pumping lines, condensate water collection tank and pumps. Depending on condensate water quality and requirement, appropriate simple treatment systems can be included accordingly.

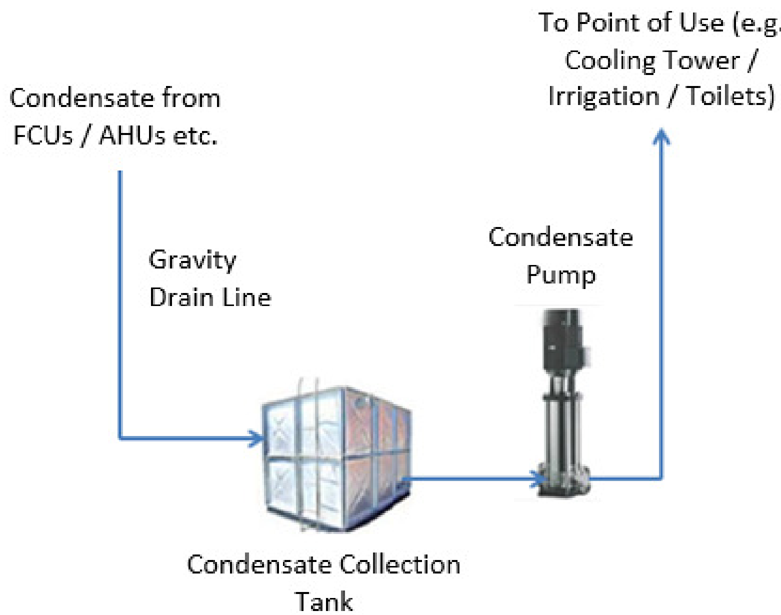


Figure 9. Typical configuration of condensate recovery and reuse system

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Annex A – Cooling Tower Water Balance

1. Makeup water

Makeup water is added to cooling tower basin to replace water lost from cooling tower through evaporation, bleed, drift, splash and overflow. It is usually regulated through a float valve.

$$MU = ER + BD + DR + L$$

MU: Makeup water

ER: Evaporation Rate

BD: Blowdown

DR: Drift Loss

L: Other losses (gland seals, overflow, splash)

In general, make up water is measured by a flowmeter. In the absence of flowmeter, make up water can be estimated using the following equation:

$$MU = ER \times COC / (COC - 1)$$

MU: Make up water

ER: Evaporation Rate

COC: Cycles of concentration

2. Evaporation

Water evaporation within the cooling tower accounts for the majority of the heat rejected. Approximately 1,000 Btu of heat is lost from the water for every pound of water evaporated. This is equal to evaporation of about 1% of the cooling water for each 10℉ temperature drop across the cooling tower. The following equation describes this relationship between evaporation, recirculation rate, and temperature change.

$$E = (f * R * \Delta T) / 1000$$

E: Evaporation in gpm

R: Recirculation rate in gpm

ΔT: Cooling Range (℉)

f: Evaporation factor

3. Cycles of Concentration

"Cycles of concentration" (or "cycles") are a comparison of the dissolved solids level of the blowdown with the makeup water. It also can be interpreted as the number of times the water circulates within the cooling system before discharged via blowdown.

Cycles can be calculated by comparison of the concentrations of a soluble component in the makeup and blowdown streams.

Cycles based on conductivity are often used as an easy way to automate blowdown. However, cycles based on conductivity can be slightly higher than cycles based on individual species, due to the addition of chlorine, sulphuric acid, and treatment chemicals.

Cycles of concentration = TDS circulating water / TDS makeup water

It is difficult to measure TDS directly in a practical way however it is the dissolved solids in the water that make the water electrically conductive. Water with higher TDS levels is more conductive to electricity than water with lower TDS levels. Water conductivity is relatively easy to measure using current technology and this is generally the parameter used as an indicator for TDS and hence for C. Bleed volume is therefore controlled by the system conductivity sensor. Therefore C can be expressed as:

Cycles of concentration = conductivity of circulating water/ conductivity of makeup water

The treatment chemicals added to a system will increase the conductivity of the circulating water and this needs to be taken into consideration when controlling cycles via TDS or conductivity. The water treatment industry has traditionally utilised chlorides either as chloride ion (Cl^-) or expressed as Calcium Carbonate ($CaCO_3$). This has been conducted as a wet analysis to determine cycles of concentration to control bleed off. Some materials such as certain grades of stainless steel and protective coatings on cooling tower components may have chloride level limitations. Cycles of concentration can have a direct effect on the corrosion / scaling potential of the circulating water and the selection of appropriate materials of construction for the cooling tower / water system combined with an appropriate corrosion control program can allow the operator to run higher cycles of concentration than would otherwise be practicable.

4. Bleed/Blowdown

By evaporating water a cooling tower concentrates both dissolved and undissolved (suspended) solids within the system circulating water. As water contaminants build up the concentration level of impurities or total dissolved solids (TDS) in the circulating water should be controlled by bleeding a portion of the circulating water from the system and replacing it with relatively clean makeup water. Without this control the TDS level in the circulating water will increase and if left unchecked it may lead to scaling and fouling of not only the cooling tower, but also the system heat exchangers. Concentration of impurities must be controlled by removing system water (bleed-off) and replacing with makeup water. In order to control the TDS, bleed-off volume can be determined by the following formula:

$$\mathbf{B= (E-[(COC-1)*DL])/ (C-1)}$$

B: Bleed Off Rate (L/s)

ER: Design Evaporative Rate (L/s)

COC: Cycles of Concentration

DL: Drift Loss Rate (L/s)

Bleed water is taken from the system either continuously or intermittently. A bleed valve, automatically controlled by a conductivity sensor, is the preferred method of bleed control. Bleed volumes should be metered. Bleed control valves and bleed meters should be protected from the contaminants in the bleed water by strainers or filters. Bleed is automatically replaced by makeup water.

5. Drift

Drift refers to small water droplets that leave the tower entrained in the tower discharge air. Drift is controlled largely by the towers' design and operation and in particular by the drift eliminators design. When drift loss is expressed as a percentage, it refers to the % loss by drift in relation to the total volume of the recirculating cooling water in a system. Modern drift eliminators can achieve a drift loss of less than 0.002%.

Other water losses

1. Overflow

Overflow is an uncontrolled water loss caused by water flowing back into the cold water basin once the circulating pump has stopped. Where the volume of this water is greater than the capacity of the cold water basin the water will overflow. Overflow can be caused by poor pipework design and installation. This should be designed out of systems. Overflow can also be caused by an incorrectly set makeup level. When the operating water level is set too high in a forced draft counter flow cooling tower, overflow can result due to air pressure forcing water out of the overflow pipe. Loss can also result from a lack of protection of the overflow pipe inlet or from siphoning on system shutdown resulting from the overflow pipe being installed below the cold water basin level without an air break.

2. Pump gland leakage

Pump gland leakage is a controlled leak designed to assist the pump glands maintain a pressure seal.

3. Splash out

Splash out refers to water leaving the tower via the air intakes and other openings in the tower casing. It is more likely to occur when the fans have cycled off (or to a low speed) for control purposes.

4. Windage

Windage refers to the effect of prevailing winds blowing water droplets out of a cooling tower, either through air inlets or outlets. Windage should not be confused with drift or splash out, both of which can occur without the presence of wind.

Annex B – Cooling Tower Water Saving Checklist

Water saving practices	Yes	No	NA
Install water meters on make up and blow-down lines to monitor water consumption.			
Install side stream water filters to remove suspended solids.			
Install anti splash louvres on the tower air intakes to reduce water splash-out.			
Ensure that tower water distribution piping is not oversized			
Ensure the float valve on the makeup line can close properly preventing uncontrolled inflow.			
Ensure that there is no overflow during normal operation.			
Ensure that the operating water levels in multiple tower/cold water basins are equal.			
Install variable frequency drive (VFD) fans which can match fan speed to actual cooling load.			
Replace ball float valves with solenoid valves that are controlled by electronic level sensors.			
Install drift eliminators to reduce drift loss.			
Ensure that the fan speed and airflow rates are within manufacturers' limits.			
Check air inlets clear of obstructions and contamination sources			

Water saving practices	Yes	No	NA
Carry out routine maintenance work in a timely manner.			
Make up water, blowdown and conductivity should be monitored, logged and charted.			
Clean the conductivity sensor at least once every month and recalibrated at least once every 6 months.			
Conduct regular inspections to monitor whether there is any leakage at cooling tower especially at pipe connections and joints, and pump.			
Examine monthly routine maintenance reports provided by the respective maintenance contractors, paying particular attention to minimize water usage and eliminating any water wastage.			
Ensure follow-up actions are taken and documented in the maintenance reports.			

Annex C - Typical Parameters of Potable Water, NEWater and Industrial Water as Makeup Water for Cooling Tower

S/N	Parameters	Unit	Typical Values		
			Potable Water	NEWater	Industrial Water
1	Turbidity	NTU	0.19	<5	0.5-2.0
2	Colour	Hazen	<5	<5	10-20
3	Conductivity	µS/cm	253	<250	600 – 1,600
4	pH		8.0	7.0 - 8.5	6.8-7.3
5	Total Dissolved Solids	mg/L	156	<150	-
6	Total Organic Carbon	mg/L	1.5	<0.5	-
7	Total Hardness ($CaCO_3$)	mg/L	63	<50	100-250
8	Ammoniacal nitrogen (as N)	mg/L	-	<1.0	<5
9	Alkalinity as $CaCO_3$	mg/L	20	-	30-80
9	Chloride (Cl)	mg/L	28	<20	100-500
10	Fluoride (F)	mg/L	0.467	<0.5	-
11	Nitrate (NO_3)	mg/L	0.35	<15	<20
12	Silica (SiO_2)	mg/L	3.59	<3	-
13	Sulphate (SO_4)	mg/L	44	<5	-
14	Phosphate as P (PO_4-P)	mg/L	0.015	-	1-4
14	Residual Chlorine (Cl, Total)	mg/L	2.3	<2	0.5 – 1.0
15	Total Trihalomethanes	mg/L	0.31	<0.08	-
16	Aluminium	mg/L	0.026	<0.1	-
17	Barium (Ba)	mg/L	0.022	<0.1	-
18	Boron (B)	mg/L	0.021	<0.5	-
19	Calcium (Ca)	mg/L	<0.002	<20	-
20	Copper (Cu)	mg/L	<0.002	<0.05	-
21	Iron (Fe)	mg/L	0.005	<0.04	-
22	Manganese (Mn)	mg/L	<0.002	<0.05	-
23	Sodium (Na)	mg/L	28	<20	-
24	Strontium (Sr)	mg/L	-	<0.1	-
25	Zinc (Zn)	mg/L	-	<0.1	-
26	Total Coliform Bacteria	CFU/100ml	<1	N.D.	N.D.
27	Enterovirus		-	N.D.	-
28	Heterotrophic Plate Count (CFU/ml, 35℃, 48 h)	CFU/ml	-	<300	-

*Users are advised to conduct water analysis before going for any chemical program for cooling towers

N.D.: Non-Detectable

"-" : Not Tested

Notes:

Notes:

Notes: