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COOLING TOWER AND BOILER WATER TREATMENT TERMINOLOGIES

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COOLING TOWER AND BOILER WATER TREATMENT TERMINOLOGIES

ABSTRACT

There has been a special partnership of the United Nations Industrial Development Organization (UNIDO) and the US Environmental Protection Agency (USEPA) for transferring the US new and well-established technologies to the developing countries and disseminating the useful technical information to the entire world. This publication is one of many technology transfer documents prepared by the Lenox Institute of Water Technology (LIWT). It introduces the UNIDO, USEPA, LIWT, and the cooling tower and boiler water treatment terminologies. The terminology subjects cover the following areas: the types of cooling tower and boiler, water treatment systems, make-up water, blowdown, drift, leakage, cycle of concentrations, ton of refrigeration, water quality parameters, water quality standards, operational problems, scale, biofilm, fouling, corrosion, inhibitors, chemical treatment, non-chemical physical water treatment, physicochemical treatment, green innovations, operation and management (O&M), O&M optimization, water recycle, and water reuse considerations.

KEYWORDS: United Nations Industrial Development Organization (UNIDO), US Environmental Protection Agency (USEPA), Lenox Institute of Water Technology (LIWT), Terminologies, Cooling Tower, Boiler, Water Treatment Systems, Make-Up Water, Blowdown, Drift, Leakage, Cycle Of Concentrations, Ton Of Refrigeration, Water Quality Parameters, Water Quality Standards, Operational Problems, Scale, Biofilm, Fouling, Corrosion, Inhibitors, Chemical Treatment, Non-Chemical Physical Water Treatment, Physicochemical Treatment, Green Innovations, Operation And Management (O&M), Optimization, Water Recycle, Water Reuse.

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INTRODUCTION OF UNIDO, USEPA AND LIWT

United Nations Industrial Development Organization (UNIDO): It is a specialized agency of the United Nations (UN) with about 170 member states. The member states regularly discuss and decide UNIDO’s guiding principles and policies in their sessions of the policymaking organs. The UNIDO's mission is to promote a new humanity science of industrial ecology (IE) and accelerate inclusive and sustainable industrial development (ISID) in member states. Natural resources recovery, environmental sustainability, and proper management solid, liquid and gaseous wastes are emphasized within ISID. The UNIDO's programmatic focus is structured, as detailed in the UNIDO's Medium-Term Program Framework 2018-2021, in four strategic priorities: (a) creating shared prosperity; (b) advancing economic competitiveness; (c) safeguarding the environment; and Strengthening knowledge and institutions. Since UNIDO is mainly assisting developing countries, so some industrialized countries which are the UN member states have refused to pay the UNIDO membership fees becoming the UNIDO member states.

US Environmental Protection Agency (EPA): It is an agency of the U.S. government that sets and enforces national pollution-control standards. In 1970, President Richard Nixon created the USEPA to fix national guidelines and to monitor and enforce them. Functions of three federal departments (of the Interior, of Agriculture, and of Health, Education, and Welfare) and of other federal bodies were transferred to the new agency. The USEPA was initially charged with the administration of the Clean Air Act (CAA) (1970), enacted to abate air pollution primarily from industries and motor vehicles; the Federal Environmental Pesticide Control Act (FEPCA) (1972); and the Clean Water Act (CWA) (1972), regulating municipal and industrial wastewater discharges and offering grants for installing wastewater collection and treatment facilities. By the mid-1990s the USEPA was enforcing 12 major statutes, including laws designed to control uranium mill tailings; ocean dumping; safe drinking water; insecticides, fungicides, and rodenticides; solid wastes, hazardous wastes, industrial effluent pre-treatment, and asbestos hazards in schools. The Resource Conservation and Recovery Act (RCRA)(1976) is the most important public law that creates the framework for the proper management of hazardous and non-hazardous solid waste. The RCRA law describes the solid waste management program mandated by the US Congress that gave USEPA authority to develop the RCRA program. In addition to the responsibility of enactment and enforcement of environmental laws, regulations, and rules, USEPA has also played its excellent leadership (XL) role in (a) developing new environmental technologies, environmental training programs, technical manuals, fact sheets, guidelines, Internet information platforms, and international programs assisting the developing countries; (b) giving construction grants to the municipalities for improving their environmental infrastructure; and (c) giving research grants to the universities and institutes for continuous environmental science and engineering investigations.

Lenox Institute of Water Technology (LIWT): It is a non-profit college in Massachusetts, USA, with expertise in environmental STEM (science, technology, engineering and mathematics) education, R&D, invention, process development, monitoring system/methods development, patent application, licensing, fund raising, engineering design and project management. LIWT teams up with Krofta Engineering Corporation (KEC), for technology transfer, equipment design, and voluntary humanitarian global service through free education, training, and academic publications. (34)

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Acidity: Acidity is a measurement of the capacity of a water to neutralize strong base. It is usually expressed in terms of mg/L of calcium carbonate ($CaCO_3$).

Advanced oxidation process (AOP): It is a physicochemical process in which ultraviolet light (UV) is used together with ozone (or other oxidizing agent) to oxidize compounds. The ultraviolet light in AOP catalyzes the decomposition of the oxidizing agent (such as ozone) to hydroxyl radicals (.OH), which are very strong oxidizing compounds. The Perozone process using both ozone (O_3) and hydrogen peroxide (H_2O_2) to generate the hydroxyl radicals is also an AOP, and Perozone also significantly enhances the oxidation and disinfection reactions.

Alkalinity: Alkalinity is the presence of acid neutralizing, or acid buffering minerals, in the water. Primary contributors to alkalinity are carbonate (CO_3^{-2}), bicarbonate (HCO_3^-), and hydroxide (OH^-). Additional alkaline components may include phosphate (PO_4^{-3}), ammonia (NH_3), and silica (SiO_2), though contributions from these ions are usually relatively small.

Anion exchange: An ion exchange process involving the use of anion exchanger (anionic ion exchange resin), mainly for removal of negatively charged ions, such as sulfate, phosphate, chloride, etc. from water.

Approach: It is the difference between the temperature of the cold water leaving a cooling tower and the wet-bulb temperature of the air. Establishment of the approach fixes the operating temperature of the cooling tower system and is an important parameter in determining both the cooling tower size and its cost.

Automate chemical feed system: An automated chemical feed system can regulate chemicals (e.g., biocides, scale inhibitors, corrosion inhibitors) that are being added to a cooling tower or boiler system.

Automation - Automation systems are available providing a broad range of capacities to control single or multiple parameters in the cooling system such as conductivity and blowdown control, pH control, and real-time chemical monitoring and dosing. Blowdown controllers are available from several different commercial suppliers and offer a range of control points from simple conductivity/blowdown control, to timed or meter relay chemical dosing. Many of them incorporate water meter inputs and alarm relays if threshold measurements are exceeded.

Backwash: The process of reversing the flow of water back through the filter media to remove the entrapped solids.

Bacteria: The principal bacterial waterborne diseases of the middle latitudes, typhoid fever and cholera, are two highly specific infections that exacted their awful toll of sickness and death in the cities emerging from the industrial revolution. *Paratyphoid (salmonellosis)* and *bacillary dysentery* *(shigellosis)* as well as *hemorrhagic jaundice (leptospirosis)*, are waterborne diseases in a less direct sense.

Base: any substance which contains hydroxyl (OH) groups and furnishes hydroxide ions in solution; a molecular or ionic substance capable of combining with a proton to form a new substance; a substance that provides a pair of electrons for a covalent bond with an acid; a solution with a pH of greater than 7.

Basin leaks or overflows of cooling tower: Properly operated towers should not have leaks or overflows. Check float control equipment to ensure the basin level is being maintained properly, and check system valves to make sure there are no unaccounted for losses.

Batch-flow sedimentation: One or more basins sized to receive a volume of flow, such as spent filter backwash water, in a specific period of time. The flow is detained for a specific period of time to allow sedimentation, and then the tank is emptied. The cycle repeats automatically.

Biocides: It is a commercially available chemical that can kill or inhibit the growth of small living organisms, such as bacteria, fungi, slimes ad molds. Typical biocides used in industrial cooling tower include: chlorine gas, sodium hypochlorite, bromine, chlorine dioxide (ClO_2), and ozone. Sometimes ozone is not considered to be a commercially available chemical because it must be generated on-site using air and/or oxygen.

Biofilm inhibitor: Biocides (chlorine, hypochlorite, bromine, chlorine dioxide, or ozone) can be the biofilm inhibitors. Another common biofilm inhibitor used in cooling tower water treatment , especially for algae control of cooling tower water is copper sulfate ($CuSO_4$). It is a chemical prepared from copper and sulfuric acid.

Biofilms: Biofilms are problematic for multiple reasons. They have strong insulating properties, they contribute to fouling and corrosion, and the biproducts they create that contribute to further micro-biological activity. They can be found in and around the tower structure, or they can be found in chiller bundles, on heat exchangers surfaces, and in the system piping. Additionally, biofilms and algae mats are problematic because they are difficult to kill. Careful monitoring of biocide treatments, along with routine measurements of biological activity are important to ensure bio-activity is controlled and limited throughout the cooling system.

Biofouling and microbiological control: Biofilm formation to reduce heat transfer efficiency significantly in the chiller tubes or Legionella bacteria growth to cause diseases are of biofouling phenomena. Reduction of biofouling requires microbiological control. Cooling towers provide an ideal environment for bacterial development, such as, warm water temperatures, nutrients from the environment, and sunlight. Inadequate microbiological control can lead to biofouling. Biofilm releases a polysaccharide layer for protection, which will continue to grow. The underlying layer is home to anaerobic bacteria that can lead to acid generation, which will attack the underlying metal. According to the Centers for Disease Control and Prevention (CDC), in 2016, as many as 6,100 cases of Legionnaires' disease were reported, of which 10 percent were fatal.

Blowdown (or bleed off): It is a portion of the circulating water in the tower, which is purposely discharged to waste to help keep the total dissolved solids (TDS) concentration of the water below a maximum allowable limit. As a result of evaporation, TDS concentration will continually increase unless reduced by bleed off. Fresh make-up water replaces the blowdown wastewater, evaporation loss, drift loss and leaks. The blowdown is necessary to limit scaling from the water. A higher COC means less blowdown compared to the makeup water. Typical COC in commercial applications is 2 to 4. Depending on water conditions and ongoing monitoring, significant added benefit can be achieved by taking COC to eight or more cycles. When systems operate at high cycles, managing corrosion rates, suspended solids, and microbial growth may become more challenging unless there is good quality monitoring procedure and supply water.

Blowdown controllers; A blowdown controller is an apparatus offerring continuous monitoring and the blowdown control of the cooling tower system. This ensures high conductivity is avoided, minimizing scaling and corrosive conditions and minimizes excessive blowdown which wastes water.

Blowdown treatment or bleed-off treatment: A cooling tower periodically disposes of concentrated liquid and solid waste prior to water reuse or effluent discharge. Cycles of concentration (COC) is a ratio that measures how concentrated solids are in the cooling tower process water compared to the fresh makeup water. COC generally is done by measuring the conductivities of the makeup water and the blowdown. The higher the COC, the better the cooling tower can tolerate impurities and the less makeup water will be needed.

Boiler and steam systems: Boiler and steam systems can be used in multifamily properties for space and water heating. Hot water boilers are used to provide hot water for bathing, laundry, dishwashing, or similar operations. Hot water boiler distribution systems can be open or closed. Open systems provide hot water to end uses, such as bathing and laundry, and closed systems are used for building heating. Water efficiency isn't a primary concern for hot water boiler systems.

British Thermal Unit (BTU): It is the heat energy required to raise the temperature of one pound of water one degree Fahrenheit in the range from 32° F to 212° F.

Bromine (Br_2): In water bromine is present as hypobromous acid (HOBr) and the hypobromite ion (OBr^-) for disinfection reactions. Bromine often is used in cooling tower water treatment, and it is more stable and effective in alkali waters,. It does not produce harmful chloramines. The disadvantage is that the extreme reactivity of bromine in water requires frequent dosing. In addition, bromine is more expensive than sodium hypochlorite.

Calcium (Ca): Ca is one of the major elements making up the earth's crust.

Calcium and magnesium, carbonate and bicarbonate: Hard water and soft water are relative terms. Hard water retards the cleaning action of soaps and detergents, causing an expense in the form of extra work and cleaning agents. Furthermore, when hard water is heated it will deposit a hard scale (as in a kettle, heating coils, or cooking utensils) with a consequent waste of fuel. Calcium and magnesium salts, which cause hardness in water supplies, are divided into two general classifications: (a) carbonate or temporary hardness and (b) noncarbonate or permanent hardness. Carbonate or temporary hardness is so called because heating the water will largely remove it. When the water is heated, bicarbonates break down into insoluble carbonates that precipitate as solid particles which adhere to a heated surface and the inside of pipes. Noncarbonate or permanent hardness is so called because it is not removed when water is heated. Noncarbonate hardness is due largely to the presence of the sulfates and chlorides of calcium and magnesium in the water. The classifications of water based on hardness are: (a) soft water, 0-40 mg/L of total hardness as

$CaCO_3$; (2) moderately hard water, 40-100 mg/L of total hardness as $CaCO_3$; (c) hard water, 100-300 mg/L of total hardness as $CaCO_3$; (d) very hard water, 300-500 mg/L of total hardness as $CaCO_3$; and (e) extremely hard water, greater than 500 mg/L of total hardness as $CaCO_3$. The total hardness in drinking water is unregulated in the U.S. The Mexico maximum allowable limit for total hardness and Canada recommended concentration for total hardness in drinking water are both 500 mg/L as $CaCO_3$.

Calcium carbonate ($CaCO_3$): It is white crystalline compound that occurs naturally as marble, limestone, etc. and is sparingly soluble sale. Its solubility decreases with increasing temperature, therefore, it has high potential to form scaling if it reaches the supersaturation condition.

Cartridge filter: It is a filtration device that has a pressure vessel containing one or more cartridges of filter media for removal of particles from water.

Cartridge filtration: It is a filtration process that has a pressure vessel containing one or more filter cartridges of a specified nominal (or absolute) pore size rating used for removal of particles from water.

Cathodic protection : A corrosion control method that involves reduction or elimination of corrosion by making the metal a cathode by means of an impressed direct current or attachment to a sacrificial anode (such as, magnesium, aluminum, zinc, etc.).

Cation exchange : An ion exchange process involving the use of cation exchanger (cationic ion exchange resin), mainly for removal of calcium, magnesium, iron, and other positively charged metal ions.

Caustic soda: sodium hydroxide, NaOH.

Cavitation: It is a phenomenon happening during the formation and sudden collapse of vapor bubbles in a liquid, usually resulting from local low pressures, as on the trailing edge of a propeller. Cavitation phenomenon develops a momentary high local pressure that can physically destroy a portion of a surface, such as scale film, or biofouling film, on a surface on which the bubbles collapse.

Cavitation systems: It is a physical system for treating the cooling tower water. Cavitation systems can cause the formation and collapse of low-pressure bubbles in a water stream imparting a shock wave and resultant high temperature region within the water flow. The energy created during the implosion promotes precipitation of minerals in the water stream, instead of forming a scale film that reduces the heat transfer efficiency of a chiller tube.

Centralized mechanical systems: A centralized mechanical system provides heating and cooling from a central location, such as a mechanical room or utility penthouse, and can include cooling towers, boilers, and steam systems, each of which uses water as the heat transfer medium. As a result, the use of water for building heating and cooling can be significant, and using sound management practices is a good opportunity for water savings.

Chemical coagulation: It is a chemical reaction or unit process in which colloidal and finely divided suspended matter are destabilized and aggregated together due to addition of inorganic coagulant or polyelectrolyte.

Chemical precipitation : (a) A chemical process in which one chemical agent precipitates another soluble chemical; (b) It is a chemical reaction or unit process in which insoluble solids are generated from the soluble matters by changing the equilibrium conditions of a solution, or by adding chemicals that react with the soluble matters.

Chemical treatment for cooling tower: Water Chemicals are typically used in cooling tower water treatment to extend the ability of the cooling water to hold scaling materials in suspension, to minimize corrosion by neutralizing acidity, and inhibit biological growth through use of algaecides and biocides, for example, phosphoric acid to inhibit scale formation, bases such as lime or carbonates to reduce increased alkalinity, and chlorine gas, sodium hypochlorite, chlorine dioxide or bromine for biologic control.

Chemical: It is substance produced or used in a chemical reaction.

Chemical-free Platforms - In recent years many innovations have been made in systems that provide chemical-free treatment replacements to traditional treatment platforms. These include systems that are singular in their target treatment,

Chiller: It is a component of a heat exchanger which is designed to remove heat from a gas (such as air), or a liquid (such as water, or refrigerant) stream.

Chloramination : A disinfection process that involves the mixing of chlorine and ammonia for production of mainly monochloramine and a small amount of dichloramine, in turn, for disinfection of water storage tank and distribution system.

Chlorides (Cl^-): Most waters contain some chloride ions. The amount of chloride present can be caused by the leaching of marine sedimentary deposits, by pollution from sea water, brine, or wastewaters. Chloride concentrations in excess of about 250 mg/L usually produce a noticeable taste in drinking water. In areas where the chloride content is higher than 250 mg/L and all other criteria are met, it may be necessary to use a water source that exceeds this limit. An increase in chloride content in water may indicate possible pollution from waste sources, particularly if the normal chloride content is known to below. Accordingly 250 mg/L is the maximum allowable limit in Mexico, and also the recommended limit in the U.S. and Canada.

Chlorination: It is the most commonly used water or wastewater disinfection process. This process involves the addition of elemental chlorine or hypochlorite to the water. When chlorine is used, it combines with water to form hypochlorous (HOC1) and hydrochloric (HC1) acids. Hydrolysis goes virtually to completion at pH values and concentrations normally experienced in municipal and cooling tower water treatment applications. Hypochlorous acid will ionize to hypochlorite (OCl) ion, with the amount greatly affected by pH. Therefore, the tendency of hypochlorous acid to dissociate to hypochlorite ion should be discouraged by maintaining a pH below 7.5. The amount of chlorine added is determined by cylinder weight loss. Chlorine demand is determined by the difference between the chlorine added and the measured residual concentration after a certain period has passed from the time of addition. This is usually 15-30 minutes. The chlorine or hypochlorite is rapidly mixed with the wastewater, after which it passes through a detention tank, which normally contains baffled zones to prevent short circuiting of water. Either chlorine or hypochlorite salts can be used in a chlorination process. The two most common hypochlorite salts are calcium and sodium hypochlorite.

Chlorine (Cl_2): The reaction of chlorine gas and water results in hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-), which is the disinfectant. Chlorine gas disinfection reaction is dependent on pH. Typically, it is effective at pH lower than 7.5. As the cycles of concentration increase, so does the water pH. As a result, operators need to dose acid to reduce the pH level.

Chlorine Dioxide (ClO_2). Chlorine dioxide is a red-yellow gas that is a strong oxidizing agent and disinfectant. Chlorine dioxide decomposes in water to yield the chlorite ion (ClO_2^-) and chlorate ion (ClO_3^-). It is not affected by pH and does not form halogenated organic compounds. Because chlorine dioxide is unstable, however, it must be produced on-site by mixing hydrochloric acid and sodium chlorite. The main disadvantage is the handling and storage of two dangerous chemical substances. Chlorine dioxide can be five to 10 times more expensive than chlorine, cost may be an issue.

Chlorine Gas (Cl_2). Chlorine gas is commercially available in 150-lb (68- kg) , 1-ton (907-kg), and 15- to 17-ton (13608 - to 15422-kg) tank trucks, as well as 16- to 90-ton (14515- to 81647-kg) railroad cars, which are regulated by the Chemical Facility Anti-Terrorism Standards (CFATS) of U.S. Homeland Security.

Clarification: It is water-solids separation process by either sedimentation (sedimentation clarification) , or flotation (flotation clarification).

Clarifier, flotation: A large circular or rectangular tank or basin in which water is held for a period of time, during which the air bubbles with suspended solids attached float to the top by flotation. Flotation clarifiers are also called flotation basins or dissolved air flotation basins.

Clarifier, sedimentation : A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom by gravity. Sedimentation clarifiers are also called settling basins and sedimentation basins.

Closed circuit cooling tower: There is no direct contact between the air or cooling tower water and the cooling fluid or refrigerant. The system contains an external and an internal circuit. The internal circuit consists of tube bundles (closed coils) that are connected to a heat exchanger for the hot refrigerant, which is cooled and returned in a closed loop. The external circuit is used to cool the internal circuit by recirculating and evaporating water like an evaporative condenser. Air is drawn through the recirculating water cascading over the outside of the hot tubes.

Cloth filter: A type of filter that uses woven filter septum made from natural or synthetic yarns.

Coagulant: A chemical (alum or iron salts) added to water to destabilize particles, allowing subsequent floc formation and removal by clarification (flotation or sedimentation) and/or filtration.

Coagulation: A process of destabilizing charges of suspended and colloidal particles in water by adding chemicals (coagulants). In coagulation process, positively charged chemicals are added to neutralize or destabilize these negative charges and allow the neutralized particles to accumulate and be removed by clarification (flotation or sedimentation) and/or filtration.

Colorimeter: Nessler tubes and filter photometers are of colorimeters. Both are used for chemical absorption analysis.

Colorimetric method: It is an analytical method involving the development of visible color in standards and water samples after chemical reactions with the specified chemical reagents. Nessler tubes, photometers and spectrophotometers can all be used in colorimetric analysis..

Combined physicochemical water treatment (PCWT) for cooling tower: It is a combined chemical treatment and non-chemical (or physical) treatment system involving the use of both chemicals and physical means, such as: (a) chemical coagulation/precipitation, sedimentation and filtration; (b) chemical coagulation/precipitation, flotation and filtration; (c) chemical coagulation/precipitation, flotation and membrane filtration; (d) ion exchange; (e) cationic surfactant coagulation/precipitation, disinfection, clarification (sedimentation or flotation); (f) cationic surfactant coagulation/precipitation, disinfection, clarification (sedimentation or flotation) and filtration.; (g) cationic surfactant coagulation/precipitation, disinfection and ultrafiltration.

Concentration: in solutions, the mass, volume, or number of moles of solute present in proportion to the amount of solvent or total solution Common measures are: molarity, normality, percent, molality, and by specific gravity scales.

Condensate: It is (a) the product from a distillation water treatment process system; (b) the condensed vapors from a heat exchanger, such as steam boiler, air conditioning unit, cooling tower, heat-pump, etc.. It is also called distillate.

Condensate Capture Potential Map.: It is a computer map prepared by the Federal Energy Management Program (FEMP), and available online for determining whether or not condensate capture is a viable in the industrial facility's area.

Condensate from air conditioning equipment: Condensate is generated when water vapor comes in contact with an air conditioner's cooling coils, and is commonly discharged to a drip pan or directly to a floor drain. Condensate from air conditioning equipment is high quality, cold water that is free of minerals and TDS, making it ideal to use as cooling tower make-up water. Even better, condensate from air conditioners is generated in the highest volumes during period of high cooling loads, which mirrors times when cooling towers are operating the most. Typically, condensate can be fed directly into the cooling tower basin as make-up water without any treatment, but work with your water treatment vendor to see if they have any concerns with this approach. To determine whether condensate capture is a viable in your area, review the Federal Energy Management Program (FEMP).

Condensate recovery system: Installing and maintaining a condensate recovery system to capture and return condensate to the boiler for reuse is the most effective way to reduce water use. Recovering condensate will : (a) Reduces the amount of make-up water required; (b) Eliminates or significantly reduces the need to add tempering water to cool condensate before discharge; (c) Reduces the frequency of blowdown, as the condensate is highly pure and adds few to no additional TDS to the boiler water; (d) Saves energy, since the hot condensate being returned to the boiler requires much less energy to reheat to produce steam again.

Condensation: It is thermal process for converting a substance (such as H_2O), from its vapor state (steam) to its liquid state (liquid water, or condensate). Many organic solvents can go through the condensation process for converting from their vapor states to their respective liquid states at their specific condensation temperature levels.

Conductivity: (a) Conductivity is a measurement of the water's ability to conduct electricity. It is a relative indication of the total dissolved mineral content of the water as higher conductivity levels correlate to more dissolved salts in solution. Conversely, purified water has very little dissolved minerals present meaning the conductivity will be very low; (b) Electrolytic conductivity is the capacity of ions in a solution to carry electrical current and is the reciprocal of the solution resistivity. Current is carried by inorganic anionic dissolved solids, such as chloride, sulfate, nitrate, phosphate, etc., and inorganic cationic dissolved solids, such as sodium, calcium, magnesium, iron, aluminum, etc. Measuring conductivity is done by measuring the resistance occurring in an area of the test solution. Voltage is applied between the two electrodes immersed in the solution, and the voltage drop caused by the resistance of the solution is calculated to be conductivity per centimeter, using a unit of Siemen (or mho)/cm. (Note: mho is the reciprocal of the ohm). 1 milliSiemens/cm = 10^{-3} S/cm = 1 mS/cm. 1 uS/cm = 10^{-6} S/cm.

Constituent : A chemical or biological substance in water, sediment, or biota that can be measured by an analytical method.

Contact clarification: A water treatment process in which flocculation and clarification (and often the rapid mix) are combined in one unit, such as an upflow solids contactor or contact clarifier.

Cooling range is the difference in temperature between the hot water entering the tower and the cold water leaving the tower.

Cooling tower: Cooling towers are heat exchangers that use water and air to transfer heat from chiller systems to the outdoor environment. Usually a cooling tower dissipates heat from recirculating significant amounts of water used to cool chillers, air conditioners, or other process equipment to the ambient air. Heat is rejected to the ambient environment from a cooling tower through evaporation. Water leaves a cooling tower system in one of four ways: (a) evaporation; (b) water drift loss; (c) blowdown; and (d) water leakage or overflow. There are three basic types of cooling towers: (a) open circuit, (b) closed circuit, and (c) hybrid.

Cooling tower water mass balance and management: The first relationship illustrates the overall mass balance consideration around a given cooling tower is Equation 1 assuming the blowdown accounts for all system losses including leaks and drift, except for evaporation. The second principal relationship defines cycles of concentration in terms of makeup flow and blowdown flow, as indicated by Equation 2. Equation 2 can be rearranged to either of the following Equation 3 or Equation 4 to solve for the make-up rate or blowdown rate, respectively. If the evaporation rate and cycles of concentration are known, the blowdown rate can then be determined Equation 4 can be substituted into Equation 1 to get Equation 5. By solving for blowdown in Equation 5, Equation 6 is obtained. If the evaporation rate and cycles of concentration are known, the blowdown rate can then be determined using Equation 6 . Also, if the blowdown rate and cycles of concentration are known, the make-up rate can be determined by solving Equation 4, and then the evaporation rate can be determined by solving Equation 7 for evaporation: (1) *Make-up = Blowdown+ Evaporation; (2) Cycles of Concentration = (Make-up)/ (Blowdown): (3) Blowdown = (Make-up)/(Cycles of Concentration); (4) Make-up = (Cycles of Concentration) x (Blowdown); (5) Cycles of Concentration x Blowdown = Blowdown + Evaporation; (6) Blowdown = (Evaporation) / (Cycles of Concentration -1); (7) Evaporation = (Blowdown) x (Cycles of Concentration - 1).*

Cooling towers categories: (a) open circuit (direct water-air contact) systems; (b) closed circuit (indirect contact) systems; and (c) hybrid systems.

Cooling towers classification based on the direction of air flow: There are two types: (a) counter-flow cooling towers; and (b) cross-flow cooling towers.

Cooling towers classification based on the type of draft: There are two types: (a) mechanical draft cooling towers; and (b) natural draft cooling towers

Copper sulfate ($CuSO_4$): It is a chemical prepared from copper and sulfuric acid. It is called blue vitriol or blue stone, or blue copperas. Since copper sulfate is frequently used for control of algal growths in cooling tower water and water supply reservoir water, It is regulated by the US Environmental Protection Agency (USEPA).

Coprecipitation: A chemical precipitation process in which two chemical agents precipitate each other producing two precipitates.

Corrosion control for cooling tower: It is a water treatment technology that keeps the metallic ions of a material, typically a pipe, heat transfer tube, etc, from going into solution, such as increasing the water pH, removing free oxygen from water, controlling the carbonate balance of the water, or forming a protective film on metal surfaces by adding a sequestration agent. Some of the chemicals used for cooling tower water's biological and scaling control are clearly corrosive and need to be monitored and carefully balanced to prevent damage to the cooling tower surfaces.

Corrosion inhibitor: It is a substance that slows or prevents corrosion by formation of a protective film on the interior surface of pipes, tubes, or tanks.

Corrosion: Corrosion is an electrochemical or chemical process that leads to the destruction of the system metallurgy. Corrosion is enhanced by elevated dissolved mineral content in the water and the presence of oxygen, both of which are typical of most cooling tower systems. There are different types of corrosion encountered in cooling tower systems including pitting, galvanic, microbiologically influenced, and erosion corrosion, among others. Loss of system metallurgy, if pervasive enough, can result in failed heat exchangers, piping, or portions of the cooling tower itself.

Counter-flow cooling towers: Counter-flow cooling towers have upward air flow that directly opposes the downward flow of the water providing very good thermal efficiency because the coolest air contacts the coolest water (in the bottom section of the tower structure).

Cream flotation: It is a new process invented by the Lenox Institute of Water Technology. The new process involves pressurization of air or other gases at 25-60 psig for dissolving air or other gas into water containing surfactant, and subsequent release of pressure (to 1 atm) under laminar hydraulic flow conditions for generation of thick cream or foam bubbles, which become attached to the suspended matter (impurities or the recoverable substances) to rise together to the water surface. The attachment of foam bubbles to the suspended matter can be a combined result of physical entrapment, electrochemical attraction and surface adsorption. The specific gravity of foam-suspended agglomerate is less than one, resulting in rapid buoyancy or flotation. Cream flotation can also be operated in different modes: (a) full flow pressurization; (b) partial flow pressurization, and (c) recycle flow pressurization. It is economically feasible for separation of insoluble matter from a water stream which already contains surfactant .

Cross-flow cooling towers: Cross-flow cooling towers are structured so that air flows horizontally across the falling water. This design provides less resistance for the air flow, thereby reducing the fan horsepower required to meet the cooling demand. These towers usually feature gravity-fed water distribution decks that are either open and uncovered, or that are covered to limit algae growth and debris from getting into the distribution deck. Gravity-fed distribution decks have evenly spaced openings that the water drops through to be spread across the tower fill.

Cycle of concentration (COC): COC is a technical term used to describe the mass flow relationship between the amount of system feed water and the amount of blowdown sent down the drain. It is sometimes referred to as cycle or concentration ratio. COC compares total dissolved solids (TDS) in makeup water with concentrated TDS in the circulating water through evaporation. COC is determined by calculating the ratio of the concentration of TDS in the blowdown water compared to the TDS in make-up water. TDS enters the system in the make-up water and exits the system in the blowdown water. COC is also approximately equal to the ratio of volume of make-up to blowdown water, using the following equation, where makeup refers to the fresh water added to the system and blowdown refers to the water being drained from the system. $\boldsymbol{COC} = (\boldsymbol{Makeup\ water},\ \boldsymbol{gallons}/\boldsymbol{minute}) / (\boldsymbol{Blowdown\ water},\ \boldsymbol{gallons}/\boldsymbol{minute})$. COC can also be estimated by dividing the conductivity of the water in the system by the makeup water conductivity. For example, chlorides are soluble in water, so the cycles of concentration are equal to the ratio of chlorides in circulating water to chlorides in makeup water. From this COC value, an operator can calculate the required water blowdown in order to replenish the loss in evaporation. A cooling tower operator wants to maximize COC which will minimize blowdown water quantity and reduce make-up water demand. However, this can only be done within the constraints of your make-up water and cooling tower water chemistry. TDS increases as COC increases, which can cause scale and corrosion problems unless carefully controlled.

Decentralized mechanical systems: A decentralized mechanical system treats each unit of a multifamily property as its own space, and are common in low- and mid-rise multifamily properties, since they typically have lower initial purchase and installation costs.

Demineralization: Any process (such as evaporation-condensation, ion exchange, reverse osmosis, etc.) that removes minerals in water is a demineralization process.

Diatomaceous earth filtration: A process resulting in substantial particulate removal in which (a) a precoat cake of diatomaceous earth filter media is deposited on a support membrane (septum), and (b) while the water is filtered by passing through the cake on the septum, additional filter media known as body feed is continuously added to the feed water to maintain the permeability of the filter cake.

Discharge: Rate of fluid flow passing a given point at a given moment in time, expressed as volume per unit of time.

Disinfectant By-Products (DBP): DBP are the byproducts of drinking water disinfection. Different disinfectants will product different DBP. They are all cancer-causing substances. The maximum allowable concentrations (MCL of U.S., MAC of Canada, MAL of Mexico or GV of WHO) of four common DBP are: (a) bromate = 0.01 mg/L (U.S., Canada, WHO); (b) chlorite = 1.0 mg/L (U.S., Canada); 0.7 mg/L (WHO); (c) haloacetic acids (HAAs) = 0.06 mg/L (U.S.); 0.08 mg/L (Canada); and (d) total trihalomethanes (TTHMs) = 0.08 mg/L (U.S.); 0.1 mg/L (Canada); 0.2 mg/L (Mexico). TTHM includes bromodichloromethane, bromoform, dibromochloromethane and chloroform. HAA5 includes five compounds -- dichloroacetic acid, trichloroacetic acid, monochloroacetic acid, bromoacetic acid and dibromoacetic acid. The guideline values (GV) established by World Health Organization (WHO) for DBP are: bromate, 0.0 1 mg/L; bromodichloromethane, 0.06 mg/L; bromoform, 0.1 mg/L; chlorate, 0.7 mg/L; chlorite, 0.7 mg/L; chloroform, 0.3 mg/L; dibromoacetonitrile, 0.07 mg/L; dibromochloromethane, 0.1 mg/L; dichloroacetate, 0.05 mg/L; dichloroacetonitrile, 0.02 mg/L; monochloroacetate, 0.02 mg/L; n-nitrosodimethylamine, 0.0001 mg/L; trichloroacetate, 0.2 mg/L; and 2,4,6-trichlorophenol, 0.2 mg/L. Although there is no collective maximum contaminant level goal (MCLG) in the U.S. for this contaminant group, there are individual MCLGs for some of the individual contaminants: (a) Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L): chloroform (0.07mg/L); and (b) Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.02 mg/L); monochloroacetic acid (0.07 mg/L). Bromoacetic acid and dibromoacetic acid are regulated with this group but have no MCLGs.

Disinfectant: Any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines, and ozone added to water in any part of the treatment or distribution process, that is intended to kill or inactivate pathogenic microorganisms. A chemical (commonly chlorine, chloramine, or ozone) or physical process (e.g., ultraviolet light) that kills microorganisms such as bacteria, viruses, and protozoa.

Disinfection by-product formation potential (DBPFP): It is the amount of disinfection by-products (DBP) formed during a special test conducted under the specified extreme environmental conditions (or extreme process conditions) in terms of pH, temperature, pressure, and long detention time.

Disinfection by-products (DBP): They are the chemical by-products of one or more disinfectants in a disinfection process. DBP are formed by the chemical reactions of the disinfectant, natural organic matter, and the added process chemicals during water disinfection process. Regulated DBPs include TTHMs, HAA5s, bromate, and chlorite.

Disinfection: A process which inactivates pathogenic organisms in water by chemical oxidants or equivalent agents.

Dispersed air flotation: Same as induced air flotation (IGF). It is one of induced gas flotation (IGF) processes when air is used for generation gas bubbles.

Dispersed gas flotation: Same as induced gas flotation (IGF).

Dispersed nitrogen flotation: Same as induced nitrogen flotation (IGF). It is one of induced gas flotation (IGF) processes when nitrogen is used for generation gas bubbles.

Dissolved air flotation (DAF): Dissolved gas flotation (DGF) becomes DAF if air is used as the gas for bubble generation in the flotation process.

Dissolved air flotation and filtration (DAFF): It is a package plant combining both dissolved air flotation (DAF) and filtration together.

Dissolved air-ozone flotation (DAOF): Dissolved gas flotation (DGF) becomes DAOF if both air and ozone are used as the gas for bubble generation in the flotation process.

Dissolved air-ozone flotation and filtration (DAOFF): It is a package plant combining both dissolved air-ozone flotation (DAOF) and filtration together.

Dissolved gas flotation (DGF): DGF is used to remove suspended solids by flotation (rising) by decreasing their apparent density. Dissolved gas flotation consists of saturating a portion or all of the water feed, or a portion of recycled effluent with gas at a pressure of 25 to 70 lb/in^2 (gauge). The pressurized water is held at this pressure for 0.5 to 3.0 minutes in a pressure retention tank (or gas dissolving tube) and then released to atmospheric pressure to the flotation chamber. The sudden reduction in pressure results in the release of microscopic gas bubbles which attach themselves to suspended particles or oil in the influent water in the flotation chamber. This results in agglomeration which, due to the entrained gas, have greatly increased vertical rise rates of about 0.5 to 2.0 ft/min. The floated materials (float or scum) rise to the surface to form a froth layer. Specially designed flight scrapers or other skimming devices, such as sludge scoop, continuously remove the float. The detention time (DT) in the flotation chambers is usually about 5 to 60 minutes depending on the flotation process design. The effectiveness of dissolved gas flotation depends upon the attachment of bubbles to the suspended solids, or oil and other particles which are to be removed from the influent water stream. The attraction between the gas bubble and particle is primarily a result of the particle surface charges and bubble-size distribution. The more uniform the distribution of water and microbubbles, the shallower the flotation unit can be. Generally, the depth of effective flotation units is between 4 and 9 feet. The surface sludge layer can in certain cases attain a thickness of many inches and can be relatively stable for a short period. The layer thickens with time, but undue delays in removal will cause a release of particulates back to the liquid. Units can be round, square or rectangular. In addition, gases other than air can be used. The petroleum industry has used nitrogen, with closed vessels, to reduce the possibilities of fire.

Dissolved nitrogen flotation (DNF): One of dissolved gas flotation (DGF) processes when nitrogen is used for generation of gas bubbles. See dissolved gas flotation (DGF).

Dissolved oxygen (DO): The level of dissolved oxygen (DO) in natural surface water is an indication of extent of pollution by oxygen-demanding substances. Low DO concentrations are associated with low-quality water, aquatic animal, may die if DO concentration is below certain tolerable level, and water treatment plants may face taste and odor problems. In treated water, the DO is one of the most important factors influencing the corrosion rate of metal treatment facilities and pipelines.

Dissolved ozone flotation (DOF): One of dissolved gas flotation (DGF) processes when ozone is used for generation of gas bubbles. See dissolved gas flotation (DGF).

Dissolved solids: Dissolved solids are the amount of dissolved minerals present in the water.

Drift loss of cooling tower: Drift loss is a small quantity of water that is carried from the tower as mist or small droplets, therefore, **it** is the water entrained in the air flow and discharged into the atmosphere. Drift can be controlled with baffles and drift eliminators.

Dual-membrane filtration : A membrane filtration system, also known as integrated membrane system, is composed of two different types of membrane filtration modules in series. For instance, a surface water treatment plant may use a microfiltration (MF) or ultrafiltration (UF) membrane module for particle and microorganisms removal followed by a nanofiltration (NF) or reverse osmosis (RO) module for dissolved solids removal.

Electrodialysis (ED): It is one of the membrane filtration processes. ED uses voltage or current as the driving force to separate ionic solutes. The sizes of ionic solutes to be rejected or separated by ED are normally in the range of 0.00025 to 0.08 microns, depending on the pore size of ED membranes. EDR is the electrodialysis reversal (or reverse electrodialysis) process, which is similar to ED, but its cathodes and anodes, can be reversed for automatic cleaning during operation. Fig. 17.13 illustrates the effect of ED and EDR.

Electrodialysis reversal (EDR) : An electrodialysis process which is not driven by pressure, but driven by an electrical potential difference between oppositely charged electrodes. In the electrodialysis reversal process, the electrical polarity f the electrodes is reversed on a set time cycle thereby reversing the direction of ions in the process system for control of membrane scaling and fouling problems.

Electroflotation: It is process involving the generation of hydrogen and oxygen bubbles in a dilute electrolytic aqueous solution by passing a direct current between two electrodes (a) anode and (b) cathode. Anode reaction generates oxygen bubbles and hydrogen ions; while cathode reaction generates hydrogen bubbles and hydroxide ions. Either aluminum or steel sacrificial electrodes can be employed for generating the gas bubbles as well as coagulants at the same time. Non-sacrificial electrodes are employed for generating the gas bubbles only, and can be mode of titanium (as the carrier material) and lead dioxide (as the coating material). Electrical power is supplied to the electrodes at a low voltage potential of 5 to 20 volts DC by means of a transformer rectifier. Small bubbles in the range of 20-50m microns are produced under laminar hydraulic flow conditions feasible for flotation separation of fragile flocs from water in a small system. The floats on the water surface are the impurities/pollutants removed from water. The clarified water is discharged from the flotation clarifier's bottom. There can be unexpected advantages and disadvantages when electroflotation is employed. For instance, chlorine bubbles may be generated as a water disinfectant if the water contains significant amount of chloride ions. Certain unexpected gas bubbles may be generated and may be undesirable.

Electrolysis systems: An electrolysis system involve passing an electric current between two electrodes. Precipitation of minerals occurs at the cathode. These electrolysis systems can also be used to inhibit biological growth by formation of chlorine gas at the anode. An electrolysis system tested by the National Renewable Energy Laboratory used a titanium anode and a basic solution at the cathode to promote scaling to the cathode. Water savings were achieved but since the baseline did not exhibit scaling, the opportunity for energy savings was not present. Biological control seemed reasonable.

Electrolytic flotation: Same as Electroflotation.

Electromagnetic current. For several years, electromagnetic current technology has been deployed to limit scale deposition as well as reduce biofilm buildup. Typically, the technology induces an AC current in the water circuit of the cooling tower. The induced magnetic fields modify the ionic surface charge of the particles in the water. This, in turn, results in the attraction of the calcium and carbonate to rapid nucleation and growth of calcium carbonate as a powder instead of being deposited on mechanical surfaces.

Evaporation of cooling tower: Evaporation is the primary function of the cooling tower and the method that transfers heat from the cooling tower system to the ambient environment. When water evaporates from the tower, dissolved solids (such as calcium, magnesium, chloride, and silica) remain in the recirculating water. As more water evaporates, the concentration of dissolved solids increases. If the concentration gets too high, the solids can cause scale to form within the system. The dissolved solids can also lead to corrosion problems.

Filter aid: Any material that assists in the separation of solids from liquids. Usually used on difficult filtration applications.

Filter backwash: A reverse flow of liquid to remove solids from the filter.

Filter medium: The permeable material that separates particles from a fluid passing through it.

Filter photometer: It is an instrument that uses filters to produce a wide band of wavelengths suitable to colorimetric analysis in which visible color in standards and water samples are developed.

Filter system: The combination of a filter and associated hardware required for the filtration process.

Filter-to-waste: The practice of discarding filter effluent that is produced during the “filter ripening” period immediately after backwash due to its impaired quality.

Filtrate: The water separated from the solids by a belt filter press or the liquid that has passed through a filter.

Filtration - Filter systems are nothing new to industrial water systems, and have been used as pre-treatment in many different applications for many years. In recent years, side-stream filtration systems have become popular among many water treatment professionals. They function to remove suspended solids, organics, and silt particles down to 0.45 microns from a portion or all of the system water on a continual basis, thereby reducing fouling, scaling and microbiological activity. This allows the cooling system to work more efficiently and often reduces the amount of water blown down. However, the net impact on water consumption must consider the fact that these platforms require back-washing to clean the filter system. The amount of water used to regenerate the filter system should be added to the water lost due to evaporation and blowdown.

Filtration, dual media filtration by gravity: It is one of the most economical forms of granular media filtration. Granular media filtration involves the passage of water through a bed of filter media with resulting deposition of solids. Eventually, pressure drop across the bed becomes excessive or the ability of the bed to remove suspended solids is impaired. Cleaning is then necessary to restore operating head and effluent quality. The time in service between cleanings is termed the run length or run time. The head loss at which filtration is interrupted for cleaning is called the terminal head loss, and this head loss is maximized by the judicious choice of media sizes. Dual media filtration involves the use of both sand and anthracite as filter media, with anthracite being placed on top of the sand. Gravity filters operate by either using the available head from the previous treatment unit, or by pumping to a flow split box after which the wastewater flows by gravity to the filter cells. The backwash wastewater can be treated for disposal or recycle to the intake of the water treatment system. The backwash wastewater can be treated for disposal or recycle to the intake of the water treatment system.

Fixed field magnetic systems: Fixed field magnetic systems cause otherwise scale-forming materials to precipitate on suspended solids instead of on heat exchanger surfaces. The non-adherent aragonite form of calcium carbonate that is produced by these systems (versus the hard, adherent calcite that results in detrimental scaling) can be removed mechanically or by blowdown or flushing.

Floc: Collections of smaller particles that have agglomerated together into larger, more separable (floatable or settleable particlks as result of the coagulation process.

Flocculating agent or flocculant, or coagulant: Any chemical that can convert soluble or colloidal substances to insoluble flocs.

Flocculation: A process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles by sedimentation (or floatable particles by flotation) through gentle stirring by hydraulic or mechanical means.

Flocculator: A process device to enhance the formation of floc in a water. Mixing energy can be provided by slow turning mechanical means or head loss.

Flotation aid: Any chemical that coagulates solids, breaks an oil emulsion, or assists in adsorbing solids onto air bubbles for water-solids separation.

Flotation chamber or flotation tank: It is the main tank of a flotation unit where the influent water enters and the water-solids separation occurs due to flotation actions.

Flotation clarification: It is flotation unit designed for clarification of water or wastewater. Therefore, the main objective of the flotation clarifier is for clarifying or cleaning the incoming water or wastewater.

Flow rate: The unit rate at which a liquid is passed through a system. Usually expressed in gallons per minute (or hour).

Forced draft: It is an air flow pattern that air flow is pushed through by fans located at the base of a process unit.

Fouling: Fouling occurs when suspended particles fall out of solution forming deposits. Common foulants include organic matter, process oils, and silt. Factors that lead to fouling are low water velocities, corrosion, and process leaks. Fouling deposits, similar to scale deposits, impede the heat exchange capabilities of the system by providing an insulating barrier to the system metallurgy.

Granular activated carbon (GAC): An activated carbon which is porous and in granular form with many micro and macro channels and surface area, suitable for adsorption of many soluble organics and some inorganics.

Granular activated carbon (GAC) filtration: A filtration bed consists of granular activated carbon.

Granular activated carbon adsorption: (a) A unit process used to remove mainly dissolved organics from water, wastewater or air. A receptacle is filled with granular carbon, and the fluid (water, wastewater or air) is passed through either fixed or moving beds. (b) A wastewater GAC systems generally consists of vessels in which the carbon is placed, forming a "filter" bed. These systems can also include carbon storage vessels and thermal regeneration facilities. Vessels are usually circular for pressure systems or rectangular for gravity flow systems. Once the carbon adsorptive capacity has been fully utilized, it must be disposed of or regenerated. Usually multiple carbon vessels are used to allow continuous operation. Columns can be operated in series or parallel modes. All vessels must be equipped with carbon removal and loading mechanisms to allow for the removal of spent carbon and the addition of new material. Flow can be either upward or downward through the carbon bed. Vessels are backwashed periodically. Surface wash and air scour systems can also be used as part of the backwash cycle. Small systems usually dispose of spent carbon or regenerate iit offsite. Systems above about 3 to 5 MGD (million gallons per day) usually provide on-site regeneration of carbon for economic reasons.

Gravity sedimentation: It is a water-solids separation process by settling solids due to specific gravity difference of water and solids (specific gravity is greater than 1, or greater than water) within water. In gravity sedimentation process unit, chemical flocs, biological flocs, silts, sands, or other substances having specific gravity greater than water (specific gravity is less than 1) are allowed to settle to the sedimentation tank's bottom. The top portion water body is clean or clarified water is discharged as the treated water effluent. The settled sludge is removed from the sedimentation tank's bottom as the waste sludge.

Green Chemistries: "Green" chemistry programs exist primarily to replace traditional treatments that have been deemed harmful for environmental reasons. "Green" chemistries often don't result in improved thermal efficiency or reduced water consumption, but provide environmental compliance and reduced discharge of harmful or illegal substances. Examples of "green" chemistry programs include polysilicate corrosion inhibitors (used for many years in potable water systems), polyaspartic acid dispersants, and hydrogen peroxide for biocide applications. Another biocide that received the 1997 US Environmental Protection Agency (USEPA) Green Chemistry Award is tetrakis (hydroymethyl) phosphonium sulfate (THPS).

Hard water: Generally it is the water that (a) contains high concentrations of calcium ions, magnesium ions, bicarbonate ions, and carbonate ions, (b) produces scale in hot water pipes, boilers, heaters, cooling towers, hot water faucets, etc.; and (c) consumes soap. Moderately hard water contains 75-150 mg/L as $CaCO_3$; hard water contains 150-300 mg/L as $CaCO_3$; very hard water contains over 300 mg/L as $CaCO_3$.

Hardness: It is a quality of water that is caused by divalent metallic cations (calcium ions, magnesium ions, etc.) and results in: (a) increased consumption of soap, (b) deposition of scale in boilers, cooling towers, (c) damage in apparatus and instrument, and (d) creation of objectionable taste in water. They are troublesome in heat exchange applications because they are inversely soluble because they precipitate from a solution at elevated temperatures and remain soluble at cooler temperatures. For this reason calcium and magnesium-related deposits will be evident in the warmest areas of any cooling system, such as the tubes or plates of heat exchangers, or in the warm top regions of the cooling tower fill where most of the evaporation occurs.

Heat exchanger: It is a device for transferring heat from one substance to another. Heat transfer can be by direct contact, as in a cooling tower, or indirect, as in a shell and tube condenser.

Heat load: It is the amount of heat that needs to be removed from the circulating water within the cooling tower system. Heat load is equal to water circulation rate (gpm), multiplied by the cooling range, multiplied by 500, and is expressed in BTU/hr. Heat load is also an important parameter in determining tower size and cost.

Hybrid cooling tower: It is usually a combination of a closed water and an air-cooled portion of the cooling tower.

Hydrogen peroxide: It is a strong oxidizing agent and disinfectant with a formula of H_2O_2. It is an ideal oxdizing agent or disinfectant for cooling tower water disinfection and groundwater remediation because it leaves no harmful disinfection by-products (DBP).

Hypochlorination: It is a chemical process involving the use of sodium hypochlorite or calcium hypochlorite for water disinfection. Hypochlorination is one kind of chlorination processes.

Induced draft: It is an air flow pattern that air flow is pulled through by fans located at the top of a process unit.

Induced gas flotation (IGF) : It is a process involving introduction of gas directly into the water through a revolving impeller, a diffuser system, or an ejector, or a combination of them, at low pressure (slightly higher than one atm) for generating big gas bubbles (80 microns to over one mm) in large volume under turbulent hydraulic flow conditions. The gas flow rate is about 400 percent of the influent water flow rate. Physical entrapment and electrochemical attraction play minor roles in an induced gas flotation system. The attachment of gas bubbles to the impurities is mainly a result of surface adsorption, gas stripping and oxidation. Surface active substances (inks, detergents, ores, soaps, etc.) together with impurities are selectively separated in a foam phase at the water surface. The foam containing the surfactant and the impurities are removed by suction device, Volatile substances are removed by gas stripping action. The clarified waster is discharged from the flotation clarifier's bottom. Reducing agents, such as ferrous ions, can be oxidized to ferric ions for subsequent separation in ferric hydroxide form if air is used as a gas.

Industrial vortex generator for cooling tower (IVG-CT): It is a low-energy use side-stream water treatment process that uses a combination of these physical treatment disciplines: (a). Removal of entrained microbubbles in water stream; (b) Hydrodynamic cavitation; (c). UV-C light microbiological control system; (d) Filtering (basin water and makeup water); and (e) Local and remote monitoring and control system. The IVG-CT side-stream water treatment unit is itself 3D printed and then assembled into a plug and play unit or "skid" and is a self-contained and monitored system with added filtration and UV-C light protection. The system dynamically monitors and controls blowdown of the cooling towers to the optimal target to maximize COC, consistent with current building code standards in the USA California Title 24.

Ion exchange (IX or IE) softening: It is a reversible chemical process in which ions from an insoluble permanent solid resin (ion exchanger) are exchanged for inorganic ions or organic ions in a solution or water mixture surrounding the insoluble resin (ion exchanger). Both cation and anion exchangers are used in water conditioning. Cation exchanger is commonly used for removal of calcium and magnesium hardness from water which is known as an ion exchange softening process.

Ion-exchange regenerant: A chemical solution used to restore an exhausted bed of ion exchange resins to the fully ionic (regenerated) form necessary for the desired ion exchange to again take place effectively.

Iron (Fe): (a) It is an element with an atomic weight of 55.847; (b) It is an important trace metal to the human health; (c) Small amounts of iron are frequently present in water because of the large amount of iron present in the soil and because corrosive water will pick up iron from pipes. The presence of iron in water is considered objectionable because it imparts a brownish color to laundered goods and affects the taste of beverages such as tea and coffee. Recent studies indicate that eggs spoil faster when washed in water containing iron in excess of 10 mg/L. The U.S. and Canada recommended limits for iron are both 0.3 mg/L, and the Mexican maximum allowable limit

(MAL) is also 0.3 mg/L.

Jar test: A laboratory procedure that simulates a water treatment plant's coagulation, rapid mix, flocculation, and sedimentation processes. Differing chemical doses, energy of rapid mix, energy of slow mix, and settling time can be examined. The purpose of this procedure is to estimate the minimum or optimal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of a single chemical are added to each jar while holding all other chemicals at a consistent dose, and observing the formation of floc, settling of solids, and resulting water quality.

Legionella pneumophila: It is a bacterial species that causes an acute pneumonia (Legionnaires' disease or Legionellosis).

Legionella, Mycobacterium avium complex, Aeromonas hydrophila, and Helicobacter pylori : They are considered as the Emerging Bacterial Waterborne Pathogens in Canada. These emerging pathogens have been linked to gastrointestinal illness in human populations. In the U.S., only Legionella which causes a type of pneumonia (Legionnaire's disease) is being controlled by an effective Treatment Technique (TT), and the USEPA specified MCLG is zero.

Legionnaires' disease, or Legionellosis: It is a disease which can be caused by Legionella bacteria in cooling towers. Tighter regulations and control on cooling tower operators mean that effective control of Legionella is essential for cooling tower operations.

Lignin: It is an organic substance that, with cellulose, forms the chief part of woody tissue. Lignin is plant constituent that often is produced during the manufacture of paper and pulp. Both tannin and lignin contain aromatic hydroxyl groups, and can be quantitatively measured by the same Standard Methods 5550 Tannin and Lignin.

Lime-soda softening process: A process for softening water by the addition of lime and soda ash to convert soluble calcium hardness to insoluble calcium carbonate, and convert soluble magnesium hardness to insoluble magnesium hydroxide. The hardness is removed when the insoluble calcium carbonate and magnesium hydroxide are removed by clarification and filtration,

Make-Up water of cooling tower: It is the amount of water required to replace normal losses caused by bleed off (blowdown), drift, and evaporation. The required makeup water amount can be calculated by the following equation: ***Make-Up = Evaporation + Blowdown + Drift + Leaks.***

Maximum concentrations for parameters in cooling tower water by U.S. Green Building Council: (a) Maximum level Calcium (as $CaCO_3$) = 1,000 parts per million (ppm); (b) Maximum level Total Alkalinity = 1,000 ppm; (c) Maximum level Silica (SiO_2) = 100 ppm; (d) Maximum level Chlorine (Cl^-) = 250 ppm; Maximum level Conductivity (TDS) = 2,000 uS/cm.

Maximum Contaminant Level (MCL): The highest level of a contaminant that is allowed in drinking water as delineated by the National Primary Drinking Water Regulations. MCLs ensure that drinking water does not pose either a short-term or long-term health risk. USEPA sets MCLs at levels that are economically and technologically feasible. Some states set MCLs which are stricter than USEPA's.

Maximum Contaminant Level Goal (MCLG): The level of a contaminant at which there would be no risk to human health. This goal is not always economically or technologically feasible, and the goal is not legally enforceable.

Mean discharge: The arithmetic mean of individual daily mean discharges during a specific period, usually daily, monthly, or annually.

Mechanical draft cooling towers: Mechanical draft cooling towers have air forced through the structure by a fan. The air flow can be pushed through by fans located at the base of the tower (referred to as forced draft), or pulled through by fans located at the top of the tower (referred to as induced draft). Induced draft towers tend to be larger than forced draft units.

Mechanical systems : They are frequently utilized to provide heating (of water as well as living spaces) and cooling for multifamily properties. They typically fall into two categories: (a) centralized and (b) decentralized systems.

Membrane filtration: Membrane filtration processes involve the use of membranes for phase separation. The phases include solid phase (such as suspended solids, organic solids, inorganic solids, etc.), liquid phase (such as water, ethanol, chloroform, etc.) and gas phase (such as air, nitrogen, oxygen, etc.). A membrane is a porous filtration medium, which can be cationic, anionic or nonionic in nature, and acts as a barrier to prevent mass movement of selected phases, but allows passage of remaining phases. The main applications of the membrane filtration processes are processing water and wastewater streams. Recently the membrane processes have been used for purification of gaseous streams. Membrane filtration processes include at least the following five main subcategories for processing water: (a) microfiltration (MF); (b) ultrafiltration (UF); (c) nanofiltration (NF); reverse osmosis (RO); and (d) Electrodialysis (ED).

Microbiological Activity: Microbiological activity is microorganisms that live and grow in the cooling tower and cooling system. Cooling towers present the perfect environment for biological activity due to the warm, moist environment. There are two distinct categories of biological activity in the tower system. The first being planktonic, which is bioactivity suspended, or floating in solution. The other is sessile biogrowth, which is the category given to all biological activity, biofilms, or biofouling that stick to a surface in the cooling system.

Microfiltration (MF): It is one of the membrane filtration processes. MF is a pressure filtration process for the separation of mainly suspended solids in the particle size-range of about 0.08 micron to 10 microns. The primary function affecting solids separation from water is the size of suspended solids. The hydraulic pressure applied in MF is about 1-2 bars (15 - 30 psig), primarily for overcoming resistance of the "cake". (1 micron = 1 micrometer = 1µm = 10^{-3} mm = 10^{-6} m = 0.00004 in. = 10,000 Angstroms = 104 A).

Nanofiltration (NF): It is one of the membrane filtration processes. NF membranes are multiple-layer thin-film composites of polymer consisting of negatively charged chemical groups, and are used for retaining molecular solids (such as sugar) and certain multivalent salts (such as magnesium sulfate), but passing substantial amounts of most monovalent salts (such as sodium chloride), at an operating-pressure of about 14 bars (200 psig; 1,388 kPa gauge). Both molecular diffusivity and ionic charge play important roles in the separation process. The sizes of molecular solids and multivalent salts to be rejected by NF are normally in the range of 0.0005 to 0.007 microns.

Natural draft cooling towers: Natural draft cooling towers are designed to move air up through the structure naturally without the use of fans. They use the natural law of differing densities between the ambient air and warm air in the tower. The warm air will rise within the chimney structure because of its lower density drawing cool ambient air in the bottom portion. Often times these towers are very tall to induce adequate air flow, and have a unique shape giving them the name "hyperbolic" towers.

Nessler Tubes: They are identical long glass tubes each with a flat bottom, and each holding about 50 mL capacity for comparison of colored water samples against standards by looking directly down the length of the tube. Human eyes serve as the detector in this visual analysis.

Nonchemical and physical water treatment for cooling tower : Non-chemical and physical water treatment (PWT) methods are available for scale, corrosion, and biologic control that avoid the use of problematic chemicals. Some of these systems are : (a) fixed field magnetic system; (b) pulsed power and electrodynamic field system; (c) cavitation system; (d) electrolysis system; (e) ultrasonic system; (f) ultraviolet light; (g) ozone system; (h) filtration; (i) membrane filtration (such as ultrafiltration); (j) advanced oxidation (such as combined UV and ozonation); (k) Industrial Vortex Generator for Cooling Tower (IVG-CT) technology.

Open circuit cooling tower systems: In open circuit systems the recirculating water returns to the tower after gathering heat and is distributed across the tower where the water is in direct contact with the atmosphere as it recirculates across the tower structure. They are designed to maximize air and water contact to provide as much evaporation as possible. This is accomplished by maximizing the surface area of the water as it flows over and down through the tower structure.

Open circuit cooling tower: The heat exchanger cools down the water by making use of direct contact with air. The water that requires cooling is directed to the upper part of the cooling tower and is spread in a thin and even film over a media or packing material. This method takes advantage of the large heat exchange surface area. The cooled water will then be gathered in the basin (or sump) and can be recirculated directly into the cooling process. Warmed water from the chiller is sprayed downward as air is blown upward with the fan. This lowers the temperature of the water and evaporates part of it, increasing the concentration of the minerals and solids (Figure 1). Ultimately, every water management solution has a limit on how much water can be reused without solid deposition negatively affecting heat transfer efficiency (energy consumption) and asset protection. Increasing the cooling towers' COC promotes both water and energy savings with improved heat transfer and system efficiency.

Oxidation: the combination of oxygen with a substance, or the removal of hydrogen from it or, more generally, any reaction in which an atom loses electrons.

Oxygenation: The process of adding dissolved oxygen to a solution

Ozonation: It is a physicochemical process involving the use of ozone for water or wastewater treatment. At ozone dosages of 10 to 300 mg/1, ozone may remove residual dissolved organics in cooling water, drinking water or secondary waste treatment effluent. The rate of ozone oxidation is both temperature and pH dependent. Reaction rates increase with increasing temperature. Because there is a wide range of ozone reactivity with the diverse organic content of water or wastewater, both the required ozone dose and reaction time are dependent on the quality of the influent to the ozonation process. Generally, higher doses and longer contact times are required for ozone oxidation reactions than are required for wastewater disinfection using ozone. Ozone tertiary treatment may eliminate the need for a final disinfection step. Ozone breaks down to elemental oxygen in a relatively short period of time (half life about 20 minutes). Consequently, it must be generated on site using either air or oxygen as the feed gas. Ozone generation utilizes a silent electric arc or corona through which air or oxygen passes, and yields an ozone in air/oxygen mixture, the percentage of ozone being a function of voltage, frequency, gas flow rate and moisture. Automatic devices are commonly applied to control and adjust the ozone generation rate.

Ozone (O_3): It is an unstable gas with three oxygen atoms, and has a pungent odor. Since ozone is very reactive, it must be produced on-site using ambient air or oxygen. It is an strong oxidizing agent. Ozone has been used for decades as a primary disinfectant for industrial and municipal water treatment. Ozone possesses one of the highest redox levels compared to other oxidizing biocides, making it suitable for neutralizing waterborne bacteria. A small amount of ozone, such as, 0.1 ppm, with a contact time of 5 min will neutralize 99.9 percent of *Legionella* bacteria, especially in the presence of UV.

Ozone systems: An ozone system is a process equipment (ozonator) that produces ozone as a disinfectant to kill or inhibit the growth of microorganisms, and as an oxidizing agent to destroy organic pollutants (such as BOD, COD, TOC) and certain inorganic pollutants (such as hydrogen sulfide). It is difficult to maintain an effective residual of ozone throughout a cooling water system because of ozone's high reactivity and fast dissipation. Successful application of ozonation for biological control requires that sufficient ozone-generating capacity be provided to sustain a level of ozone residual that will control microbial contamination throughout the cooling-water system.

Ozone-assisted coagulation/precipitation and clarification: It is an improved coagulation/precipitation and clarification process by using ozone to alter the surface charge on particles and hardness in water. This new process reduces coagulant/flocculant dosages, improves hardness removal and works best in low-particle and low-organic content waters, such as the cooling tower water. A low ozone dosage (0.1 ppm) with about 5 minutes of short detention time (DT) neutralizes 99.9 percent of *Legionella* bacteria in cooling tower water. Higher ozone dosage is required for inactivation of larger pathogen cysts, such as Giardia and Cryptosporidium in drinking water treatment. Either sedimentation or flotation can be used for clarification although flotation is naturally suitable for ozonation related applications due to the fact that: (a) the pressure vessel (gas dissolving tube) generates extremely fine ozone bubbles with much more surface area for ozone-pathogen contact; and (b) the flotation clarifier tank is also the ozone contactor with sufficient contact time DT for inactivation of Legionella bacteria. Conventional coagulation-sedimentation clarification system needs a separate ozone contactor in which dispersed nozzles are use to generate and distribute huge ozone bubbles with much less surface area for bubble-pathogen contact.

Package plant filtration : A single compact filtration plant that contains all supporting unit processes and unit operations for water filtration treatment.

Perozone process: It is an advanced oxidation process (AOP) in which both ozone (O_3) and hydrogen peroxide (H_2O_2) are used to generate the hydroxyl radicals for enhancement of the oxidation and disinfection reactions.

pH: pH is a measurement of how acidic or how alkaline a substance is on a scale of 0 to 14. A pH of 7.0 is neutral when the concentration of hydrogen ions is equal to the concentration of hydroxide ions. The measurements below 7.0 indicate acidic conditions, and measurements above 7.0 indicate basic or alkaline conditions. The pH scale is logarithmic (each incremental change corresponds to a ten-fold change in the concentration of hydrogen ions), so a pH of 4.0 is ten times more acidic than a pH of 5.0 and one hundred times more acidic than a pH of 6.0. Similarly, a pH of 9.0 is ten times more basic or alkaline than a pH of 8.0 and one hundred times more alkaline than a pH of 7.0. Natural waters usually have a pH between 6.5 and 8.5.

pH adjustment: a means of maintaining the optimum pH through the use of chemical additives.

Polyelectrolyte: Long chained, ionic, high molecular weight, synthetic, water soluble, organic coagulants. Also referred to as polymers. Non-ionic polymers are not polyelectrolytes.

Polymer: A synthetic organic compound with high molecular weight and composed of repeating chemical units (monomers). Polymers may be polyelectrolytes (such as watersoluble flocculants), water-insoluble ion exchange resins, or insoluble uncharged materials (such as those used for plastic or plastic-lined pipe).

Powdered activated carbon adsorption: A unit process involving the addition of powdered activated carbon to water for removal of impurities, such as taste and color-causing substances, color-causing substances, volatile organic compounds, etc.

Precoat filtration: A process that is designed to remove particulates by applying the water to be treated to a fabric or membrane module coated with very fine granular medium, such as diatomaceous earth. Precoat filtration is also called diatomaceous earth filtration.

Precoat: The initial layer of CELITE that is deposited on the filter septum. Usually 1/8" thick on pressure filters and 2" to 6" thick on R.V.P.F.

Pressure filtration: Pressure filters utilize pumping to increase the available head. Normally filter systems include multiple filter compartments. This allows for the filtration system to continue to operate while one compartment is being backwashed. A filter unit generally consists of a containing vessel, the filter media, structures to support the media, distribution and collection devices for influent, effluent and backwash water flows, supplemental cleaning devices, and necessary controls for flows, water levels and backwash sequencing. Filtration systems can be constructed out of concrete or steel, with single or multiple compartment units. Steel units can be either horizontal or vertical and are generally used for pressure filters. Systems can be manually or automatically operated. Backwash sequences can include air scour or surface wash steps.

Backwash water can be stored separately or in chambers that are integral parts of the filter unit. Backwash water can be pumped through the unit or can be supplied through gravity head tanks. The backwash wastewater can be treated for disposal or recycle to the intake of the water treatment system.

Pretreatment of make-up water: Potential pretreatment technologies for the cooling tower make-up water or boiler make-up water include water softeners, water conditioners, reverse osmosis (RO) systems, or demineralization. Since the make-up water supply is of high quality except the problems of total dissolved solids and hardness, the pretreatment processes are aimed at removal of TDS and hardness.

Pulsed power and electrodynamic field systems: Pulsed power and electrodynamic field systems generate a combination of variable magnetic flux density with a variable electric field. The induced electric fields alter the surface charge on suspended solids and particulate and force precipitation on selected surfaces that can periodically be removed and cleaned.

Pumping head: It is the pressure required to pump the water from a cooling tower basin, through the entire system, and return to the top of the cooling tower.

Rainwater Availability Map: It is a computer service provided by the Federal Energy Management Program (FEMP), and available online for determining whether or not rainwater capture for reuse is a viable in the industrial facility's area.

Rainwater: Rainwater is natural precipitation from the sky where water particles have become too large and too heavy to be held by the atmosphere as the cloud. Rainwater that runs off rooftops is typically of high quality, making it suitable for many end uses, including cooling tower make-up, boiler make-up, and irrigation. Rainwater can be collected from gutters or roof drains into a storage cistern. Gutter screens should be used to remove debris. Similar to condensate, rainwater may be used as the cooling tower make-up or boiler make-up water. Rainwater Availability Map may be use to determine rainwater harvesting potential in a facility's area.

Rapid mixing: A water or wastewater treatment unit process of quickly mixing a chemical solution uniformly through the process water.

Rapid sand filtration: A type of granular filter for which the granular material is sand, and the filtration rate is at least 2 gpm/ft^2 (5 m/h)

Recycled water to cooling tower: Water from other facility equipment can sometimes be recycled and reused for cooling tower make-up with little or no pre-treatment, including: (a) Air handler condensate (water that collects when warm, moist air passes over the cooling coils in air handler units). This reuse is particularly appropriate because the condensate has a low mineral content and is typically generated in greatest quantities when cooling tower loads are the highest; (b) Water used once through a cooling system; (c) Pretreated effluent from other processes provided that any chemicals used are compatible with the cooling tower system; and (d) High-quality municipal wastewater effluent or recycled water (where available).

Resin: (a) an ion exchange resin product; or (b) a non-ionic polymeric resin product (usually in the form of specifically manufactured organic polymer beads).

Reverse Osmosis (RO): It is one of the membrane filtration processes. RO membranes are mainly made of cellulose acetate with the pore sizes of about 5 to 20 Angstroms, and are used for rejecting salts (as high as 98%) and organics (as high as 100 %), at an operating pressure of about 20-50 bars (300-750 psig; 2,082-5,205 kPa gauge). The hydraulic pressure (through a pump) is used to provide the driving force for permeation, or for overcoming the chemical potential difference between the concentrate and the permeate, expressed in terms of the osmotic pressure. The sizes of molecular solids and salts (multivalent as well as monovalent) to be rejected by RO are normally in the range of 0.00025 to 0.003 microns.

Scale (or hard water scale): It is a coating or precipitate deposited on metal, glass, or ceramic surfaces. Boiler water, heat exchanger water, cooling tower water, etc. that contain carbonates or bicarbonates of calcium or magnesium are likely to form scale when heated. Scale is mainly caused by supersaturation of a hardness compound in the hot bulk water. So it is a big problem for operation and management (O&M) of a cooling tower.

Scale and biofilm buildup: Buildup of scale and biofilms on cooling tower surfaces will inhibit heat transfer and adversely affect cooling tower performance.

Scale inhibitor (or scale prevention compound, or antiscalants): It is a chemical additive, such as sodium polyphosphate, that prevents the buildup and formation of a scale.

Scaling: Scaling is the precipitation of inorganic dissolved solids that have become saturated in water. Scale formation reduces the heat exchange ability of the system because of the insulating properties of scale, making the entire system work harder to meet the cooling demand.

Sedimentation: A process for removal of solids before filtration by gravity or separation. (Note: The Federal definition refers to the sedimentation process used in the main treatment train, but sedimentation can also be used for recycle streams.)

Sedimentation-flotation (SediFloat): A combined sedimentation and dissolved air flotation clarifier, with sedimentation at the bottom and dissolved air flotation on the top. A typical example is SediFloat manufactured by Krofta Engineering Corporation.

Side-stream cooling water treatment: It is a water treatment technology using mainly physical or physicochemical treatment system, such as filtration, ultrafiltration, ion exchange, flotation, ozonation, UV, advanced oxidation, fixed field magnetic , pulsed power and electrodynamic field , cavitation, electrolysis, ultrasonic, Industrial Vortex Generator for Cooling Tower (IVG-CT), etc.. to treat approximately 10 percent of the circulating cooling water for disinfection and/or removal of total suspended solids (TSS) from cooling tower water, and recycling the side-stream treated water (about 10 %) to the main stream of cooling water (about 90%). Recently a biological side-stream cooling water treatment involving the use of Sphagmum moss has been attempted.

Silica (SiO_2): Silicon dioxide in nature form can be sand, stone, quartz, diatomite, flint, etc. Silica in water can be measured by the Standard Methods for the Examination of Water and Wastewater

4500-Si. silica and phosphate in water react with molybdate ion under acidic conditions to form yellow silicomolybdic acid complexes and phosphomolybdic acid complexes. Silica is then determined by measuring the remaining yellow color at 452 nm.

Single-Pass Cooling: Single-pass cooling systems use water to remove heat and cool specific pieces of equipment, such as a condenser or air conditioning unit. After the water is passed through the equipment, it is typically discharged to the sewer, rather than being recooled and recirculated. It uses approximately 40 times more water to remove the same heat load than a cooling tower operating at five cycles of concentration. Most types of equipment cooled with single pass water can be replaced with air-cooled systems.

Slow sand filtration : A process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/h) resulting in substantial particulate removal by physical and biological mechanisms.

Sodium hypochlorite (NaOCl): It is a common chemical known as liquid bleach, that is used for disinfection. It is cheaper than chlorine gas for small operations where safety concern over chlorine gas storage exist. For large operation, chlorine gas storage can be handled properly by experts, so application of gas chlorination is cheaper. Sodium hypochlorite is impacted by pH levels. High organic load in cooling water can lead to chloramines as well as disinfection byproducts that can be found in the water blowdown.

Soft water: It is water having a low hardness within the range of 0 to 75 mg/L as calcium carbonate. Specifically very soft water contains 0-25 mg/L as $CaCO_3$; soft water contains 25-75 mg/L as $CaCO_3$.

Softening: It is physicochemical process (such as lime-soda softening process, ion exchange process, etc.) for removal of calcium and magnesium hardness from water.

Solenoid valve: It is an automatic hydraulic valve that can shut off single-pass cooling water, boiler water or any other process water when the equipment is turned off or when there is no heat load present.

Spectrophotometer: It is an instrument that uses a diffraction grating or a prism to control the light wavelengths used for specific analysis with or without development of visible color.

Sphagnum moss: This plant is found mainly in bogs on the surface, and has been used for centuries for water and food preservation. Bog is permanently wet terrain characterized by an acidic soil that produces peat and dominated by sphagnum and shrubs. The moss's ability to naturally absorb impurities such as calcium, magnesium and other metals means it can be used to minimize scaling and corrosion problems. Its ability to inhibit organic contamination can assist in reducing biocidal costs. Also, hydrogen ions are released in the exchange process, providing neutralizing alkalinity to lower pH levels in the water. Once the moss is saturated, it must be removed. It can be disposed of locally as an organic material, making it an interesting ecological product.

Steam boilers: They include water-tube boilers or fire-tube boilers, which generate steam by burning fuel (i.e., gas or oil) and indirectly or directly heating water within the boiler system, thus generating steam. As steam is distributed throughout the property, its heat is transferred to the ambient environment and, as a result, condenses to water. This condensate is either discharged to the sewer or captured and returned to the boiler for reuse. If the condensate is discharged to the sanitary sewer, most codes require it to be cooled to an acceptable temperature before discharging (usually between 120°F and 140°F). The hot condensate is typically tempered with cool water to meet the temperature discharge requirements.

Tannin: Tannin is a colored plant constituent having aromatic hydroxyl groups. Tannin may enter the water supply through the vegetable matter degradation or through the waste discharge of the leather tanning industry. Both tannin and lignin have been applied in the internal boiler water treatment as the scale control chemical.

Ton of refrigeration (TR): (a) **TR** is a unit of heat extraction capacity of the refrigeration or cooling equipment. Generally, TR is defined as the amount of heat transferred to freeze or melt 1 short ton (2000 lb) of ice at 0 deg. C in 24 hours; This is only for the latent heat, so the water would need to be at zero degrees Celsius, 32 degrees Fahrenheit, and the ice would then also still be at zero degrees Celsius, 32 degrees Fahrenheit; (b) 1 TR = 12000 Btu/hour when US customary units are used; (c) 1 TR = 3.5168525 kW for conversion to the metric units.

Total alkalinity: Total alkalinity primarily includes hydroxide, carbonate, and bicarbonate alkalinities. Alkalinity is a measure of the capacity of a water to neutralize strong acid, in natural waters this neutralizing capacity is usually attributable to bases such as carbonate, bicarbonate and hydroxide ions, but this capacity may also includes silicates, borates, and ammonium ions.

Total dissolved solids (TDS): **(a)** They are total solids that have been dissolved into a liquid. They may be ionic and/or polar in nature. Technically it is the weight per unit volume of solids remaining after a sample has been filtered to remove suspended and colloidal solids. The solids passing the filter are evaporated to dryness. The filter pore diameter and evaporation temperature are frequently specified. (b) TDS in natural water are due to soluble inorganic mineral compounds. The TDS concentration in normal surface waters is generally less than 200 mg/L. The recommended upper limit of TDS in irrigation water is 1500 mg/L. The specific conductance or the electrical conductivity (EC) of water is related to TDS linearly, or TDS = k (EC), where TDS is in mg/L, EC is in µmho/cm, and k is a constant varying from 0.5 to 0.9 (average 0.64). A maximum of 500 mg/L TDS in drinking water supplies is recommended by the U.S. Environmental Protection Agency, although TDS is not a measure of the safety or harmfulness of water. The Canada guideline value for TDS is 500 mg/L and the Mexico maximum allowable limit for TDS is 1000 mg/L.

Total organic carbon (TOC): Total organic carbon in mg/L measured using heat, oxygen, ultraviolet irradiation, chemical oxidants, or combinations of these oxidants that convert organic carbon to carbon dioxide, rounded to two significant figures.

Total solids (TS): It is a term applied to the material residue left in the vessel after evaporation of a water sample and its subsequent drying in an oven at a defined temperature. Total solids includes (a) total suspended solids (TSS), which is the portion of TS retained by a filter (2 um pore size), and (b) total dissolved solids (TDS) which is the portion that passes through the 2 um pore size filter (or smaller). TS = TSS + TDS.

Total suspended solids (TSS): It represents the total amount of substances that are suspended in water. Total solids (TS) minus total dissolved solids (TDS) equals to total suspended solids (TSS). TSS = TS - TDS.

Total trihalomethane precursors : Organic materials in the raw water that promote the formation of trihalomethanes.

Total trihalomethanes (TTHM): The sum of the concentration in milligrams per liter of the trihalomethane compounds (trichloromethane [chloroform], dibromochloromethane, bromodichloromethane and tribromomethane [bromoform]), rounded to two significant figures.

Total trihalomethanes formation potential (TTHMFP): A measure of the ability of a water to create trihalomethanes.

Trihalomethane (THM) : One of a family of organic compounds, named as derivatives of methane, wherein three of the four hydrogen atoms in methane are each substituted by a halogen atom in the molecular structure.

Ultrafiltration (UF): It is one of the membrane filtration processes. UF is another pressure filtration process for the separation of macromolecular solids in the particle size-range of about 0.001 micron to 0.1 micron. The primary factor affecting solids separation from water relies on the size of macromolecular solids. The hydraulic pressure required by UF for overcoming hydraulic resistance of the polarized macromolecular layer on the membrane surface is about 1-7 bars (about 15 – 100 psig; 104-695 kPa gauge)

Ultrasonic systems: Ultrasonic systems impart high-frequency sonar energy that can cause mechanical damage to bacteria cell walls. Like cavitation devices, ultrasonic energy can also produce low-pressure bubbles, which can collapse and contribute to the damaging of bacteria cell walls.

Ultraviolet light systems: Ultraviolet (UV) light systems irradiate a water stream with UV-C wavelength light in the 100- 280 nanometer range. When UV-C light penetrates the cell of a microorganism, it typically breaks down the DNA, altering functions such as the DNA replication process necessary for cell division and thus disturbing the ability of the subject microorganisms to procreate.

Ultraviolet-hydrogen peroxide (UV-H_2O_2) process: One of advanced oxidation processes (AOP) involving the use of both UV and H_2O_2 for the production of hydroxyl radicals as the strong oxidizing agent.

Ultraviolet-ozone (UV-O_3) process: It is one of advanced oxidation processes (AOP) involving the use of UV to catalyze the decomposition of ozone to hydroxyl radicals for enhanced oxidation and disinfection in water treatment.

Vacuum flotation: In vacuum flotation, the influent process water to be treated is usually almost saturated with air at atmospheric pressure. There is an air-tight enclosure on the top of the flotation chamber in which partial vacuum is maintained. The fine air bubbles (20-80 microns) are generated under laminar hydraulic flow conditions by applying a vacuum (negative pressure) to the flotation chamber. The theory is that the lower the pressure, the lower the air solubility in water. The soluble air originally in water is partially released out of solution as extremely fine bubbles due to a reduction in air solubility caused by negative vacuum pressure. The bubbles and the attached solid particles rise to the water surface to form a scum blanket, which can be removed by a continuous scooping or skimming mechanism. Grit and other heavy solids that settle to the bottom are raked to a central sludge sump for removal. Auxiliary equipment includes an aeration tank for saturating the water or wastewater with air, vacuum pumps, and sludge pumps.

Water quality: The physical, chemical and biological characteristics of water and the measure of its condition relative to the requirements for one or more biotic species and/or to any human need or purpose.

Water Reuse: Water reuse options vary depending on the nature of water uses from site to site along with a broad range of other considerations, including local and regional water reuse laws and the availability of an adequate reuse resource. It is a concept to take discharge water from one application, apply sufficient treatment to it if needed, and then use it as a make-up water resource for the cooling tower system.

Water softener: (a) A chemical compound that reduces hard water minerals (i.e. divalent metallic cations, such as calcium ions and magnesium ions) when it is introduced into a hard water; (b) a pressurized water treatment device consisting of a bed of cation exchange resin that reduces hard water minerals (i.e. divalent metallic cations, such as calcium ions and magnesium ions) when the hard water passes through it.

Water-quality criteria: Criteria that comprise numerical and narrative *criteria*. Numerical criteria are scientifically derived ambient concentrations developed by the US Environmental Protection Agency (USEPA) or the States for various pollutants of concern so that human health and aquatic life can be protected. Narrative criteria are statements that describe the desired water-quality goal.

Wet bulb: It is the lowest temperature that water theoretically can reach by evaporation. Wet-bulb temperature is an important factor in cooling tower design and should be measured by a psychrometer.

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APPENDIX:

INTRODUCTION OF THE SERIES EDITORS OF "ENVIRONMENTAL SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM)"

1. Editor Lawrence K. Wang

Editor Lawrence K. Wang has served the society as a professor, inventor, chief engineer, chief editor and public servant (UN, USEPA, New York State) for 50+ years, with experience in entire field of environmental science, technology, engineering and mathematics (STEM). He is a licensed NY-MA-NJ-PA-OH Professional Engineer, a certified NY-MA-RI Laboratory Director, a licensed MA-NY Water Operator, and an OSHA Instructor. He has special passion, and expertise in developing various innovative technologies, educational programs, licensing courses, international projects, academic publications, and humanitarian organizations, all for his dream goal of promoting world peace. He is a retired Acting President/Professor of the Lenox Institute of Water Technology, USA, a Senior Advisor of the United Nations Industrial Development Organization (UNIDO), Vienna, Austria, and a former professor/visiting professor of Rensselaer Polytechnic Institute, Stevens Institute of Technology, University of Illinois, National Cheng-Kung University, Zhejiang University, and Tongji University. Dr. Wang is the author of 750+ papers and 50+ books, and is credited with 29 invention patents. He holds a BSCE degree from National Cheng- Kung University, Taiwan, ROC, a MSCE degree from the University of Missouri, a MS degree from the University of Rhode Island and a PhD degree from Rutgers University, USA. Currently he is the book series editor of CRC Press, Springer Nature Switzerland, Lenox Institute Press, World Scientific Singapore, and John Wiley. Dr. Wang has been a Delegate of the People to People Internatonal Foundation, a Diplomate of the American Academy of Environmental Engineers, a member of ASCE, AIChE, ASPE, WEF, AWWA, CIE and OCEESA, and a recipient of many US and international engineering and science awards.

2. Editor Mu-Hao Sung Wang

Editor Mu-Hao Sung Wang has been an engineer of the New York State Department of Environmental Conservation, an editor of CRC Press, Springer Nature Switzerland, and Lenox Institute Press, and a university professor of the Stevens Institute of Technology, National Cheng-Kung University, and the Lenox Institute of Water Technology. Totally she has been a government official, and an educator in the USA and Taiwan for over 50 years. Dr. Wang is a licensed Professional Engineer, and a Diplomate of the American Academy of Environmental Engineers (AAEE). Her publications have been in the areas of water quality, modeling, environmental sustainability, solid and hazardous waste management, NPDES, flotation technology, industrial waste treatment, and analytical methods. Dr. Wang is the author of over 50 publications and an inventor of 14 US and foreign patents. She holds a BSCE degree from National Cheng-Kung University, Taiwan, ROC, a MS degree from the University of Rhode Island, RI, USA, and a PhD degree from Rutgers University, NJ, USA. She is the Co-Series Editor of the Handbook of Environmental Engineering series (Springer Nature Switzerland), Coeditor of the Advances in Industrial and Hazardous Wastes Treatment series (CRC Press of Taylor & Francis Group) and the Coeditor of the Environmental Science, Technology, Engineering and Mathematics series (Lenox Institute Press). She is a member of AWWA, NYWWA, NEWWA, WEF, NEWEA, CIE and OCEESA.

3. Editor Yuriy I. Pankivskyi

Editor Yuriy I. Pankivskyi has 25 years of professional experience of scientific research and environmental education. He has expertise in strategic environmental assessment, environmental impact assessment, drinking water treatment, waste waters treatment, water and air pollution control, solid waste management. He works as environmental consulting engineer for industrial enterprises, state administrations of cities and towns of Western Ukraine, communities, private firms and institutions and as researcher, educator for state universities. He is the Associate Professor and Deputy Head of Department of Ecology of Ukrainian National University of Forestry. His research and publications have been in areas of water and air quality control, waste water treatment, environmental sustainability and education, analytical methods, investigations of multifunctional material for optoelectronics and environment testing. Dr. Pankivskyi is author of over 70 scientific publications. He earned his Specialist degree from Lviv State Ivan Franko University (Ukraine), ME degree from Lenox Institute of Water Technology (MA, USA), and his PhD degree from Lviv National Ivan Franko University (Ukraine). He is a member of National Ecological Center of Ukraine (Lviv Department).