

Code of Practice for Fresh Water Cooling Towers

Part 3: Water Treatment Methods



2023 Edition

EMSD 

Code of Practice
For
Fresh Water Cooling Towers
Part 3: Water Treatment Methods

2023 Edition
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Electrical and Mechanical Services Department
The Government of the Hong Kong Special Administrative Region

Foreword

This Code of Practice was prepared to promote the proper use of fresh water cooling towers with guidelines for cooling tower design, installation, testing, commissioning, operation and maintenance in order to meet the energy efficiency objective with due consideration of the environment and health issues. It was developed by the Task Force which comprises members from eight government departments, three professional institutions and three trade unions on Code of Practice for Fresh Water Cooling Towers.

Part 3 of this series of Code of Practice for Fresh Water Cooling Towers (previously known as Code of Practice for Water-cooled Air Conditioning Systems) provides details on the water treatment for cooling towers. It should be read in conjunction and made cross-reference with the followings:

Part 1 – Design, Installation and Commissioning; and
Part 2 – Operation and Maintenance

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Definitions

Biocide	: A physical or chemical agent that kills bacteria and other microorganisms.
Biodispersant	: A chemical compound added to the water inside cooling tower system, to penetrate and break down any biofilm that may be present on the wetted surfaces of the cooling tower system.
Biofilm	: A surface layer of microorganisms. It is usually combined with particulate matter, scale and products of corrosion.
Bleed off (blowdown)	: The removal of water from a cooling tower system to maintain the concentration of total dissolved solids and suspended solids in an acceptable level.
Commissioning	: A systematic and progressive process of putting the components of a system into operation, calibrating instruments and controls, and then making adjustments and checks to ensure that the total system is providing satisfactory operation and performance.
Cooling tower	: A device for lowering the temperature of water by evaporative cooling in which ambient air is in contact with falling water, thereby exchanging heat. The term also includes those devices that incorporate a water-refrigerant or water-water heat exchanger (evaporative condenser or closed-circuit cooling tower).
Cooling tower system	: A heat exchange system comprising a heat-generating plant (chiller condenser or heat exchanger), a heat-rejection plant (cooling tower or evaporative condenser) and interconnecting water recirculating pipework and associated pumps, valves and controls. Cooling tower systems is considered as a part of WACS.
Corrosion coupon	: Small strip of metal, usually placed into water circuits so that they can easily be removed, to enable the corrosion characteristics of the water to be assessed.
Corrosion inhibitor	: Chemical which protects metals by: (a) passivating the metal by the promotion of a thin metal oxide film (anodic inhibitors); or (b) physically forming a thin barrier film by controlled deposition (cathodic inhibitors).
Cycle of concentration	: The ratio between the concentration of dissolved solids in the cooling water and the concentration of dissolved solids in the make-up water as a result of the evaporation that takes place in the cooling tower.

Dead leg	: Water pipe with length equal to or larger than one diameter of the pipe, ending at a fitting through which water flows only when the fitting is opened. These extra areas of the cooling tower system contain stagnant water, which can cause building up of bacteria and sludge in recirculating system, and can then contaminate the system.
Decontamination	: A process used when a cooling tower system is found with a level of bacterial count which involves a series of actions to disinfect, clean and re-disinfect the cooling tower system.
Disinfection	: Preventive maintenance action of applying a treatment to a system, in conjunction with system cleaning, in order to reduce the general concentration of infectious agents.
Dispersant	: Reagent usually added with other treatment chemicals to prevent accumulation of sludge.
Drift eliminator	: A grid or grille-like arrangement of physical barriers located before the cooling tower exhaust designed to minimise the drift emanating from a tower.
Drift	: Water lost from the cooling tower as liquid droplets or aerosols entrained in the exhaust air, excluding condensation.
Exhaust air outlet	: A termination of a mechanical or natural ventilation system that allows air removed from a space and discharged outside the building. The exhaust air outlets, which are crucial in the consideration of separation distance with the cooling tower, are exhausts from kitchens, toilets, outlets of drainage vent pipes, generator flue discharge, carpark ventilation, fume cupboard and refuse collection room, and any exhaust that contains contaminants or nutrients for microbial growth in cooling water.
Fan	: A rotary machine which propels air continuously. This is used for moving air in a mechanical draft tower. The fan may be of induced draft or forced draft application.
Fill (packing)	: Material placed within cooling tower to increase heat and mass transfer between the circulating water and the air flowing through the tower.
Filtration	: The process of separating solids from a liquid by means of a porous substance through which only the liquid passes.
Fouling	: Organic growth or other deposits on heat transfer surfaces causing loss in efficiency.

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Heterotrophic colony count (HCC)	:	The number of viable units of bacteria per millilitre of water sample. It is also known as Total Bacteria Count (TBC), Total Plate Count or Viable Bacteria Count.
Legionnaires' disease	:	It is a type of bacterial pneumonia caused by legionella.
Medical and health care premises	:	Hospitals, general clinics, specialist clinics; community support facilities for the elderly, such as residential elderly homes, social centre for the elderly; and establishments providing health care and services for the sick and infirm.
Non-oxidising biocide	:	A non-oxidising biocide is one that functions by mechanisms other than oxidation, including interference with cell metabolism and structure.
Operable window	:	An operable window is a window that has moving parts, such as hinges, and can be opened. If a window is permanently locked or required special tools to be opened, that window would not be considered as an operable window when examining the separation distance.
Outdoor air intake	:	A termination of a mechanical or natural ventilation system that allows ambient air entering a building. The outdoor air intakes, which are crucial in the consideration of separation distance with the cooling tower, are fresh air intake for the air conditioning system of a building, and any air intake that draws outdoor air into the building. Vent pipe of water tanks are considered as outdoor air intake since it draws air from outdoor to the tank during discharge of water.
Oxidising biocide	:	Agents capable of oxidising organic matter, e.g. cell material enzymes or proteins which are associated with microbiological populations resulting in death of the micro-organisms.
Passivation	:	The formation of a protective film, visible or invisible, which controls corrosion.
Plume	:	The visible discharge of air and moisture from a cooling tower due to condensation. It is usually most visible in cool and humid days when water vapour emanates from the cooling tower exhaust.
Public accessible area	:	An area that is accessible by the public or building occupants other than building management/maintenance staff. Some of the examples are pedestrian thoroughfare/ footpath, place where people gather together for activities, accessible green roof/garden. Restricted area with proper access control which is only accessible by building management/maintenance staff is not considered as a public accessible area.
Podium Roof	:	Roof of the lower part of a building.

Scale	:	A crystalline deposit that can form on surfaces or pipework within the cooling tower system due to build up of minerals (usually calcium carbonate).
Scale inhibitor	:	Chemicals used to control scale. They function by holding up the precipitation process and/or distorting the crystal shape, thus preventing the build-up of a hard adherent scale.
Sludge	:	A building up of sediment that can be found in the basin or pipework of a cooling tower system.
Slug dosing / Shock dosing	:	The process of adding in a single dose a much higher amount of chemical biocide than is normally applied, with the intention of rapidly raising the concentration of biocide in the water to a level expected to kill most of the organisms in the water.
Spray nozzle	:	A device used in an open distribution system to break up the flow of the circulating water into droplets, and effect uniform spreading of the water over the wetted area of the tower.
Stagnant water	:	Pockets of motionless water within the cooling tower system that can allow microorganisms to grow.
Temporary shut-down	:	Cooling tower temporarily shut-down is the entire/part of the system not in function and isolated from the main water-cooled condenser/heat exchanger to avoid contamination. Standby unit(s) with cooling water running once a week is not defined as temporary shut-down.
Total Legionella count	:	The number of Legionella colony-forming units (CFU's) found in one millilitre of the water sample.

1. Introduction

1.1 Scope

This Part of the Code of Practice describes water treatment methods applicable in fresh water cooling tower systems. It helps in minimising the health risk posing to the public by using cooling towers, and optimising the system operating performance in water treatment. Emphasis has been put on the following issues:

- a) Provide technical information for the users to understand the operating principles, application, advantages and limitations of common water treatment methods;
- b) Introduce major factors and considerations in selecting water treatment methods, which helps the owner of system, designer and operator to design, monitor, control and maintain the water treatment systems;
- c) Describe the basic requirement and performance of water treatment programme such that operation and maintenance (O&M) contractors of cooling tower or water treatment services providers can provide appropriate services to various cooling tower systems.

1.2 Objectives

This Part of the Code of Practice aims at providing technical guidelines for an appropriate water treatment programme design and implementation in cooling tower systems so as to achieve the following objectives:

- a) Assure public health and safety by preventing any potential risks associated with cooling tower systems;
- b) Achieve better/maintain energy efficiency and operational performance of cooling tower systems;
- c) Minimise nuisances caused by cooling tower systems to the public;
- d) Prevent pollution and misuse of water;
- e) Assure occupational safety and health of the staff concerned.

1.3 Applications

- 1.3.1 This Code of Practice is intended for use by personnel who are responsible for the water treatment of cooling tower systems, etc. It should be applied to the newly installed and existing systems.
- 1.3.2 This Code of Practice should be read in conjunction with any additional recommendations provided by suppliers/ manufacturers of the water treatment chemicals/cooling tower equipment and any relevant specification and applicable ordinances and regulations in Hong Kong.
- 1.3.3 EMSD reserves the right to interpret the contents of this Code of Practice.
- 1.3.4 In case of conflict between the requirements of this Code of Practice and any other relevant requirements, the following order of priority should apply:
 - a) All currently in force Legislation and other Subsidiary Legislation.
 - b) The relevant Codes of Practice and Technical Standards.
 - c) This Code of Practice.

2. Corrosion Inhibition

2.1 Causes of Corrosion Problems

- 2.1.1 Corrosion is defined as the destruction or loss of metal through chemical or electrochemical reaction with its surrounding environment.
- 2.1.2 Common problems arising from corrosion are reduction in heat transfer due to deposits of corrosion products on the heat transfer surface of a heat exchanger and reduction of water flow resulting from a partial or complete blockage of pipes, valves, strainers, etc. Also, excessive wear of moving parts, such as pump, shaft, impeller and mechanical seal, etc. may resist the movement of the equipment. Hence, thermal and energy performance of a cooling tower may degrade.

2.2 Corrosion Prevention Methods

The principal methods to prevent corrosion in cooling tower system include:

- a) Selecting suitable materials of construction to resist corrosion;
- b) Controlling corrosion process using corrosion inhibiting chemicals;
- c) Controlling scaling; and
- d) Controlling micro-biological growth.

2.3 Chemical Water Treatment Methods

2.3.1 General

Several major chemical treatment methods can be used to minimise operational problems arising from corrosion and to assure efficient and reliable operation of cooling tower systems. Selection of water treatment programme for a specific system depends on the system characteristics, including:

- a) System design, including system capacity, cooling tower type, basin depth, materials of construction, flow rates, heat transfer rates, temperature drop and associated accessories;
- b) Water, including make-up water composition/quality, availability of pre-treatment and assumed cycle of concentration;
- c) Contaminants, including process leaks and airborne debris;
- d) Wastewater discharge restrictions; and
- e) Surrounding environment and air quality.

2.3.2 Corrosion Inhibitor

2.3.2.1 Corrosion inhibitors are almost universally used to prevent deterioration of carbon steel and other alloys in cooling tower systems. In general, there are four types of inhibitor, including anodic, cathodic, mixed and adsorption, commonly adopted in cooling tower water treatment. Typical dosage concentration, pH range and characteristics of corrosion inhibitors are described in Appendix 3A for reference.

2.3.2.2 Working principles of common corrosion inhibitors are described in the following sections.

2.3.2.3 Anodic inhibitor

Applying anodic inhibitor enables a protective oxide/inhibitor film to cover the anodic corrosion points inside the cooling water circulation system. This method is effective only if all points are filmed and isolated from corrosion initiator. Otherwise, severe localised corrosion may occur at the points without effective protection by protective film. Therefore, sufficient safety margin should be applied to anodic inhibition method and anodic inhibitors are generally applied at high dosage levels (hundreds of mg/L). Meanwhile, mixing of anodic inhibitor with other types of inhibitors can reduce the dosage level required for the same effectiveness.

2.3.2.4 Cathodic inhibitor

Cathodic inhibitor is effective by the formation of protective inhibitor film at cathodic corrosion sites so as to prevent oxygen reduction. It is more effective than anodic inhibitor and lower dosage level is required. Therefore, it is commonly used in cooling water treatment.

2.3.2.5 Mixed inhibitor

Mixed inhibitor composes of two or three types of inhibitor and majority of the proprietary corrosion inhibitor formula falls into this category. Since chemicals with different characteristics supplement their deficiency with each other, efficacy of the mixed inhibitor increases. Hence, dosage concentration can be significantly reduced, thus lowering the operating cost and environmental impacts caused by chemicals.

2.3.2.6 Adsorption

Protective adsorbed film is formed over the entire metal surface if adsorption inhibitor is used. The film helps to protect electrochemical reactions between metal and aqueous ions. Some of the organic compounds are suitable to act as adsorption inhibitors.

2.3.2.7 Passivation

In order to prevent corrosion on galvanised steel cooling towers and associated pipes (usually known as white rust), formation of a non-porous surface layer of basic zinc carbonate is one of the effective methods. The zinc carbonate layer is a barrier layer to protect galvanised steel from corrosion, which normally protects the metal for many years. The formation of zinc carbonate layer is called passivation, which should be accomplished by controlling pH during initial operation of the cooling tower. Control of the cooling water pH in the range of 7 to 8 for 45 to 60 days usually allows passivation of galvanised surfaces to occur. In addition to pH control, operation and moderate hardness levels of 100 to 300 ppm as CaCO₃ and alkalinity levels of 100 to 300 ppm as CaCO₃ will promote passivation.

2.3.3 Other considerations

2.3.3.1 Cooling tower system fabricated from stainless steel, PVC and FRP are generally having inherent resistance to corrosion. However, the entire cooling system is generally constructed by various materials such that effective corrosion inhibition measures should be implemented to suit all materials exposed to cooling tower system. The owner of cooling tower system should consult competent O&M contractor of cooling tower/water treatment services provider to select appropriate corrosion inhibitors for specific system and material used.

2.3.3.2 Erosion on the metal surface of a cooling tower system is usually caused by high cooling water velocity, sand ingress and cavitations due to pressure changes and existence of air bubble inside the system. Erosion should be minimised by keeping the circulating water velocity in a reasonable range. The minimum water velocity should be of 0.9 m/s, while the maximum value is 3 m/s and 4 m/s for 6 000 system operating hours/year and 3 000 system operating hours/year respectively.

3. Scale Inhibition

3.1 Causes of Scaling Problems

- 3.1.1 Scale is caused by the precipitation of mineral particles in water to form a hard deposit on heating transfer surfaces. The most common type of scaling is formed by carbonates and bicarbonates of calcium and magnesium, as well as iron salts in water. Calcium dominates in fresh water. Therefore, consideration on make-up water composition is required to select an appropriate scale inhibition method.
- 3.1.2 Scale leads to reduction in heat transfer efficiency due to the formation of an insulating deposit on heat transfer surface and reduction of water flow resulting from partial or complete blockage of valves, strainers, pipes and heat exchangers, etc.
- 3.1.3 Hardness is considered as the major cause of scale formation, with chain effect connecting to other principle factors, such as evaporation, alkalinity, pH value, total dissolved solids and ambient temperature that influencing the rate of scale formation.
- 3.1.4 Evaporation causes the salt remaining in the circulating water becomes more concentrated and results in an increase of total dissolved solids. Negative solubility of calcium and magnesium salts, biocarbonate decomposition is other factors that cause scale formation.
- 3.1.5 Optimum scale control for cooling tower system depends on make-up water composition (mineral concentration), operating parameters of the cooling tower system, cycle of concentration adopted and the effluent restrictions.

3.2 Scale Prevention Methods

- 3.2.1 The common methods to prevent scale in cooling tower system are:
 - a) Remove scale forming minerals in make-up water by means of softening process;
 - b) Limit the concentration of scale forming minerals in circulating water by bleed-off process;
 - c) Apply scale inhibitors in circulating water;
 - d) Dose acid to increase the solubility of scale-forming salts; and
 - e) Remove scale forming minerals and prevent deposition of hard deposit using physical methods.

3.3 Chemical Water Treatment Methods

3.3.1 General

Chemicals are widely used to prevent scale formation in cooling tower systems. Apart from scale inhibitor, softener and acid can be used to enhance the performance of scale prevention.

3.3.2 Scale Inhibitor

There are two main types of scale inhibitors, namely, threshold inhibition chemicals (scale suppressant) and scale conditioners. Threshold inhibition chemicals prevent scale formation by keeping the scale forming minerals in solution by dispersing the precipitating substances, so that scale is unable to form. Scale conditioners modify the crystal structure of scale, creating a bulky, transportable sludge instead of a hard deposit. Characteristics of some common scale inhibitors are attached in Appendix 3B.

3.3.3 Softener

Hot and cold lime can be added to reduce the hardness of cooling water supplies, and water with high bicarbonate alkalinity, because lime treatment can effectively reduce the hardness, alkalinity and solid content of water. In Hong Kong, softener application may not be necessary as the hardness of the mains fresh water is relatively low.

3.3.4 pH control

Reducing the pH value/alkalinity in cooling tower water with mineral acid is a simple and cost-effective way to reduce the scaling potential for many common scale constituents, such as calcium carbonate and calcium phosphate. Solubility of potential scale forming minerals increases with decreasing pH or alkalinity. However, Calcium Sulphate scaling cannot be effectively controlled by adding acid because the solubility of this salt is almost independent of pH.

Scale forming potential is minimised in acidic environment; however, reducing pH value may increase the corrosion caused by water, as well as the solubility of calcium/corrosion inhibitor salts. Therefore, proper pH control is required to provide a suitable environment for both scale and corrosion inhibitors work effectively.

3.3.5 Ion exchange resin

Ion exchange resin is a softening process and suitable for make-up water containing dissolved salts. The techniques make use of ion exchange process. The ion exchange process is to remove calcium and magnesium ions by replacing them with an equivalent amount of sodium ions and takes place in a vessel containing resin beads incorporating sodium ions. Sodium ions form highly soluble salts, which will not precipitate and form scale.

3.4 Physical Water Treatment Methods

3.4.1 General

Physical treatment methods can also be used to prevent scale formation in cooling tower systems and are always considered as effective supplement in water treatment process. Also, many physical methods can improve water quality by minimising corrosion, scale formation and biofouling simultaneously.

3.4.2 Filtration System and Equipment

3.4.2.1 Filtration System

Filtration is a mechanical process to remove suspended solids from water by collecting the solids on a porous medium. Both in-line filtration and side-stream filtration processes help in reducing suspended solids to an acceptable level.

- a) **In-Line Filtration** – In-line filtration allows all system circulating water to pass through a strainer or filter in order to remove impurities and suspended solids.
- b) **Side-stream filtration** – Side-stream filtration means placing a filter in a bypass stream so that a portion of the total cooling water circulation rate (at least 5%) is filtered. Higher bypass portion leads to better water quality but also increase the filtration equipment capacity. The advantage of side-stream filtration includes lower capital and space requirement than in-line filtration using the same filtration method. In addition, side-stream filtration has the advantage of being able to process the recirculation cooling system and remove debris, which has been drawn in by the cooling tower, as well as impurities precipitated in the bulk water.

3.4.2.2 Filtration Equipment

A number of mechanical filtration devices commonly used in cooling tower systems are described as follows.

- a) **Strainers** – A strainer is a closed vessel with a cleanable screen to remove and retain foreign particles down to 25µm diameter inside cooling water. It should only be used as pre-filtration to remove large particles in the system. Routine inspection and cleaning is necessary to ensure strainers are in good condition and normal function.
- b) **Cartridge filters** – Cartridge filters can be used as final filters to remove nearly all suspended solids from about 100µm down to 1µm or less. Cartridge filters are typically disposable, which should be replaced if required. Frequency of replacement depends on the concentration of suspended solids in water, the size of the smallest particles to be removed and the removal efficiency of the cartridge filter selected.
- c) **Sand filters (Permanent media filters)** – The degree of suspended solids removal in sand filters depends on the combinations and grades of the medium being used in the vessel. Typical sand filter can remove suspended contaminants down to 10µm. Specialised fine sand media filters are designed to remove suspended solids down to less than 1µm. Multimedia vessels with each layer containing medium of different size may also be used for low suspended solids application. When the vessel has retained enough suspended solids to develop a substantial pressure drop, the unit must be backwashed either manually or automatically by reversing the direction of flow.
- d) **Centrifugal-gravity separators** – Cooling water is drawn through tangential slots and accelerated into the separation chamber. Centrifugal action tosses the particles heavier than the liquid to the perimeter of the separation chamber. Efficiency of centrifugal-gravity separator depends on the gravitational mass of suspended solids; performance data indicate that separator efficiency is about 40% for particles in the range of 20µm to 40µm.
- e) **Bag type filters** – Bag filters are composed of a bag of mesh or felt supported by a removable perforated metal basket, placed in a closed housing with an inlet and outlet. Filter bags can be made of many materials (cotton, nylon, polypropylene and polyester) with a range of ratings from 0.01mm to 0.85mm. Mesh bag are generally coarser, but are reusable. However, periodic replacement of filters is required to ensure the efficiency of filters.

3.4.3 Bleed-off

3.4.3.1 Evaporative loss from a cooling tower system leads to an increased concentration of dissolved or suspended solids within the system water as compared to the make-up water. Over concentration of these impurities may lead to scale and corrosion formation, hence, fouling of the system. Therefore, concentration of impurities must be controlled by removing system water (bleed-off) and replacing with make-up water. In order to control the total dissolved solids (TDS), bleed-off volume can be determined by the following formula:

$$B = \frac{E - [(C - 1) \times D]}{(C - 1)}$$

where B – Bleed-off rate (L/s)
E – Design evaporative rate (L/s)
C – Cycle of concentration
D – Design drift loss rate (L/s)

3.4.3.2 Increasing the bleed-off rate from a cooling tower system is a simple way to reduce the levels of calcium and alkalinity in the water, thus reducing the calcium carbonate scaling potential. However, this is not a cost effective and water saving option. Increased blowdown, which means operating the cooling tower system at lower cycles of concentration, requires more make-up water and produces more wastewater for disposal. Increase of make-up leads to the increase of chemicals dosage. The minimum cycle of concentration should be maintained at six (6) for fresh water cooling tower. Bleed-off control should refer to the Section 5.2 of this Code of Practice.

3.4.4 Magnetic devices

This method involves the exposure of recirculating water under magnetic field. Magnetic field affects the suspended solids or ions in solution to separate the charged particles or ions to prevent the deposition of a hardened deposit. The particles will then form a mobile suspension or do not precipitate at all. Also, existing deposits of scale can be converted into solution. The device may require protection from electromagnetic field generated by high-voltage electronic devices.

3.4.5 Electromagnetic technology

Electromagnetic technology produces a time-varying electromagnetic field, which induces electric field in water. Dissolved ions are then charged and collided with each other. Collisions between positive and negative ions facilitate precipitation of the ions in the pipework. This can avoid hard-lime scale by producing a non-adherent mineral powder in water. The technology should be applied to the recirculating water.

4. Bacterial and Microbiological Control

4.1 Causes of Bacterial and Microbiological Problems

4.1.1 Microbiological organisms enter the cooling tower system through make-up water and airborne particulates scrubbed in the cooling tower. Normally, micro-organisms that proliferate in cooling water systems include algae, fungi (yeast and mould) and bacteria.

Table 3.1: Possible types of micro-organisms existing in cooling water

Micro-organisms	Impact on cooling tower system
Algae	• Provide a nutrient source for bacterial growth • Deposit on surface contributes to localised corrosion process • Loosened deposits can block and foul pipework and other heat exchange surfaces
Fungi	• Proliferate to high number and foul heat exchanger surfaces
Bacteria	• Some types of pathogenic bacteria, such as Legionella, may cause health hazards • Sulphate reducing bacteria can reduce sulphate to corrosive hydrogen sulphide • Cathodic depolarisation by removal of hydrogen from the cathodic portion of corrosion cell • Acid producing bacteria produce organic acids, which cause localised corrosion of deposit laden distribution piping and also provide the potential for severe pitting corrosion of heat exchanger surface

4.1.2 In order to effectively control the growth of micro-organisms in cooling water, chemical and physical water treatment methods can be adopted.

4.2 Chemical Water Treatment Methods

4.2.1 General

Chemical biocides are the most common products to control the growth of micro-organisms. Different types of biocides should be used together to supplement the deficiency of each other. To dose two types of biocides alternatively can avoid micro-organisms to build up resistance against specific type of biocides. Selection of biocides depends on the required dose rates and contact times, field trials and prior experience of water treatment services providers.

4.2.2 Oxidising Biocide

4.2.2.1 Oxidising biocides are powerful chemical oxidants, which kill virtually all micro-organisms, including bacteria, algae, fungi and yeasts. Oxidising biocides are also capable to react with a wide range of organic substances including many of the constituents of bacterial cells. Therefore, they are effective in bacteria killing. Six common types of oxidising biocides are described below.

4.2.2.2 Chlorine

Chlorine is a widely adopted oxidising biocide, which processes chlorination for micro-biological control. It provides a residual biocide in the treated water and can be readily checked. In general, the dosage required is below 1 mg/L free residual chlorine. It is cheap and readily available as a pure gas, as well as in the form of various liquid and solid compounds. It can be dosed in the form of sodium hypochlorite. It may also be generated in situ by electrolysis of brine. Its effectiveness increases when it is used with other non-oxidising biocides and biological dispersants.

However, chlorination has several limitations in application, including:

- loss of effectiveness in alkaline waters (i.e. pH of 8 and greater);
- loss of effectiveness in the presence of contaminants, such as ammonia, methanol and ethylene glycol, etc.;
- corrosive towards common materials utilised in cooling tower installations;
- potential formation of less environmentally acceptable products;
- rapid degradation under heat and light.

Storage and handling of chlorine should comply with the Dangerous Goods Ordinance.

4.2.2.3 Chlorine dioxide

Chlorine dioxide is another disinfecting agent similar to free chlorine but having certain advantages. It is more effective than free chlorine at high pH values and in the presence of ammonia. Also, chlorine dioxide is very effective against *Legionella* and its relatively long half-life allows chlorine residual remains in cooling tower water circuit for a relatively long period. Chlorine dioxide is produced by mixing the chlorinated water from a normal chlorinator and sodium chlorite solution. The reaction takes place very quickly; however, the process is more costly than simple chlorination.

4.2.2.4 Bromine

Bromine is produced either by the reaction of sodium hypochlorite with sodium bromide on site, or from pellets. Bromine has certain advantages over chlorine, including:

- More effective at higher pH;
- Effective disinfectant at low dose rates;
- Effective in the presence of nitrogenous compounds and organics such as methanol and ethylene glycol;
- It kills micro-organisms more quickly;
- Reduced potential for systems corrosion;
- Lower environmental impact.

4.2.2.5 Iodine

Similar to chlorine and bromine, iodine is a good oxidising biocide. However, it is relatively expensive.

4.2.2.6 Ozone

Ozone is a powerful disinfectant agent and virus deactivant that is capable to oxidise many organic and inorganic compounds. Ozone kills bacteria by rupturing their cell walls, a process to which micro-organisms cannot develop resistance. Ozone controls micro-organisms completing by instantaneous kill. Residual ozone concentrations greater than or equal to 0.4 mg/L have been shown to result in a 100% kill in 2 to 3 minutes for *Pseudomonas fluorescens* (a biofilm producer) in a biofilm. The effectiveness of ozone is about 100 to 300 times more than chlorine.

Since ozone has a short half-life (usually less than 10 minutes), it readily decomposes into oxygen after oxidation. However, ozone may cause unwanted precipitation of iron and manganese and destroy commonly used inhibitors and dispersants. Also, injection equipment for ozone should be designed to provide adequate contact of the ozone with the circulating water and in larger system, multiple injection point may be required.

Application of ozone is not suitable under the following situations where excessive organic material in the water or high operating temperature has a high depletion of applied ozone:

- High organic loading from air, water or industrial processes that would require a high chemical oxygen demand (COD) since ozone oxidises the organics and insufficient residual may remain for the water treatment.
- Water temperatures that exceed 43.3°C since high temperatures decrease ozone residence time and reduce overall effectiveness of the ozone treatment.

- Make-up water is hard (>500 mg/L as CaCO_3) or dirty make-up water. Softening and/or prefiltering of make-up water is recommended.
- Long piping systems which may require long residence time to get complete ozone coverage.
- Installation in dusty and smoky environment, and hot places such as boilers, kitchen and their chimney and exhaust.

4.2.2.7 Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is a powerful oxidiser, with its power stronger than chlorine and chlorine dioxide, but weaker than ozone. However, it can be catalysed into hydroxyl radicals ($\text{OH}\cdot$), which is more powerful than ozone, for micro-organisms control. Catalysts, such as iron, copper or other transition metals compounds can be added to hydrogen peroxide to generate hydroxyl radicals for more rigorous oxidation. This is the most powerful method to destroy micro-organisms and trace organics in water.

Hydrogen peroxide decomposes into oxygen and water readily. It is a simple and effective treatment technology when comparing with conventional water treatment chemicals and does not cause any gaseous release or chemical residue problem. However, hydrogen peroxide is totally soluble in water, which may cause safety problems if high concentration ($>8\%$ H_2O_2 by weight) is used. Safety precaution in storage, delivery, handling and disposal of hydrogen peroxide should be considered, which should be complied with related guidelines, the Factory and Industrial Undertakings Ordinance and the Dangerous Goods Ordinance.

4.2.3 Application of oxidising biocide

4.2.3.1 The most effective use of oxidising biocides is to maintain a constant level of residual in the system. Oxidising biocides are usually maintained at a continuous level in the system. Dosage may be adjusted in response to regular testing but fully automatic control of biocide level in using reliable and durable redox measuring systems is desirable since overdosing can lead to increased corrosion and adversely affect the water treatment performance. Shock dosing is also applicable, which can enhance the effectiveness by faster killing action.

4.2.3.2 Since oxidising biocide may sometimes be corrosive, corrosion inhibitors should be added and selected to ensure compatibility. Characteristics of different types of commonly used oxidising biocides are listed in Appendix 3C for reference.

4.2.4 Non-oxidising Biocide

4.2.4.1 Non-oxidising biocides are organic compounds, which kill micro-organism by targeting specific element of the cell structure or its metabolic or reproductive process. However, it may be inactive against organisms having slightly different structure or cell processes.

4.2.4.2 Although non-oxidising biocides, such as quaternary ammonium salts or diamines, are sometimes found to be toxic, the low concentration application allows them to maintain in an acceptable limit for discharge. Isothiazolinones are biodegradable, which cause little adverse impacts to the environment. Glutaraldehyde is an effective and rapid-acting biocide and its reactivity prevents it from persisting to harm the environment. Non-oxidising biocides kill micro-organism by different mechanisms, prolonged use of a particular biocide may allow micro-organisms to develop resistance towards the chemicals. This can be prevented by adopting an alternating biocide regime. The table enclosed in Appendix 3D summarised the characteristics of some common non-oxidising biocides.

4.2.4.3 Non-oxidising biocides should be presented in sufficient concentration with adequate time for effective micro-biological control. System capacity, evaporation rate, bleed-off and make-up rates should be considered in calculating dosage concentration and frequency. Also, biocide hydrolysis (chemical degradation) rate affects the residual concentration of biocides containing in the cooling tower system. Concentration of biocides should be maintained at its minimum effective level to kill the micro-organisms at the end of the required contact time. The period between non-oxidising biocide additions should be based on the system half-life, with sequential additions timed to prevent re-growth of bacteria in the water. In order to ensure the effectiveness of non-oxidising biocides, monitoring of chemical concentration in cooling tower systems is required.

4.2.5 Biodispersants

Biodispersants are used to loose microbial deposits, which can then be killed by biocides or flushed away easily. They also expose new layers of microbial slime or algae to the attack of biocides. Biodispersants are an effective preventive measure because they make it difficult for micro-organisms to attach to equipment and / or pipework surfaces to form deposits. Biodispersants can greatly enhance performance of biocides, particularly oxidising biocides. Possible biodisperants include Acrylates, Lignosulphonates, Methacrylates and Polycarboxylic acids, etc.

4.3 Physical Water Treatment Methods

4.3.1 Ultraviolet Disinfection

- 4.3.1.1 Ultra-violet irradiation is commonly used to kill bacteria in drinking water, which can also be applied to cooling water systems. Specific wavelengths of electromagnetic radiation are used to inactivate micro-organisms through the denaturing of their DNA. Wavelengths ranging from 250 to 270 nanometres (nm) are effective in deactivating certain pathogens found in water.
- 4.3.1.2 Bacteria are vulnerable to UV light and can be killed, provided that light of the correct wavelength and intensity can penetrate individual cell walls. Effectiveness is compromised by the obstructing effect of particulate suspended solids or water turbidity, as well as deposition of solids on the light source. In order to maintain a wide coverage of UV light, it is necessary to install a filter located upstream of the UV lamp.
- 4.3.1.3 Ultra-violet irradiation systems can be controlled by UV source intensity and water flow rate. The dose of UV light is measured as the product of intensity and exposure time, as milliwatt-seconds per square centimetre ($\text{mW/s}\times\text{cm}^2$). The minimum UV dosage requirement is 20 $\text{mW/s}\times\text{cm}^2$. It is desirable to have integral monitoring instruments to ensure the lamp performance is not degraded. Also, regular cleaning of quartz sleeves surfaces and UV sensors are required to prevent particles from obstructing the UV light.

4.3.2 Copper and Silver Ionisation

- 4.3.2.1 Ionisation indicates the electrolytic generation of copper and silver ions in cooling tower water. If properly managed, copper and silver ion concentrations at 20 to 30 $\mu\text{g/L}$ and 10 to 15 $\mu\text{g/L}$ respectively can be effective to kill bacteria in the systems. The ions assist in the control of bacterial populations in the presence of a free chlorine residual of at least 0.2 mg/kg .
- 4.3.2.2 It should be noted that in hard water systems, silver ion concentrations is difficult to maintain due to build-up of scale on the electrodes, and the high concentration of dissolved solids precipitating the silver ions out of solution. For both hard and soft water, the ionisation process is pH sensitive and it is difficult to maintain silver ion concentrations above pH 7.6. It is not recommended to adopt ionisation in systems having steel or aluminium heat exchanger since deposition of the copper ion and subsequent galvanic corrosion is significant.

4.3.3 Magnetic devices

This method involves the exposure of recirculating water under magnetic field. Magnetic field causes water, solutes and suspended solids to be exposed to steady interaction and then create an electrical current to flow in the fluid-flow. The current can cause biological activity in living organism that may disrupt energy flows and lead to disruption of cell membranes. The device may require protection from electromagnetic field generated by high-voltage electronic devices.

4.3.4 Electromagnetic technology

Electromagnetic technology is not only effective in scale control (refer to Section 3.4.5), but also in bacterial control. It avoids hard-lime scale by producing a non-adherent mineral powder in water. Bacteria are encapsulated into this mineral powder and cannot reproduce, thereby resulting in low bacteria populations. This technology can also control microbiological corrosion. However, for other types of corrosion, other treatment methods may be applied.

5. Water Treatment System Controls and Monitoring

5.1 Chemical Dosing

5.1.1 Water treatment chemicals should be added to turbulent zones of cooling tower water system to achieve rapid mixing and well distribution of chemicals. Also, separate dosing point should be used to ensure potentially reactive chemical is diluted prior to adding the second chemical so that no chemical reaction between different chemicals will be occurred to reduce the effectiveness. The dosage concentration of chemicals, including inhibitors and biocides, should be calculated based on the total quantity of water, make-up water quality and bleed-off rate.

5.1.2 The purpose of most chemical treatment control programmes (other than certain biocides) is to maintain a constant concentration in the recirculating water at all times. In order to maintain a stable chemical concentration in cooling water, a number of application methods can be adopted, including:

- a) Shot/slug dosing;
- b) Continuous/intermittent dosing;
- c) Proportional dosing related to bleed-off volume;
- d) Proportional dosing related to make-up water volume;
- e) Dosing controlled by sensor.

5.1.3 Shot/slug dosing

Chemicals are added to the system manually on a routine basis. Shot/slug dosing is the most economic and effective application method, which may be adopted in small-scale cooling tower installation. However, it is not recommended because chemical concentration cannot be controlled accurately and large fluctuations in chemical levels are always found.

5.1.4 Continuous/intermittent dosing

Continuous/intermittent dosing makes use of mechanical devices, such as timer and pump for chemical dosing. It is the simplest type of automatic dosing system. Since chemical dosing frequency and amount is regulated by the pre-set value, fluctuation of chemical concentration inside cooling tower water is always found.

5.1.5 Proportional dosing related to bleed-off volume

System bleed-off can be controlled by conductivity sensor or make-up water flow. Signal from the device can also be used to initiate chemical dosing. When the conductivity of the system water reaches a pre-determined value, a timer can be actuated which allows a dosage pump to run for a period to add the requisite amount of chemicals, in relation to the make-up water entered the system. A delay timer should be installed to prevent wasteful chemical addition during bleed-off.

5.1.6 Proportional dosing related to make-up water volume

Proportional dosing maintains a nearly constant chemical level by dosing in proportion to a varying make-up water rate. The treatment requirement is based on make-up water quantity and injection rate varies as the water make-up changes. Impulse water meter installed in make-up line should be used to activate a chemical dosing pump. Proportional dosing can be applied to all cooling tower systems continuously. Such dosing is particular benefit to systems which operate under conditions with great varieties.

5.1.7 Dosing controlled by sensor

Dosing controlled by sensor is ideal for controlling chemical concentration in a system. Correct amount of chemical is continuously presented to the system once the dosing rate and frequency are gauged by operational parameters. Therefore, concentration of chemicals inside cooling tower water can be maintained within a designated range. pH sensor, redox probes and oxidation reduction potential (ORP) probes are commonly used to control dosing of acids and oxidising biocides, respectively.

5.2 Bleed-off Control

5.2.1 For an accurate bleed-off control system, automatic control by conductivity sensor is recommended to regulate the amount of bleed-off required. Conductivity is a measure of total ionic concentration in water, hence, concentration of total dissolved solids (TDS). Bleed-off control is a critical part to ensure scale prevention in cooling tower systems.

5.2.2 Bleed-off rate is related to the cycle of concentration, which should be determined by water treatment methods being adopted. If a comprehensive water treatment programme, including both chemical and physical methods, is implemented to control scale, corrosion and micro-biological growth effectively, bleed-off rate can be significantly reduced.

5.2.4 For conductivity control, the cooling water conductivity is continuously monitored and the bleed-off valve is opened at a pre-set conductivity.

- 5.2.5 A number of points should be considered for a bleed-off system.
- a) To ensure the bleed assembly can be isolated from the system for maintenance purposes;
 - b) To ensure the head of the conductivity sensing probe is positioned in the main water flow, but not where air pockets can develop;
 - c) To place the conductivity sensing probe upstream of the bleed-off system solenoid valve;
 - d) To clean the conductivity sensing probe regularly;
 - e) To regulate valve in the bleed line so that the flow cannot exceed the make-up water to the system;
 - f) To provide an alarm signal when solenoid valve and flow switch signals in the bleed-off line do not correspond.

5.3 Integrated Control and Monitoring System

- 5.3.1 It is recommended to integrate the water treatment system to:
- a) IoT Water treatment controller with cloud-based water treatment management software*; and/or
 - b) Central server based Central Control and Monitoring System (CCMS) or Building Management System (BMS) of the building.

*Attention should be paid to assure cyber security of cloud-based control system.

- 5.3.2 The integrated control and monitoring system allows the system operator and water treatment service provider, etc. to real-time remote monitor and/or control the water treatment system. This control and monitoring strategy may have the following advantages:
- a) Accurate dosing control is assured which optimises chemical usages;
 - b) Bleed-off and chemical dosage would not occur at the same time and time delay of bleed-off after chemical dosage shall be considered so that wastage of chemicals on drainage can be avoided;
 - c) Adjustment of water treatment programme in accordance with cooling tower system operation can be performed in the central control system;
 - d) Minimal chemical handling is required to reduce the risks of the operators' health and safe;
 - e) Water consumption, energy consumption, chemicals consumptions are recorded accurately;
 - f) Any malfunction of water treatment equipment can be reported immediately; and
 - g) Real time control and monitoring with real time alert is available via online interface.

5.4 Monitoring Devices

5.4.1 Sensors are generally used as monitoring devices in cooling tower system. Comparison between the measuring results and the set points for specific parameter are useful to determine the control action required for normal operation. Different type of sensors to be selected is relied on the control strategy. Common types of sensors are described as follows.

5.4.2 Flow meter

Chemical feeding requirements are proportional to the make-up water flow. Many chemical feeding systems are designed according this basis, which is the simplest automatic dosing method. Flow meters including orifices venturi, flow tubes and turbine meters can be used to suit the design.

5.4.3 Level sensor

Make-up water supply to cooling tower sump depends on water level of cooling tower basin. Hence, chemical dosing can be controlled by monitoring of the water level. However, this dosing method is not accurate and cannot control the concentration of chemicals contained in the cooling system water precisely.

5.4.4 Conductivity sensor

Electrical conductivity of water relies on total ionic concentration of water, which indicates the concentration of total dissolved solids (TDS) in water. Both corrosion rate and scale formation potential for any specific systems are normally proportional to the conductivity of water. Conductivity sensor is frequently employed as chemical detection device. The sensor is usually used for bleed-off system for the control of cycles of concentration.

5.4.5 pH sensor

Carbon steel corrosion rate decreases with an increase in pH value, and the scale potential for most scale forming compounds increases with pH value. Also, water treatment chemicals work in specific range of pH value. Hence, pH value measurement is often the basic principle for acid dosing to maintain effective water treatment programme.

5.4.6 ORP probe

ORP probe is used as real time monitoring and recording of oxidation reduction potential, which can be utilised to monitor chlorine residuals in cooling tower systems. It measures the inorganic and organic particles remains in cooling water so as to facilitate chemical dosing. ORP probe should be used together with pH sensor since ORP values vary with pH value.

5.4.7 Chlorine residuals sensor

Chlorine is commonly employed biocide for cooling tower system. Continuously measuring chlorine residual analyser is commercially available to measure either free or total chlorine residual.

5.4.8 Turbidity sensor

Turbidity measurement provides an indication of the amount of suspended solids in cooling water, which is useful in determining deposit potential. Therefore, it can be used for bleed-off control.

5.4.9 Corrosion rate sensors

Corrosion rate sensors are available in the market to provide continuous, instantaneous measurement of corrosion rates for any alloy. These sensors are normally based on linear polarisation resistance between a pair of electrodes. Corrosion coupon test method can also be used to determine corrosion rate.

5.4.10 Sensors for specific ions and Compounds

Sensors are commercially available to measure ion concentrations in water. Many analysers are also available to measure either compounds or classes of compounds or classes of compounds dissolved in water.

5.4.11 The selection of proper location of sensors in the fresh water cooling tower system is very important. Sensors measuring treatment chemicals should be located at a point after the treatment is well mixed. Corrosion rate increases with increasing temperature. Therefore, corrosion monitoring device should be installed at the outlet of the heat exchanger where water with the highest temperature is passing through. Requirement of measurement and reliability of sensor should also be considered in selecting an appropriate device.

5.5 Control Devices

5.5.1 In order to achieve maximum effectiveness of water treatment programme, chemicals must be dosed into the system in an appropriate concentration periodically. Since handling of chemicals may be dangerous, it is always recommended to perform chemical dosing by means of automatic monitoring and control strategy. Chemical injection can be facilitated by different control devices.

5.5.2 Timer

It is a simple device allowing operator to set the operation of chemical dosing valve, hence, chemical dosing frequency, in a fix interval. Also, circulation of water during system intermittent down time can be achieved by using timer control.

5.5.3 Dosing pump

Dosing pump can be operated manually or automatically. For automatic control, dosing pump activates upon receiving signal from timer or sensors. It runs for a certain period to inject chemicals into the cooling tower water circuit.

5.5.4 Motorised valve

Motorised valve is an essential component for automatic controlled chemical dosing and bleed-off. It will switch to open/close position upon receipt of signal from monitoring devices, such as water meter and conductivity sensor.

6. Occupational Safety and Health

- 6.1. Sufficient personal protective equipment should be provided to the personnel responsible to carry out pre-commissioning and commissioning work of a cooling tower system. Recommended list of personal protective equipment required related to different job nature is shown in Appendix 3E.
- 6.2. Training in safe work procedure, including the use and maintenance of protective equipment should be provided to the personnel carrying out the cooling tower system commissioning.
- 6.3. Water treatment may involve application of relatively aggressive and toxic chemicals, which is the major concern. All personnel involved must be fully conversant with the safe handling of the products.
- 6.4. Material safety data sheet (MSDS) and relevant recognised data sheet for chemicals used in water treatment process should be provided by water treatment services providers and included in the operation and maintenance manual. MSDS and relevant warning/safety label should be provided on the surface of water treatment chemical bucket. The MSDS and labels should be properly protected against water and chemical damage.
- 6.5. Eye wash bottles or washing basin with fresh water tap should be provided adjacent to water treatment chemicals tanks or any appropriate location for emergency use. However, the water contained in the eye wash bottle should be replaced periodically.
- 6.6. Water treatment chemical should be stored at an appropriate location to facilitate chemical handling.
- 6.7. Mechanical/natural ventilation should be provided to the room entirely/partially used for water treatment chemical storage.
- 6.8. Electrical fittings and luminaries serving water treatment chemical storage area should be weather-proof and corrosion resistant type.
- 6.9. Warning signs should be erected to alert for operation and maintenance personnel of the potential hazard caused by cooling tower.

- 6.10. Warning signs should also be erected to restrict the unauthorised access to cooling towers.
- 6.11. Workers exposed to hazardous substances and engaged in processes of cleaning and disinfection and water treatment should undergo regular health surveillance with a medical practitioner. In case any worker develops respiratory, cutaneous and other symptoms when exposed to hazardous chemicals, immediate medical attention should be sought.

7. Reference Information

The following Ordinances, Technical Memorandum and Code of Practice should be complied with in selecting water treatment methods for cooling towers:

- Waterworks Ordinance (WWO) (Cap. 102)
- Buildings Ordinance (BO) (Cap. 123)
- Sewage Services Ordinance (SSO) (Cap. 463)
- Water Pollution Control Ordinance (WPCO) (Cap. 358)
- Air Pollution Control Ordinance (APCO) (Cap. 311)
- Noise Control Ordinance (NCO) (Cap. 400)
- Occupational Safety and Health Ordinance (OSHO) (Cap. 509)
- Public Health and Municipal Services Ordinance (PHMSO) (Cap. 132)
- Buildings Energy Efficiency Ordinance (BEEO) (Cap. 610)
- Technical Memorandum on Standards for Effluent Discharged into Drainage and Sewerage System, Inland and Coastal Waters, EPD
- Technical Memorandum for the Assessment of Noise from Places other than Domestic Premises, Public Places or Construction Sites, EPD
- Fresh Water Cooling Towers Scheme, EMSD
- Code of Practice for the Prevention of Legionnaires' Disease, PLDC

Appendix 3A Common Types of Corrosion Inhibitors

Corrosion Inhibitors	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Anodic Type						
Orthophosphates	5 - 20 (as PO ₄)	6.5 - 8.5	By promoting the formation of gamma iron oxide film at the anode.	Applicable but no specific advantage.	- Well control of the system is required to control sufficient dissolved oxygen (DO) in water for oxide film formation. - Deposits of iron phosphate can form anodes if corrosion starts and encourages under-deposit corrosion. - Formation of orthophosphate leads to precipitation of calcium phosphates.	Calcium phosphate scale inhibitors are always included in phosphate based corrosion inhibitor.
Molybdate	50 - 150 (as MoO ₄)	7.0 - 8.5	By forming a protective film of molybdate anions complex with oxidised iron.	- Less toxic compare with chromate. - Can prevent pitting corrosion and underdeposit corrosion crack.	- Expensive - Sensitive to chlorine and sulphate.	
Nitrite	250-1 000	9 - 9.5	By promoting the formation of gamma iron oxide film at the anode.	Applicable but no specific advantage.	- Subject to biological degradation, which leads to the loss of inhibitor and biofouling problems. - Require careful control in open recirculating system as it can be easily oxidised to nitrate in open system.	
Cathodic Type						
Polyphosphate (Molecular dehydrated, condensed polymeric, poly and metaphosphates)	10 - 20	6.5 - 8.5	By forming either calcium or heavy metal polyphosphate films on the cathodic surface of the metal.	Water quality insensitive.	Certain bacterial enzymes increase the reversion rate of polyphosphates. Formation of orthophosphate leads to precipitation of calcium phosphates.	Calcium phosphate scale inhibitors are always included in phosphate based corrosion inhibitor.

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Corrosion Inhibitors	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Organic Phosphorous Compounds (Phosphonates)	10 - 20	7 - 9	By forming protective film on metal surface with metal ions.	- Water quality insensitive. - Phosphonates do not revert to orthophosphate, thus no calcium orthophosphate deposition.	No specific limitation.	Require either calcium or metal ion, such as zinc, for effective corrosion inhibition.
Zinc Salt	0.5 - 2	6.5 – 7.5	By forming Zinc hydroxide or another sparingly soluble zinc salt.	Applicable but no specific advantage.	Above pH 7.5, zinc hydroxide precipitates from solution as hydroxides or as various organic zinc salts.	The pH range can be extended upward by including stabiliser to prevent zinc precipitation.
Mixed Type						
Zinc/Phosphonate	1 – 5 (as Zn)	7 – 8.5	By forming protective film on metal surface with metal ions.	- A more tenacious and protective film can be formed by adding zinc. - Reduction in the dosage concentration when comparing with the usage of phosphonate only.	- Hardness sensitive. - Reduced rate of film formation.	
Zinc/Polyphosphate	7- 20 (as PO ₄)	6 – 7.5	By forming either calcium or heavy metal polyphosphate films on cathodic surface of metal.	- A more tenacious and protective film can be formed by adding zinc. - Reduction in the dosage concentration when comparing with the usage of polyphosphate only.	- Biological nutrient. - Reduced rate of film formation.	

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Corrosion Inhibitors	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Zinc/Polymeric Carboxylates	2 - 5 (as Zn)	7 – 8.5	By forming protective film on metal surface with metal ions.	- A more tenacious and protective film can be formed by adding zinc. - Reduction in the dosage concentration when comparing with the usage of polymeric carboxylates only.	- Toxic to fish. - Reduced rate of film formation.	
Zinc/Phosphate Esters	4 – 10 (as Zn)	7 – 8.0	By forming protective film on metal surface with metal ions.	- A more tenacious and protective film can be formed by adding zinc. - Reduction in the dosage concentration when comparing with the usage of phosphate esters only.	- A Toxic to fish. - Potential increase in biological oxygen demand. - Reduced rate of film formation.	
Phosphonate/ Polyphosphate	5 – 15 (as PO ₄)	7 – 9.0	By forming protective film on metal surface with metal ions.	Prevent hydrolysis.	- It may act as biological nutrient - Calcium phosphate sludge may be formed.	
Molybdate/ Phosphonate	5 – 20 (MoO ₄)	7 – 8.5	By forming protective film on metal surface with metal ions.	Improved corrosion protection can be achieved at lower concentrations of molybdate when blended with organic inhibitors.	Film formation ability remains relatively weak, and the level of protection is marginal in corrosive environments.	

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Corrosion Inhibitors	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Adsorption						
Benzotriazole (BTA)	1 - 5 ppm	6 – 9	By bonding directly with cuprous oxide at the metal surface to form protective layer.	Applicable but no specific advantage.	Toxic	Act as copper corrosion inhibitor
Tolytriazole (TTA)	1 - 5 ppm	6 – 9	By bonding directly with cuprous oxide at the metal surface to form protective layer.	Applicable but no specific advantage.	No specific limitation.	Act as copper corrosion inhibitor

Appendix 3B Common Types of Scale Inhibitors

Scale Inhibitors	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Polyphosphate [Inorganic]	1 - 5	6.8 - 7.5	By forming complexes with iron and manganese ion to prevent the deposition of iron and manganese containing salts.	- Cost effective - Highly soluble in water, thus low concentration is required - Low order of toxicity	It has a tendency to hydrolyse and revert back to orthophosphate and forms insoluble calcium orthophosphate.	Can be used for calcium carbonate and calcium sulphate inhibition
Organic polymer	10 - 15	Not specified	By modifying the morphology and size of the scale particles.	- No hydrolysis problem when compared with polyphosphate - More hydrolytically stable in highly alkaline environment.	Low calcium tolerance	It should be used together with anionic or non-ionic type non-oxidising biocide.
Sodium Polyacrylate	2 - 3	Not specified	By increasing the solubility of calcium phosphate, distorting the crystal growth of calcium phosphate, so as to form non-adherent precipitate.	Applicable but no specific advantage.	No specific limitation.	Can be used for calcium carbonate and calcium phosphate inhibition

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Scale Inhibitors	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Organic phosphorus compound [e.g.: phosphonates, Organic Phosphonic Acid]						
Aminotris [methylene phosphonic acid] (AMP)	10 - 20	7 - 9	By sequestering the ions to reduce the rate of precipitation and stabilise iron and manganese.	No hydrolysis problem when compare with polyphosphate	- Attack rapidly by oxidising biocides - Careful dosage is required to prevent precipitation	Can be used for calcium carbonate inhibition
(1- hydroxyethylidene) diphosphonic acid (HEDP)	5 - 40	7 - 9	By sequestering the ions to reduce the rate of precipitation and stabilise iron and manganese.	No hydrolysis problem when compare with polyphosphate	- Careful dosage is required to prevent precipitation - Attack slowly by oxidising biocides	Can be used for calcium carbonate inhibition
2- Phosphonobutane – 1,2,4-tricarboxylic acid (PBTC)	20 - 40	7 - 9	By sequestering the ions to reduce the rate of precipitation and stabilise iron and manganese.	- No hydrolysis problem when compare with polyphosphate - Stable to oxidising biocides	Careful dosage is required to prevent precipitation	Can be used for calcium carbonate inhibition

Appendix 3C Common Types of Oxidising Biocides

Oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Chlorine	2 - 20	6 - 8	By reacting with water to form hypochlorous acid, which destroys bacteria's structure by oxidation.	■ Economic and readily available. ■ Broad-spectrum activity. ■ Simple monitoring for dosage and residuals.	■ Loss of effectiveness in alkaline water (pH≥8) ■ Hydrochloric acid is by-product of the reaction which decreases system pH. ■ Loss of effectiveness in the presence of contaminants: ○ Nitrogen compound ○ Ammonia ○ Hydrocarbon ○ Methanol ○ Ethylene glycol ○ Iron ○ Manganese ○ Sulphides ■ Degrades rapidly under heat and UV light. ■ Potential corrosion problem. ■ Potential formation of environment unacceptable formulation of environment unacceptable degradation.	■ Free chlorine residuals: 0.2-1mg/L (continuous). ■ 0.5-2mg/L (periodic slug-dose). ■ Effectiveness increases with the usage of non-oxidising biocides and biological dispersants.

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Oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Sodium hypochlorite Solution (Bleach)	1 - 3	6 - 7.5	By reacting with water to form hypochlorous acid which destroys bacteria's structure by oxidation.	■ Broad-spectrum activity. ■ Simple monitoring for dosage and residuals. ■ Compare with chlorine gas, it is easier to handle.	■ Loss of effectiveness in alkaline water (pH ≥ 7.5) ■ Potential scaling problem. ■ Expensive. ■ Sodium hydroxide is by-product of the reaction which increases system pH. ■ Loss of effectiveness in high pH since hypochlorous acid convert to hypochlorite ion. ■ Loss of effectiveness in the presence of contaminants: ○ Nitrogen compound ○ Hydrocarbon ○ Iron ○ Manganese ○ Sulfides ■ Degrades rapidly under heat and UV light.	■ Free chlorine residuals: 0.2 - 1 mg/L (continuous) ■ 0.5 - 2 mg/L (periodic slug-dose)
Calcium hypochlorite (Cal Hypo)	Not specified	6 - 7.5	By reacting with water to form hypochlorous acid which destroys bacteria's structure by oxidation.	■ Broad-spectrum activity ■ Simple monitoring for dosage and residuals.	■ Loss of effectiveness in alkaline water (pH ≥ 7.5) ■ Sodium hydroxide is by-product of the reaction which increases system pH. ■ Loss of effectiveness in high pH since hypochlorous acid convert to hypochlorite ion. ■ Loss of effectiveness in the presence of contaminants: ○ Nitrogen compound ○ Hydrocarbon ○ Iron ○ Manganese ○ Sulfides ■ Degrades rapidly under heat and UV light.	■ Free chlorine residuals: 0.2 - 1 mg/L (continuous) ■ 0.5 - 2 mg/L (periodic slug-dose)

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Oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Chlorine dioxide	0.1 - 5	4 - 10	By disrupting the transportation of nutrient across the cell wall of bacteria and removing biofilm from the system.	■ pH insensitive. ■ Powerful oxidising agent. ■ Unlike bleach and chlorine, it can be used in the system containing nitrogen and organic compound. ■ Good solubility. ■ Dissolves iron sulphide.	■ Can be degraded by sunlight and UV. ■ Expensive. ■ On-site generation by special equipment is required.	■ Residuals: 0.2 mg/L (continuous) ■ 0.5 - 1.0 mg/L (slug-dose)
Trichloroisocyanuric acid [TCCA]	0.5	7 - 8	By reacting with water to form hypochlorous acid which destroys bacteria's structure by oxidation.	■ Broad-spectrum activity. ■ Easy management. ■ Safe and easier to handle when compare with other common chlorine base biocides.	■ Loss of effectiveness in high pH since hypochlorous acid convert to hypochlorite ion. ■ Loss of effectiveness in the presence of contaminants: ○ Nitrogen compound ○ Hydrocarbon ○ Iron ○ Manganese ○ Sulphides	■ Free chlorine residuals: 0.2 – 1 mg/L (continuous). ■ 0.5 – 2 mg/L (periodic slug-dose).
Halogenated Hydantoin e.g.: bromo-3-chloro-5, 5-dimethylhydantoin (BCDMH), Dichloro-5, 5-dimethylhydantoin	Not specified	7 - 10	By reacting with water to form hydrobromous acid and/or hypochlorous acid which kill bacteria by oxidation.	■ Maintain its effectiveness in alkaline condition.	■ Loss of effectiveness in the presence of contaminants: ○ Hydrocarbon ○ Iron ○ Manganese	

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Oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Sodium bromide	Not specified	7 - 10	By reacting with water to form hydrobromous acid which destroys bacteria's structure by oxidation.	Activated sodium bromide becomes more effective by increasing pH of the system.	- Addition of activating agent (such as chlorine gas and bleach) is required. - Loss of effectiveness in the presence of contaminants: - Hydrocarbon - Iron - Manganese - Degrades rapidly under heat and UV light.	- Total halogen residuals: 0.2 - 0.5 mg/L (continuous) 0.5 - 2.0 mg/L (periodic slug-dose)
Hydrogen peroxide	Not specified	7 - 9	By decomposition to release free oxygen radicals which destroys proteins of the micro-organisms by oxidation.	No residues produces and create no effluent problem.	High concentration required.	Extra safety precaution should be considered in storage and handling of hydrogen peroxide
Ozone	1 - 5	7 - 9	By decomposition to release hydroxyl radicals which will oxidise components of bacteria and make direct destruction.	- Powerful oxidising agent - No residues produce and create no effluent problem. - No re-growth of micro-organism - Fast kill rate	- Unstable, must be generated on-site before use. - Leaving no residue in water and make it difficult to be detected. - Very reactive and corrosive, not suitable to use in system constructed by low corrosion resistance materials. - May cause unwanted precipitation of iron and manganese - May destroy inhibitors and dispersants. - Not suitable to be used in hard make-up water (> 500 mg/L as CaCO₃).	- Multi ingestion may require in large system to ensure full protection. - Air pre-treatment and side-stream filtration of cooling tower water can enhance the performance of ozone. - Air conditioning system or mechanical ventilation system is required to remove excessive heat generated by ozone generator plant.

Appendix 3D Common Types of Non-oxidising Biocides

Non-oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Carbamate e.g.: Sodium dimethyldithiocarbamate, Potassium dimethyldithiocarbamate	12 - 18	7 - 8.5	By interrupting cell metabolism to kill micro-organism by chelation for essential metallic ions.	- Against fermentation-producing organisms. - Practically effective at low pH or in the presence of heavy metal.	React with metal and cause potential corrosion problem.	
2,2-dibromo-3-nitripropionamide (DBNPA)	1 - 2	6 - 8.5	- By attacking the cell wall of bacteria to interfere transportation of materials. - By binding with protein to interfere metabolism of bacteria.	Fast acting biocidal action.	- Not effective against algae. - Hydrolyses rapidly with pH $\geq$ 8.0. - Photodegradable - Not compatible with hydrogen sulphide, organic contaminant or strong reducing agents.	
Isothiazolines	0.5 - 2	6.5 - 9.0	By inhibiting food transport through the cell wall and microbial respiration.	- Effective against both general aerobic and spear-forming bacteria. - Effective under wide range of pH value	Fair performance to act as algicides.	

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Part 3: Water Treatment Methods

Non-oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Methylene-bis(thiocyanate) (MBT)	0.5 - 1	6 - 7.5	- By blocking electron transfer in micro-organism which prevent redox reaction. - By denaturing enzyme.	Fast kill rate	- Sensitive with pH and rapid hydrolysis occurs at pH ≥ 7.5 - Not very soluble in water - Poor penetration	MBT blended with Quats can have maximum effectiveness
Quaternary ammonium salts (Quats)	5 - 10	6.5 - 8.5	By forming electrostatic bond with the cell wall of bacteria which denature proteins and affect permeability.	- Effective for algae and bacteria. - Low-cost.	Deactivated by high hardness, chlorides, oil, dirt, silt and debris	
Poly[oxyethylene (dimethyliminio) ethylene-dimethyliminio] ethylene dichloride] (Polyquat)	3 - 6	7.5 - 9.0	By forming electrostatic bond with the cell wall of bacteria which affect permeability and denature protein	- Safe. - Broad spectrum. - Minimal risk of harsh skin irritation.	No specific limitation.	
Triazine group e.g.: 2-(tert-butylamino)-4-chloro-6-(ethylamino)-s-triazine	Not specified	0 - 14	By inhibiting the photosynthesis of algae.	- Excellent for killing algae - Operates at full range of pH - Non-foamer - Not interfere by hardness	No specific limitation.	

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Part 3: Water Treatment Methods

Non-oxidising Biocides	Common Dosage [mg/L]	Applicable pH Range	Working Principles	Advantages	Limitations	Remarks
Tributyl tetradecyl phosphonium chloride (TTPC)	5 - 20	2 - 12	By surface acting properties, that cause severe damage to microbial cell membranes By deactivating cell enzyme processes.	■ Broad spectrum ■ Good for killing algae	■ No specific limitation.	
Glutaraldehyde	45 - 56	6.5 - 9.0	By cross-linking outer proteins of cell and preventing cell permeability.	■ Fast acting biocide ■ Effective to treat sulphur reducing bacteria and biofilms. ■ Short half-life and cause minimal environmental impact.	■ Limited effectiveness for killing algae and fungi.	

Appendix 3E

Recommendation List of Personal Protective Equipment

Job	Potential Hazard	Respirator and Clothing
Testing and commissioning	Aerosol	Half face piece, capable of filtering smaller than 5µm particulates, ordinary work clothing
Inspection	Aerosol	Half face piece, capable of filtering smaller than 5µm particulates, ordinary work clothing
Water Sampling	Aerosol	Half face piece, capable of filtering smaller than 5µm particulates, ordinary work clothing
High pressure spraying	Aerosol	Respirator as above, waterproof overalls, gloves, boots, goggles or face shield
Chemical treatment with sodium hypo-chlorite solution in ventilated space	Spray mist and very low concentration chlorine	Half face piece, acid gas and particulate respirator, goggles or face shield, overalls, gloves, and boots
As above, in confined space	Unknown chlorine concentration, high mist, possible lack of oxygen	To comply with the requirement under the Factories and Industrial Undertakings (Confined Spaces) Regulation

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