



Water Cooled Air Conditioning Systems Part 3

Two (2) Continuing Education Hour
Course #ME1013

Approved Continuing Education for Licensed Professional Engineers

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Course Description:

The Water Cooled Air Conditioning Systems Part 3 course satisfies two (2) hours of professional development.

The course is designed as a distance learning course and is the third course in a three part series overviewing water cooled air conditioning systems.

Objectives:

The primary objective of this course is enable the student to understand water-cooled air conditioning systems and the guidelines for cooling tower design, installation, testing, commissioning, operation and maintenance.

Grading:

Students must achieve a minimum score of 70% on the online quiz to pass this course. The quiz may be taken as many times as necessary to successful pass and complete the course.

A copy of the quiz questions are attached to last pages of this document.

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List of Abbreviation

AS	Australian Standard
AP	Authorized Person
AMP	Aminotris [methylene phosphonic acid]
APCO	Air Pollution Control Ordinance
APHA	American Public Health Association
ARI	Air Conditioning and Refrigeration Institute
BCYE	Buffered charcoal yeast extract
BCDMH	bromo-3-chloro-5, 5-dimethylhydantoin
BO	Buildings Ordinance
BOD ₅	5 days Biochemical oxygen demand
BS	British Standard
BTA	Benzotriazole
CFD	Computational Fluid Dynamic
CFU	Colony forming Unit
COD	Chemical Oxygen Demand
CoP	Code of Practice
CTSC	Cooling Tower Specialist Contractor
DBNPA	2,2-dibromo-3-nitrilopropionamide
DFA	Direct fluorescence antibody
DNA	Deoxyribonucleic acid
DSD	Drainage Services Department, HKSAR Government
EMSD	Electrical and Mechanical Services Department
EPD	Environmental Protection Department
FRP	Fibreglass Reinforced Polyester
HCC	Heterotrophic colony count
HEDP	(1-hydroxyethylidene) diphosphonic acid
ISO	International Organization for Standardization
MBT	Methylene-(bis)thiocyanate
MoO ₄	Molybdate

MSDS	Material safety data sheet
NCO	Noise Control Ordinance
NZS	New Zealand Standard
O&M	Operation and Maintenance
ORP	Oxidation Reduction Potential
OSHO	Occupational Safety and Health Ordinance
PBTC	2-Phosphonobutane-1,2,4-tricarboxylic acid
PCR	Polymerase chain reaction
PO ₄	Phosphosphate
ppm	Parts per million
PVC	Polyvinyl Chloride
Quats	Quaternary ammonium salts
RPE	Registered Professional Engineer
SSO	Sewage Services Ordinance
T&C	Testing and Commissioning
TBC	Total Bacteria Count
TCCA	Trichloroisocyanuric acid
TDS	Total Dissolved Solid
TTA	Tolytriazole
TTPC	Tributyl tetradecyl phosphonium chloride
WACS	Water-cooled Air Conditioning Systems
WPCO	Water Pollution Control Ordinance
WSD	Water Supplies Department
WWO	Waterworks Ordinance
Zn	Zinc

Definitions:

Aerosol	:	A suspension in a gaseous medium of solid particles, liquid particles or solid and liquid particles having negligible falling velocity.
Algae	:	Multicellular plants found in water or moist ground, that contain chlorophyll but lack true stems, roots and leaves.
Area of public access	:	Sitting-out area, playground or places where people would gather together for activities.
Bacteria	:	A microscopic, unicellular (or more rarely multicellular) organism (singular: bacterium).
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).
Corrosion resistant	:	Material that is not inherently susceptible to rapid corrosion under the conditions normally prevailing in the system.
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 grill-like arrangement of physical barriers located before the cooling tower exhaust designed to minimize 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.
Evaporative condenser	:	A heat exchanger in which refrigerant is cooled by a combination of air movement and water spraying.
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, emergency generator

(combustion gas), 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.
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	:	An illness characterized by pneumonia and caused by infection with legionella bacteria species, commonly Legionella pneumophila.
Legionella count	:	The number of Legionella colony-forming units (CFU's) found in one millilitre of the water sample.
Maintenance	:	Regular routine activity aimed at preserving the operational standard and cleanliness of equipment, which includes inspection, repair, preventive service and cleaning.
Maintenance programme	:	Assembly of relevant data and the setting out of a formal strategy and recording system for the effective management of a series of maintenance procedures.
Maintenance report	:	Written communication, giving details of the physical and operational state of a piece of equipment when maintenance is carried out, which is sent to the building owner or agent.
May	:	Indicates that a course of action is permissible and the existence of an option.
Medical and health facilities	:	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.
Oxidising biocide	:	Agents capable of oxidizing 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.
Pedestrian thoroughfares	:	A heavily travelled passage for the public from one place to another.
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.
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.
Shall	:	Indicates that the statement is mandatory.
Sludge	:	A build 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.

1. Introduction

1.1 Scope

This Part of the Code of Practice describes water treatment methods applicable in water-cooled air conditioning systems. It helps in minimizing the risk of using cooling towers, and optimizing 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 system owner, 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 cooling tower specialist contractors 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 to provide guidelines and technical reference for an appropriate water treatment programme design and implementation in water-cooled air conditioning systems so as to achieve the following objectives:

- a) Assure public health and safety by preventing any potential risks associated with water-cooled air conditioning system;
- b) Achieve better / maintain energy efficiency and operational performance of water-cooled air conditioning system;
- c) Minimize nuisances caused by water-cooled air conditioning system to the public;
- d) Prevent pollution and mis-use 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 building owners, cooling tower system owners, cooling tower system designers, building professionals, building and

services contractors, cooling tower specialist contractors, operation and maintenance staff responsible for design, operation and monitoring of cooling tower management programme. It shall be applied to both the newly installed and existing systems.

- 1.3.2 This Code of Practice shall be read in conjunction with any additional recommendations provided by cooling tower services providers and suppliers / manufacturers of the water treatment chemicals / cooling tower equipment and any relevant specification and applicable ordinances and regulations in Hong Kong.

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 principle methods to prevent corrosion in water-cooled air conditioning system include:

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

2.3 Chemical Water Treatment Methods

2.3.1 General

Several major chemical treatment methods can be used to minimize operational problems arising from corrosion and to assure efficient and reliable operation of water-cooled air conditioning 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;

- 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 water-cooled air conditioning 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 localized corrosion may occur at the points without effective protection by protective film. Therefore, sufficient safety margin shall 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 absorbed 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.

2.3.3 Passivation

In order to prevent corrosion on galvanized 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 galvanized steel from corrosion, which normally protects the metal for many years. The formation of zinc carbonate layer is called passivation, which shall 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 galvanized 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.

2.3.4 Seawater application

For seawater application, nitrites and phosphates at appropriate concentrations can provide adequate protection. Organic inhibitors can also be used to provide protection where nitrites cannot be used.

2.3.5 Other considerations

2.3.5.1 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 shall be implemented to suit all materials exposed to cooling tower system. The cooling tower system owner shall consult competent cooling tower specialist contractor / water treatment services provider to select appropriate corrosion inhibitors for specific system and material used.

2.3.5.2 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 shall be minimized by keeping the circulating water velocity in a reasonable range. The minimum water velocity shall 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 while magnesium dominates in seawater. 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 water-cooled air conditioning 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 water-cooled air conditioning 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 water-cooled air conditioning 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 minimized 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 Method

3.4.1 General

Physical treatment methods can also used to prevent scale formation in water-cooled air conditioning systems and are always considered as effective supplement in water treatment process. Also, many physical methods can improve water quality by minimizing 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 matter 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 25 μ m diameter inside cooling water. It shall 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 particles from about 100 μ m down to 1 μ m or less. Cartridge filters are typically disposable, which shall 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 10 μ m. Specialized fine sand media filters are designed to remove suspended particles down to less than 1 μ m. 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 20 μ m to 40 μ m.
- 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 shall be maintained at 6 for fresh water type cooling tower and 2 for seawater type cooling tower. Bleed-off control shall refer to the Section 5.2 of this Code.

3.4.4 Magnetic devices

This method involves the exposure of incoming make up water under the intense magnetic field. Magnetic field affects the suspended particles or the ions in solution and prevents 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. Some magnetic devices use permanent magnets and hence do not require electrical power input to the device.

3.4.5 Electronic de-scaling technology

Electronic de-scaling technology makes use of induced oscillating electric fields using time-varying magnetic fields generated in the solenoid wrapped around a water pipe. Dissolved ions are then charged and collided with each other. Collisions between positive and negative ions facilitate precipitation of the ions in the pipework. Electronic de-scaling technology can be used to enhance a chemical-based water

treatment programme. Selection of chemicals used in corrosion inhibition and micro-biological control shall be compatible with the technology. Scale inhibitor is not recommended to use together with this method. Also, filtration system is essential to remove any precipitate formed during the de-scaling process.

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.

Micro-organisms	Impact on cooling tower system
Algae	<ul style="list-style-type: none"> • Provide a nutrient source for bacterial growth • Deposit on surface contributes to localized corrosion process • Loosened deposits can block and foul pipework and other heat exchange surfaces
Fungi	<ul style="list-style-type: none"> • Proliferate to high number and foul heat exchanger surfaces
Bacteria	<ul style="list-style-type: none"> • Some types of pathogenic bacteria, such as Legionella, may cause health hazards • Sulphate reducing bacteria can reduce sulphate to corrosive hydrogen sulphide • Cathodic depolarization by removal of hydrogen from the cathodic portion of corrosion cell • Acid producing bacteria produce organic acids, which cause localized corrosion of deposit laden distribution piping and also provide the potential for severe pitting corrosion of heat exchanger surface

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

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 shall be used together to supplement the deficiency of each other. To dose two types of biocides alternatively can avoid micro-organisms to build up immunity against specific type of biocides. Selection

of biocides depends on the required dose rates and contact times, field trails and prior experience of water treatment services providers.

4.2.2 Oxidizing Biocide

4.2.2.1 Oxidizing biocides are powerful chemical oxidants, which kill virtually all micro-organisms, including bacteria, algae, fungi and yeasts. Oxidizing 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 oxidizing biocides are described below.

4.2.2.2 Chlorine

Chlorine is a widely adopted oxidizing 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 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-oxidizing 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 utilized in cooling tower installations;
- potential formation of less environmentally acceptable products;
- rapid degradation under heat and light.

Storage and handing of chlorine shall 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 oxidizing biocide. However, it is relatively expensive.

4.2.2.6 Ozone

Ozone is a powerful disinfectant agent and virus deactivant that is capable to oxidize many organic and inorganic compounds. Ozone kills bacteria by rupturing their cell walls, a process to which micro-organisms cannot develop immunity. 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 oxidization. However, ozone may cause unwanted precipitation of iron and manganese and destroy commonly used inhibitors and dispersants. Also, injection equipment for ozone shall 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 oxidizes 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 CaCO₃) 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 (H₂O₂) is a powerful oxidizer, with its power stronger than chlorine and chlorine dioxide, but weaker than ozone. However, it can be catalysed into hydroxyl radicals (OH[•]), 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% H₂O₂ by weight) is used. Safety precaution in storage, delivery, handling and disposal of hydrogen peroxide shall be considered, which shall be complied with related guidelines, Factory and Industrial Undertakings Ordinance and Dangerous Goods Ordinance.

4.2.3 Application of oxidizing biocide

4.2.3.1 The most effective use of oxidizing biocides is to maintain a constant level of residual in the system. Oxidizing 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 oxidizing biocide may sometimes be corrosive, corrosion inhibitors shall be added and selected to ensure compatibility. Characteristics of different types of commonly used oxidizing biocides are listed in Appendix 3C for reference.

4.2.4 Non-oxidizing Biocide

4.2.4.1 Non-oxidizing 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-oxidizing 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-oxidizing biocides kill micro-organism by different mechanisms, prolong usage of a particularly biocides may allow micro-organisms to develop resistance towards the chemicals. This can be prevented by adoption an alternating biocide regime. The table enclosed in Appendix 3D summarized the characteristics of some common non-oxidizing biocides.

4.2.4.3 Non-oxidizing biocides shall be presented in sufficient concentration with adequate time for effective micro-biological control. System capacity, evaporation rate, bleed-off and make up rates shall 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 shall be maintained at its minimum effective level to kill the micro-organisms at the end of the required contact time. The period between non-oxidizing biocide additions shall 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-oxidizing 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 oxidizing biocides. Possible biodisperants include Acrylates, Ligonsulphonates, 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 matter 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 ($\text{mW/s}\cdot\text{cm}^2$). The minimum UV dosage requirement is $20 \text{ mW/s}\cdot\text{cm}^2$. 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 ionization in systems having steel or aluminium heat exchanger since deposition of the copper ion and subsequent galvanic corrosion is significant.

5. Water Treatment System Controls and Monitoring

5.1 Chemical Dosing

5.1.1 Water treatment chemicals shall be added to turbulent zones of cooling tower water system to achieve rapid mixing and well distribution of chemicals. Also, separate dosing point shall be used to ensure dilution of one potentially reactive chemical prior to adding the second chemical. The dosage concentration of chemicals, including inhibitors and biocides, shall 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 simple timer, 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 shall 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 shall 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 oxidizing 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 water-cooled air conditioning systems.

5.2.2 Bleed-off rate is related to the cycle of concentration, which shall 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.

5.2.3 There are a number of methods to control bleed-off, including:

- a) manual control: a bleed valve is opened in response to test measurements

- b) timer / intermittent control: a simple interval timer is set to open and close the bleed valve intermittently
- c) continuous bleed: an orifice plate or pre-set valve is set to release water continuously
- d) proportional control: an impulse water meter on the make up line actuates the bleed valve
- e) conductivity control: the cooling water conductivity is continuously monitored and the bleed-off valve is opened at a pre-set conductivity.

5.2.4 A number of points shall 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 Central Monitoring and Control

Water treatment monitoring can be controlled through Building Management System (BMS). It co-ordinates the entire system operation and water treatment programme. This control strategy may have the following advantages:

- a) Accurate dosing control is assured which optimizes chemical usages;
- b) Bleed-off and chemical dosage would not occur at the same time 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 consumption are recorded accurately; and
- f) Any malfunction of water treatment equipment can be reported immediately.

5.4 Monitoring Devices

5.4.1 Sensors are generally used as monitoring devices in water-cooled air conditioning 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 utilized 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 shall 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 water-cooled air conditioning system. Continuously measuring chlorine residual analyzer 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 matter 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 polarization 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 analyzers are also available to measure either compounds or classes of compounds or classes of compounds dissolve in water.

5.4.11 The selection of proper location of sensors in the water-cooled air conditioning system is very important. Sensors measuring treatment chemicals shall 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 shall 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 Motorized valve

Motorized 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 shall 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 shall 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 recognized data sheet for chemicals used in water treatment process shall be provided by water treatment services providers and included in the operation and maintenance manual. MSDS and relevant warning / safety label shall be provided on the surface of water treatment chemical bucket. The MSDS and labels shall be properly protected against water and chemical damage.
- 6.5** Eye wash bottles or washing basin with fresh water tap shall be provided adjacent to water treatment chemicals tanks or any appropriate location for emergency use. However, the water contained in the eye wash bottle shall be replaced periodically.
- 6.6** Water treatment chemical shall be stored at an appropriate location to facilitate chemical handling.
- 6.7** Mechanical / natural ventilation shall 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 shall be weather-proof and corrosion resistant type.
- 6.9** Warning signs shall be erected to alert for operation and maintenance personnel of the potential hazard caused by cooling tower.
- 6.10** Warning signs shall 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 shall 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 shall be sought.

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.	<ul style="list-style-type: none"> ▪ Applicable but no specific advantage. 	<ul style="list-style-type: none"> ▪ 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. 	<ul style="list-style-type: none"> ▪ 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 oxidized iron.	<ul style="list-style-type: none"> ▪ Less toxic compare with chromate. ▪ Can prevent pitting corrosion and underdeposit corrosion crack. 	<ul style="list-style-type: none"> ▪ Expensive ▪ Sensitive to chlorine and sulphate. 	

Corrosion Inhibitors	Common Dosage [mg/L]	Applicable PH range	Working Principles	Advantages	Limitations	Remarks
Nitrite	250-1000	9-9.5	By promoting the formation of gamma iron oxide film at the anode.	<ul style="list-style-type: none"> Applicable but no specific advantage. 	<ul style="list-style-type: none"> 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 oxidized 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.	<ul style="list-style-type: none"> Water quality insensitive. 	<ul style="list-style-type: none"> Certain bacterial enzymes increase the reversion rate of polyphosphates. Formation of orthophosphate leads to precipitation of calcium phosphates. 	<ul style="list-style-type: none"> Calcium phosphate scale inhibitors are always included in phosphate based corrosion inhibitor.
Organic Phosphorous Compounds (Phosponates)	10-20	7-9	By forming protective film on metal surface with metal ions.	<ul style="list-style-type: none"> Water quality insensitive. Phosponates do not revert to orthophosphate, thus no calcium orthophosphate deposition. 	<ul style="list-style-type: none"> No specific limitation. 	<ul style="list-style-type: none"> Require either calcium or metal ion, such as zinc, for effective corrosion inhibition.

Corrosion Inhibitors	Common Dosage [mg/L]	Applicable PH range	Working Principles	Advantages	Limitations	Remarks
Zinc Salt	0.5-2	6.5 – 7.5	By forming Zinc hydroxide or another sparingly soluble zinc salt.	<ul style="list-style-type: none"> ▪ Applicable but no specific advantage. 	<ul style="list-style-type: none"> ▪ Above pH 7.5, zinc hydroxide precipitates from solution as hydroxides or as various organic zinc salts. 	<ul style="list-style-type: none"> ▪ The pH range can be extended upward by including stabilizer 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.	<ul style="list-style-type: none"> ▪ 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. 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ 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. 	<ul style="list-style-type: none"> ▪ Biological nutrient. ▪ Reduced rate of film formation. 	

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.	<ul style="list-style-type: none"> ▪ 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. 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ 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. 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ Prevent hydrolysis. 	<ul style="list-style-type: none"> ▪ It may act as biological nutrient ▪ Calcium phosphate sludge may be formed. 	

Corrosion Inhibitors	Common Dosage [mg/L]	Applicable PH range	Working Principles	Advantages	Limitations	Remarks
Molybdate / Phosphonate	5 –20 (MoO ₄)	7 – 8.5	By forming protective film on metal surface with metal ions.	<ul style="list-style-type: none"> Improved corrosion protection can be achieved at lower concentrations of molybdate when blended with organic inhibitors. 	<ul style="list-style-type: none"> Film formation ability remains relatively weak, and the level of protection is marginal in corrosive environments. 	
Adsorption						
Benzotriazole (BTA)	1 - 5 ppm	6 – 9	By bonding directly with cuprous oxide at the metal surface to form protective layer.	<ul style="list-style-type: none"> Applicable but no specific advantage. 	<ul style="list-style-type: none"> Toxic 	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> Applicable but no specific advantage. 	<ul style="list-style-type: none"> No specific limitation. 	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> ▪ Cost effective ▪ Highly soluble in water, thus low concentration is required ▪ Low order of toxicity 	<ul style="list-style-type: none"> ▪ It has a tendency to hydrolyze and revert back to orthophosphate and forms insoluble calcium orthophosphate. 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ No hydrolysis problem when compared with polyphosphate ▪ More hydrolytically stable in highly alkaline environment. 	<ul style="list-style-type: none"> ▪ Low calcium tolerance 	<ul style="list-style-type: none"> ▪ It shall be used together with anionic or non-ionic type non-oxidizing biocide.

Scale Inhibitors	Common Dosage [mg/L]	Applicable pH range	Working principles	Advantages	Limitations	Remarks
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.	<ul style="list-style-type: none"> Applicable but no specific advantage. 	<ul style="list-style-type: none"> No specific limitation. 	<ul style="list-style-type: none"> Can be used for calcium carbonate and calcium phosphate inhibition
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 stabilize iron and manganese.	<ul style="list-style-type: none"> No hydrolysis problem when compare with polyphosphate 	<ul style="list-style-type: none"> Attack rapidly by oxidizing biocides Careful dosage is required to prevent precipitation 	<ul style="list-style-type: none"> 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 stabilize iron and manganese.	<ul style="list-style-type: none"> No hydrolysis problem when compare with polyphosphate 	<ul style="list-style-type: none"> Careful dosage is required to prevent precipitation Attack slowly by oxidizing biocides 	<ul style="list-style-type: none"> 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 stabilize iron and manganese.	<ul style="list-style-type: none"> No hydrolysis problem when compare with polyphosphate Stable to oxidizing biocides 	<ul style="list-style-type: none"> Careful dosage is required to prevent precipitation 	<ul style="list-style-type: none"> Can be used for calcium carbonate inhibition

Appendix 3C

Common Types of Oxidizing Biocides

Oxidizing 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.	<ul style="list-style-type: none"> ▪ Economic and readily available. ▪ Broad-spectrum activity. ▪ Simple monitoring for dosage and residuals. 	<ul style="list-style-type: none"> ▪ 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: <ul style="list-style-type: none"> ○ Nitrogen compound ○ Ammonia ○ Hydrocarbon ○ Methanol ○ Ethylene glycol ○ Iron ○ Manganese ○ Sulphides ▪ Degrades rapidly under heat and UV light. ▪ Potential corrosion problem. ▪ Potential formation of environment formulation of environment unacceptable degradation 	<ul style="list-style-type: none"> ▪ Free chlorine residuals: 0.2-1mg/L (continuous). ▪ 0.5-2mg/L (periodic slug-dose). ▪ Effectiveness increases with the usage of non-oxidizing biocides and biological dispersants.

Oxidizing 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.	<ul style="list-style-type: none"> ▪ Broad-spectrum activity. ▪ Simple monitoring for dosage and residuals. ▪ Compare with chlorine gas, it is easier to handle. 	<ul style="list-style-type: none"> ▪ Loss of effectiveness in alkaline water (pH \geq 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: <ul style="list-style-type: none"> ○ Nitrogen compound ○ Hydrocarbon ○ Iron ○ Manganese ○ Sulfides ▪ Degrades rapidly under heat and UV light. 	<ul style="list-style-type: none"> ▪ Free chlorine residuals: 0.2-1mg/L (continuous) ▪ 0.5-2mg/L (periodic slug-dose)

Oxidizing Biocides	Common Dosage (mg/L)	Applicable pH range	Working Principles	Advantages	Limitations	Remarks
Calcium hypochlorite (Cal Hypo)	Not specified	6-7.5	By reacting with water to form hypochlorous acid which destroys bacteria's structure by oxidation.	<ul style="list-style-type: none"> ▪ Broad-spectrum activity ▪ Simple monitoring for dosage and residuals. 	<ul style="list-style-type: none"> ▪ 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: <ul style="list-style-type: none"> ○ Nitrogen compound ○ Hydrocarbon ○ Iron ○ Manganese ○ Sulfides ▪ Degrades rapidly under heat and UV light. 	<ul style="list-style-type: none"> ▪ Free chlorine residuals: 0.2-1mg/L (continuous) ▪ 0.5-2mg/L (periodic slug-dose)

Oxidizing 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.	<ul style="list-style-type: none"> ▪ pH insensitive. ▪ Powerful oxidizing agent. ▪ Unlike bleach and chlorine, it can be used in the system containing nitrogen and organic compound. ▪ Good solubility. ▪ Dissolves iron sulphide. 	<ul style="list-style-type: none"> ▪ Can be degraded by sunlight and UV. ▪ Expensive. ▪ On-site generation by special equipment is required. 	<ul style="list-style-type: none"> ▪ Residuals: 0.2mg/L (continuous) ▪ 0.5-1.0mg/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.	<ul style="list-style-type: none"> ▪ Broad-spectrum activity. ▪ Easy management. ▪ Safe and easier to handle when compare with other common chlorine base biocides. 	<ul style="list-style-type: none"> ▪ Loss of effectiveness in high pH since hypochlorous acid covert to hypochlorite ion. ▪ Loss of effectiveness in the presence of contaminants: <ul style="list-style-type: none"> ○ Nitrogen compound ○ Hydrocarbon ○ Iron ○ Manganese ○ Sulphides 	<ul style="list-style-type: none"> ▪ Free chlorine residuals: 0.2-1mg/L (continuous). ▪ 0.5-2mg/L (periodic slug-dose).

Oxidizing Biocides	Common Dosage (mg/L)	Applicable pH range	Working Principles	Advantages	Limitations	Remarks
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.	<ul style="list-style-type: none"> ▪ Maintain its effectiveness in alkaline condition. 	<ul style="list-style-type: none"> ▪ Loss of effectiveness in the presence of contaminants: <ul style="list-style-type: none"> ○ Hydrocarbon ○ Iron ○ Manganese 	
Sodium bromide	Not specified	7-10	By reacting with water to form hydrobromous acid which destroys bacteria's structure by oxidation.	<ul style="list-style-type: none"> ▪ Activated sodium bromide becomes more effective by increasing pH of the system. 	<ul style="list-style-type: none"> ▪ Addition of activating agent (such as chlorine gas and bleach) is required. ▪ Loss of effectiveness in the presence of contaminants: <ul style="list-style-type: none"> ○ Hydrocarbon ○ Iron ○ Manganese ▪ Degrades rapidly under heat and UV light. 	<ul style="list-style-type: none"> ▪ Total halogen residuals: 0.2-0.5mg/L (continuous) ▪ 0.5-2.0mg/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.	<ul style="list-style-type: none"> ▪ No residues produces and create no effluent problem. 	<ul style="list-style-type: none"> ▪ High concentration required. 	<ul style="list-style-type: none"> ▪ Extra safety precaution shall be considered in storage and handling of hydrogen peroxide.

Oxidizing Biocides	Common Dosage (mg/L)	Applicable pH range	Working Principles	Advantages	Limitations	Remarks
Ozone	1-5	7-9	By decomposition to release hydroxyl radicals which will oxidize components of bacteria and make direct destruction.	<ul style="list-style-type: none"> ▪ Powerful oxidizing agent ▪ No residues produce and create no effluent problem. ▪ No re-growth of micro-organism ▪ Fast kill rate 	<ul style="list-style-type: none"> ▪ 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). 	<ul style="list-style-type: none"> ▪ 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-oxidizing Biocides

Non-oxidizing 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.	<ul style="list-style-type: none"> ▪ Against fermentation-producing organisms. ▪ Practically effective at low pH or in the presence of heavy metal. 	<ul style="list-style-type: none"> ▪ React with metal and cause potential corrosion problem. 	
2,2-dibromo-3-nitrilopropionamide (DBNPA)	1-2	6-8.5	<ul style="list-style-type: none"> ▪ By attacking the cell wall of bacteria to interfere transportation of materials. ▪ By binding with protein to interfere metabolism of bacteria. 	<ul style="list-style-type: none"> ▪ Fast acting biocidal action. 	<ul style="list-style-type: none"> ▪ Not effective against algae. ▪ Hydrolyzes rapidly with $\text{pH} \geq 8.0$. ▪ 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.	<ul style="list-style-type: none"> ▪ Effective against both general aerobic and spore-forming bacteria. ▪ Effective under wide range of pH value 	<ul style="list-style-type: none"> ▪ Fair performance to act as algicides. 	

Non-oxidizing Biocides	Common Dosage (mg/L)	Applicable pH range	Working Principles	Advantages	Limitations	Remarks
Methylene-(bis)thiocyanate (MBT)	0.5-1	6-7.5	<ul style="list-style-type: none"> ▪ By blocking electron transfer in micro-organism which prevent redox reaction. ▪ By denaturing enzyme. 	<ul style="list-style-type: none"> ▪ Fast kill rate 	<ul style="list-style-type: none"> ▪ Sensitive with pH and rapid hydrolysis occurs at pH \geq 7.5 ▪ Not very soluble in water ▪ Poor penetration 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ Effective for algae and bacteria. ▪ Low-cost. 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ Safe. ▪ Broad spectrum. ▪ Minimal risk of harsh skin irritation. 	<ul style="list-style-type: none"> ▪ 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.	<ul style="list-style-type: none"> ▪ Excellent for killing algae ▪ Operates at full range of pH ▪ Non-foamer ▪ Not interfere by hardness 	<ul style="list-style-type: none"> ▪ No specific limitation. 	

Non-oxidizing 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.	<ul style="list-style-type: none"> ▪ Broad spectrum ▪ Good for killing algae 	<ul style="list-style-type: none"> ▪ No specific limitation. 	
Glutaraldehyde	45-56	6.5-9.0	By cross-linking outer proteins of cell and preventing cell permeability.	<ul style="list-style-type: none"> ▪ Fast acting biocide ▪ Effective to treat sulphur reducing bacteria and biofilms. ▪ Short half life and cause minimal environmental impact. 	<ul style="list-style-type: none"> ▪ Limited effectiveness for killing algae and fungi 	

Appendix 3E

Recommendation List for Personal Protective Equipments

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, 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

Water Cooled Air Conditioning Systems Part 3 Quiz

1. What is the purpose of a turbidity sensor?

- Measure the corrosion rates
- Measure the pH value
- Measure the ion concentrations in the water
- Measure the amount of suspended matter in the cooling water

2. What are the two main types of scale inhibitors?

- Water softener and filter
- Water softeners & threshold inhibition chemicals
- Threshold inhibition chemicals & scale conditioners
- Scale conditioners & water softeners

3. What is a simple way to reduce the levels of calcium and alkalinity in the water?

- Increasing the bleed-off rate
- Increase the drift loss rate
- Decrease the drift loss rate
- Decreasing the bleed-off rate

4. Biodispersants are used to:

- Loosen microbial deposits
- Ionize the water
- Filter the water
- Kill bacteria in the water

Water Cooled Air Conditioning Systems Part 3 Quiz

5. What causes scaling?

- Evaporation
- Hardness
- All of the above
- Precipitation of mineral particles

6. What is a commonly used method to kill bacteria in a cooling water system?

- Ultra-violet irradiation
- Silver ionization
- Copper ionization
- Gold ionization

7. Which is an advantage of using bromine over chlorine?

- Lower environmental impact
- Reduces potential for systems corrosion
- Kills micro-organisms more quickly
- All of the above

8. What is the formation of the zinc carbonate layer called?

- Corrosion
- Passivation
- Erosion
- Adsorption

Water Cooled Air Conditioning Systems Part 3 Quiz

9. Why is shot/slug dosing not recommended?

- It cannot be controlled accurately
- It is not an economic method
- It is not an effective method
- It causes small fluctuations

10. Which is not a type of corrosion inhibitor?

- Cathartic
- Osmosis
- Anodic
- Absorption

11. Which is a type of filtration system?

- In-line
- Side-stream
- Two step
- Both A and B

12. Which is a principle method to prevent corrosion?

- Selecting suitable materials and chemicals
- Controlling scaling
- All of the above
- Controlling micro-biological growth

Water Cooled Air Conditioning Systems Part 3 Quiz

13. Which is not an objective of Part 3 of the Code of Practice for Water Cooled Air Conditioning Systems?

- Maintain energy efficiency and operational performance**
- Minimize nuisances caused by water-cooled air conditioning system**
- Minimization of water loss**
- Prevent pollution and misuse of water**

14. Which is a control device to facilitate chemical injections?

- Motorized valve**
- Timer**
- All of the above**
- Dosing pump**

15. How many types of corrosion inhibitors are there?

- 5**
- 2**
- 3**
- 4**