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# An Introduction to Water Cooling Towers

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Editor

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- 2. COOLING TOWER WATER CALCULATIONS**

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**1. TYPES OF COOLING TOWER SYSTEMS.** Cooling water systems remove heat generated from a variety of industrial processes. There are three basic types of cooling water systems: once-through, open recirculating, and closed recirculating cooling water systems. This discussion describes once-through and open recirculating systems. Chapter 5 describes the closed recirculating system.

**1.1 ONCE-THROUGH COOLING WATER SYSTEMS.** Once-through cooling water systems use cool water that circulates only once through the entire system before being discharged. This type of system is commonly found along rivers or coastlines where abundant water is available for use. The system contains heat exchange equipment and transfer piping, as shown in Figure 1. Power utility services often use this type of system.

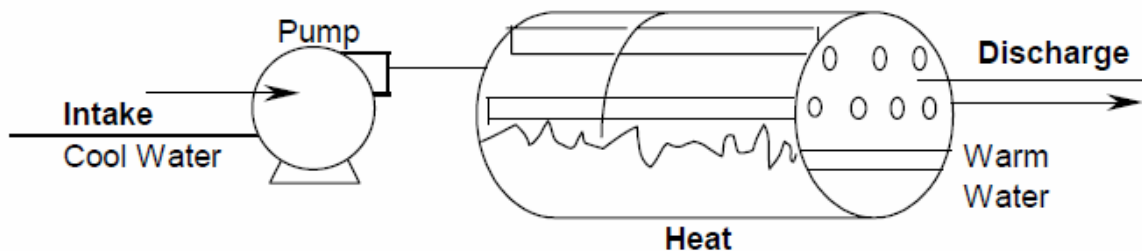


Figure 1

Once-Through Cooling Water System Diagram

**1.2 OPEN RECIRCULATING COOLING WATER SYSTEMS.** Open recirculating cooling water systems are open to the atmosphere and continuously recycle and reuse the cooling water. These systems are composed of an evaporator unit, a cooling tower, or an evaporative condenser. These units mix air and water and allow some of the water to evaporate, cooling the balance of the water volume. The cooled water is then circulated to heat exchangers or chillers, where heat is added to the cooling water thereby removing heat from the process flow stream. The warmed water is then circulated to the cooling tower, where the cycle is repeated. Water is lost from the system primarily through evaporation; however, a portion of the cooling water must be discharged as waste (i.e., blowdown) to maintain a suitable water quality within the system. All water lost from the

system is replaced by makeup water. Recirculating cooling water systems are found in most air conditioning chiller operations, as well as many heat exchange operations. Evaporative fluid coolers and evaporative condensers are terms defining open recirculating cooling water systems that use evaporators, which are slightly different than a cooling tower and do not send the cooled water out of the evaporative unit itself. An evaporative cooler cools a circulating fluid that does not change phase (e.g., does not condense from a gas to a liquid). An evaporative condenser cools a circulating fluid from a gas into a liquid, such as a refrigerant. The hot fluid that is to be cooled is brought to the unit. Figure 2 shows a typical evaporative cooler and evaporative condenser diagram. Figure 3 shows a typical open recirculating cooling water system; and Figure 4 shows a typical cooling tower system.

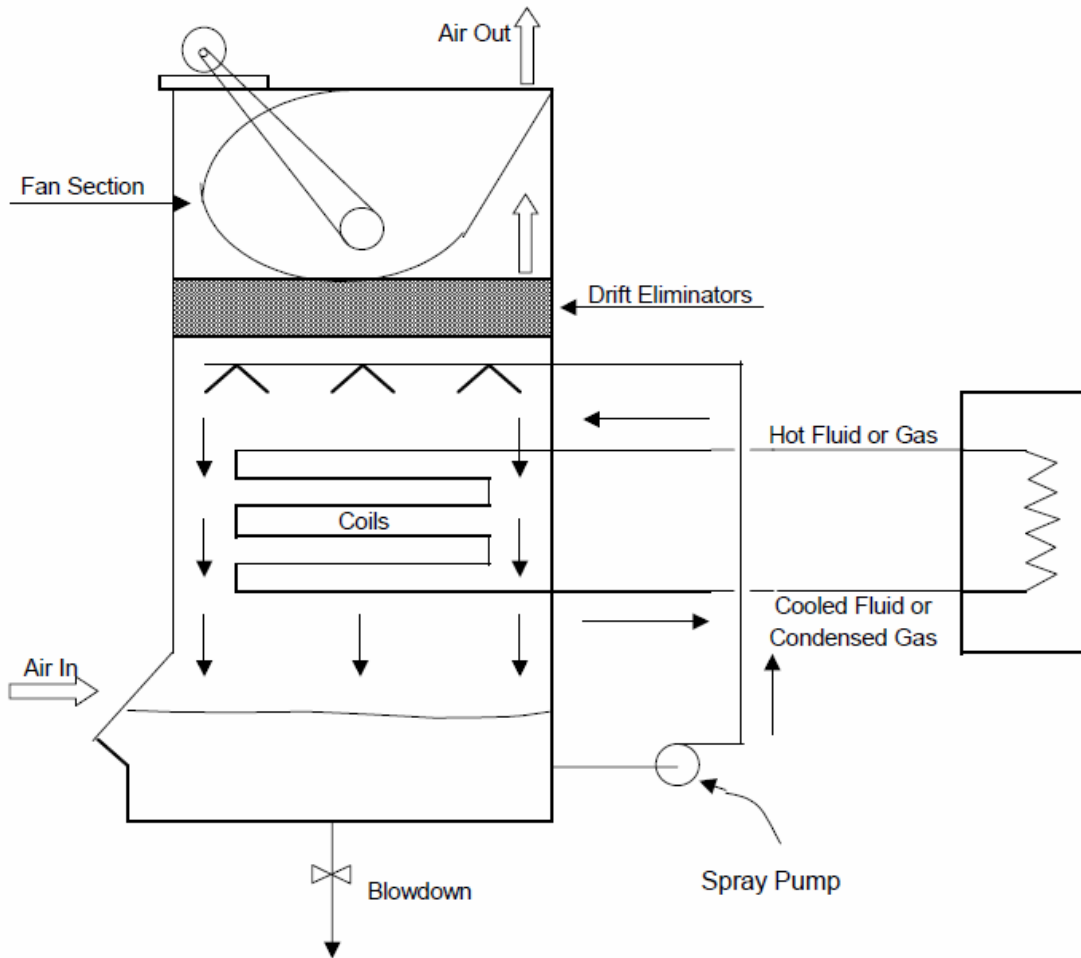


Figure 2

Evaporative Fluid Cooler and Evaporative Condenser Diagram

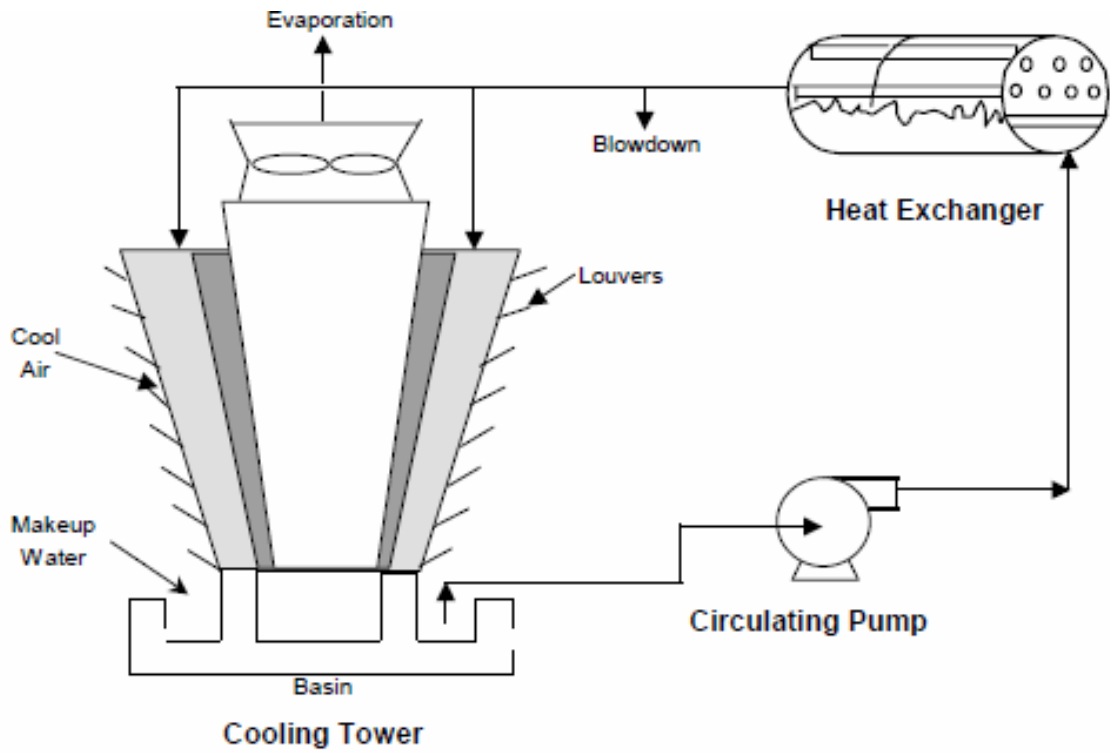


Figure 3  
Open Recirculating Cooling Tower Water System Diagram

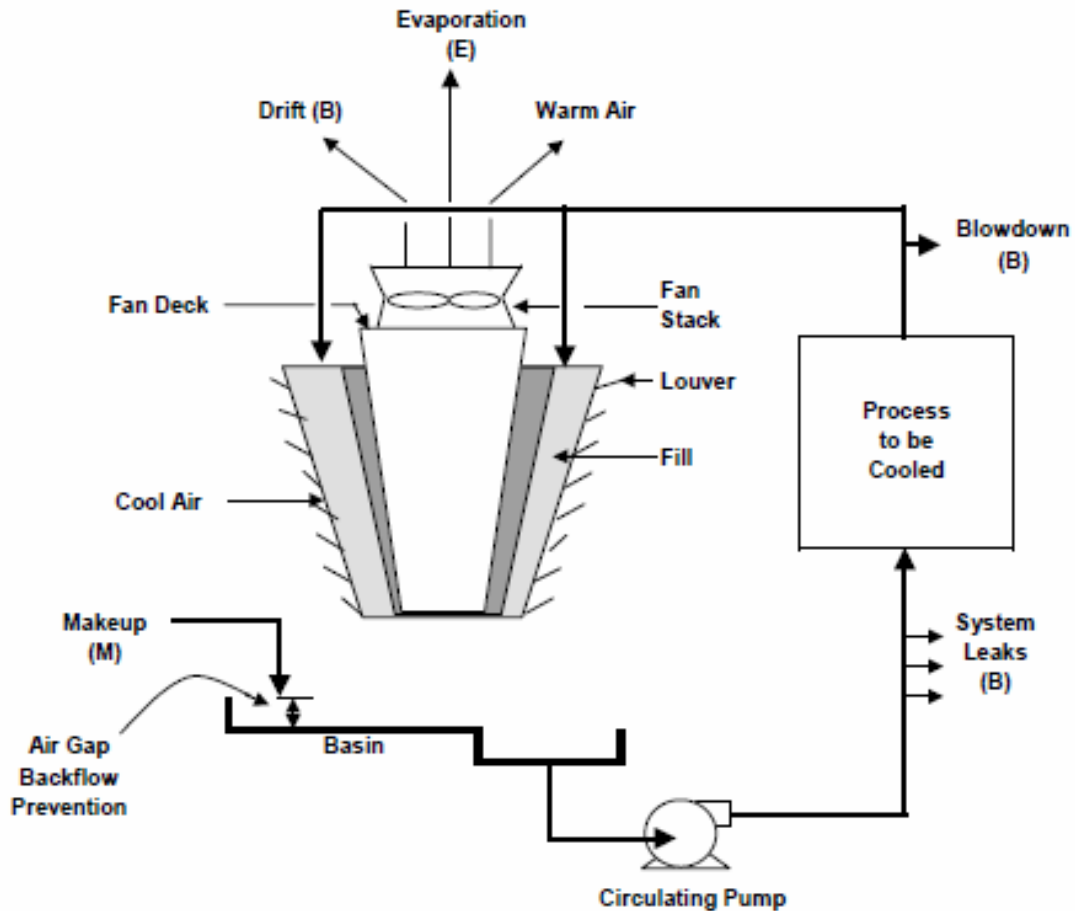


Figure 4  
Cooling Tower Water System

**1.3 TYPES OF COOLING TOWERS.** Types of cooling towers include natural draft, induced draft, and forced draft.

**1.3.1 NATURAL-DRAFT TOWERS.** In natural-draft towers, airflow through the tower is achieved naturally (i.e., without any mechanical means such as fans). Air flows across the falling water and up through the cooling tower as a result of the differential density between the lighter, heated and humidified, air within the tower and the cooler and dryer outside air. Fitting the tower with spray nozzles, which create more mixing of air and water droplets and improve the evaporation efficiency, produces increased water-cooling rates. Large utility power plants use these large natural-draft cooling towers, which are called hyperbolic cooling towers due to their hyperbolic shape (see Figure 5).



Figure 5  
Hyperbolic Natural-Draft Cooling Towers

**1.3.2 FORCED-DRAFT TOWERS.** The term “forced draft” denotes that air is forced or blown by fans into the cooling tower and up through the flow of falling water in the cooling tower. Drift eliminators are installed to prevent water entrained in the air from leaving the system.

**1.3.3 INDUCED-DRAFT TOWERS.** The term “induced draft” denotes that air is drawn by fans through the flow of falling water and up and out of the cooling tower. The airflow can be drawn either cross-flow or counter-flow with respect to the orientation of the falling water, resulting in either a cross-flow tower or a counter-flow tower. Drift eliminators are also present. (See Figures 6, 7, 8, and 9 for diagrams and photos of cross-flow and counter-flow cooling towers.)



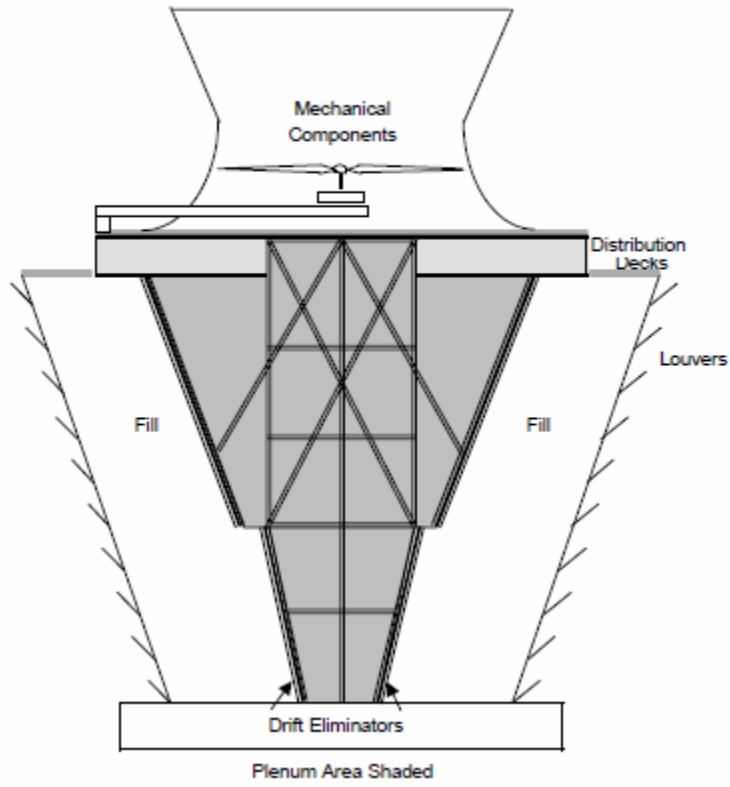


Figure 6  
Cross-Flow Cooling Tower



Figure 7  
Cross-Flow Cooling Tower

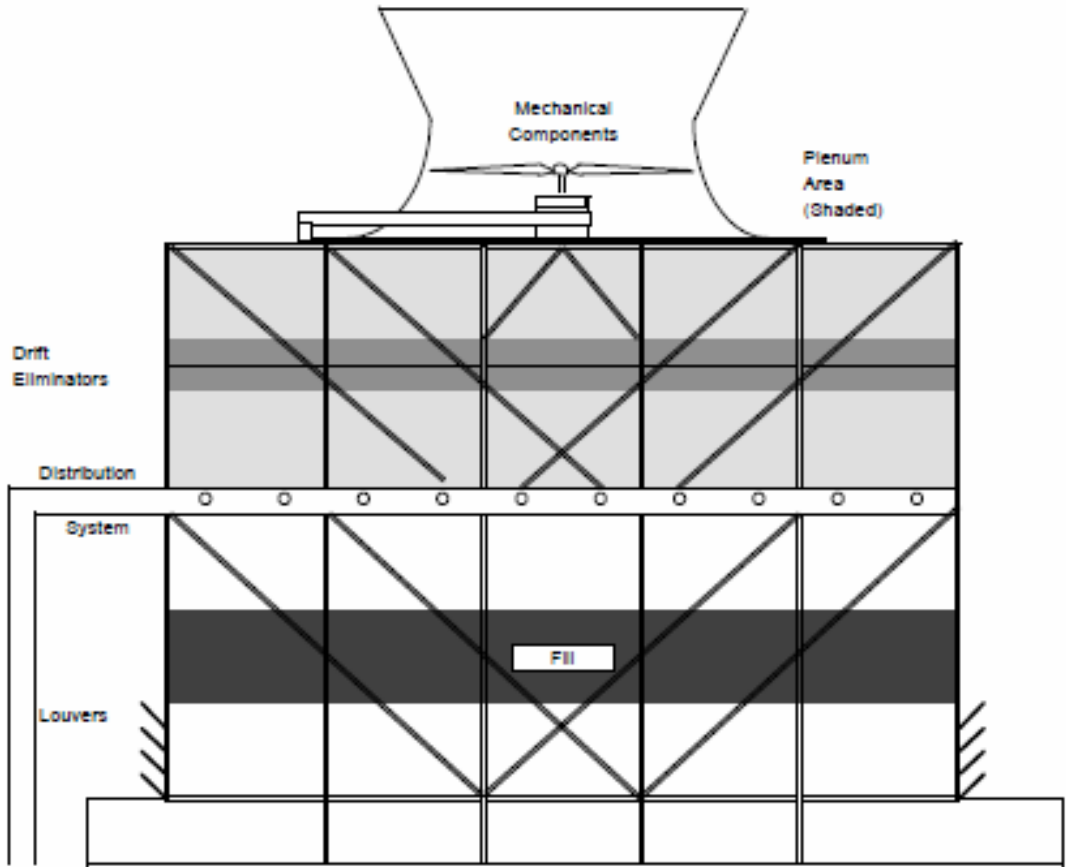


Figure 8  
Counter-Flow Cooling Tower Diagram



Figure 9  
Counter-Flow Cooling Tower

**1.3.4 TYPICAL COOLING TOWERS.** Cooling towers are commonly of the induced-draft, cross-flow variety, although counter-flow and forced-draft cooling towers are also represented. The cooling towers range in size from small to large capacity.

**1.4 COMPONENTS OF A COOLING TOWER.** Figure 10 shows a simple diagram of a 1-fan, induced-draft, cross-flow cooling tower. The major parts of the tower include the basin and cold well, louvers, fill, water distribution (and fan) deck, drift eliminators, fan and fan discharge, and the endwall casings.

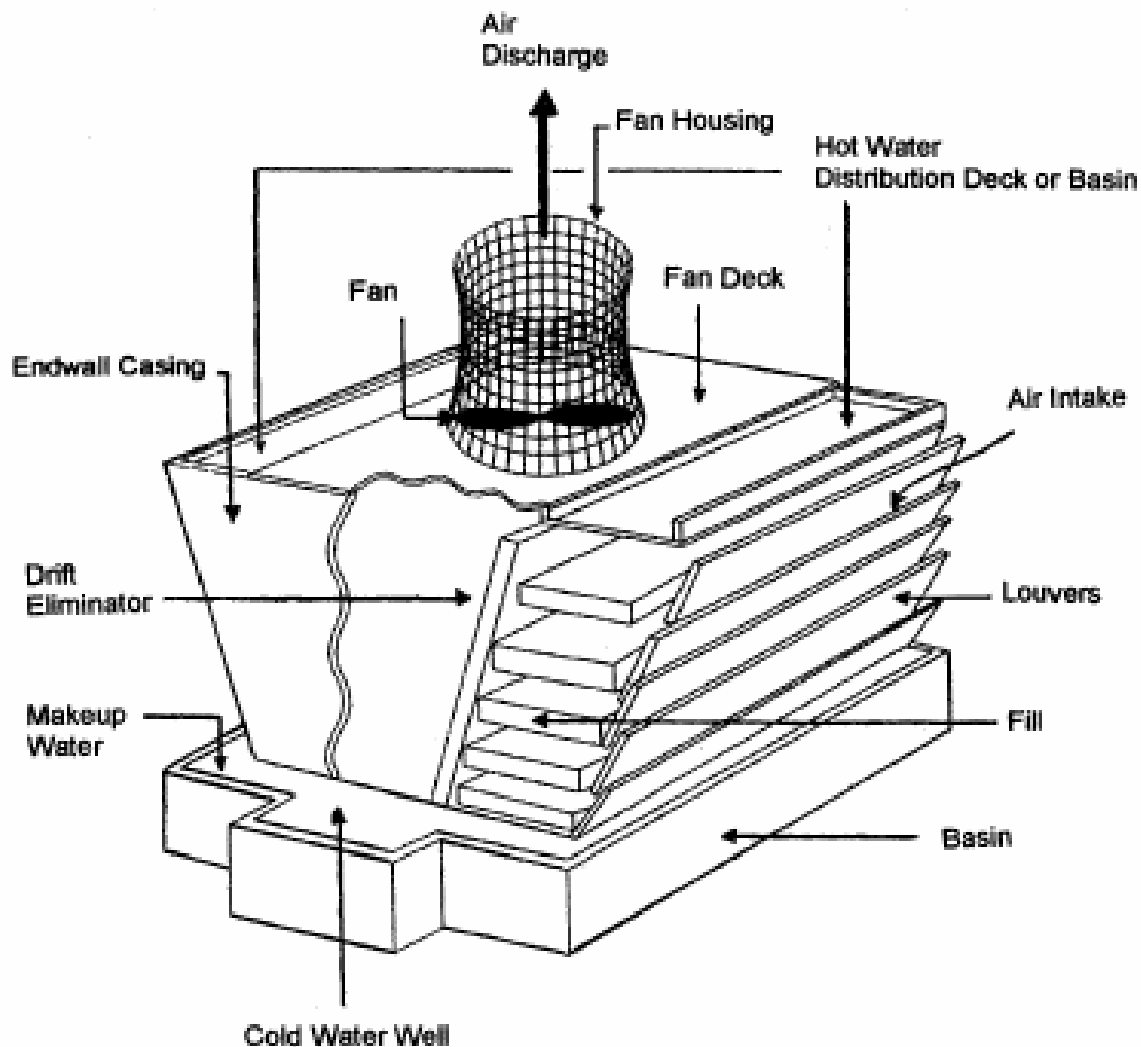


Figure 10  
 Induced-Draft Cross-Flow Cooling Tower Components

**1.4.1 BASIN AND COLD WELL.** The basin is that portion of the cooling tower structure located under the tower that is used for collecting cooled water and which can be used as a location for adding makeup water. The cold well is a deepened portion of the basin that contains submerged water circulation pumps. The basin may be constructed of concrete, wood, metal, or fiberglass.

**1.4.2 LOUVERS.** Louvers are flat or corrugated members constructed of wood, plastic, cement board, or fiberglass, and installed across (horizontally) the open side of a tower.

The main function of louvers is to prevent water from splashing out of the cooling tower through the openings where air enters the tower. Louvers are usually set at an angle to the direction of airflow.

**1.4.3 FILL.** Fill is the internal part of a tower where air and water are mixed. The fill intercepts the downward fall of water. The water is mixed with the air contained in the fill material and water is evaporated and cooled. There are two types of fill: splash fill and film fill. The falling water hits the splash fill, splashes, and breaks up into smaller water droplets, resulting in an increased rate of evaporation. The splash fill is made of wooden slats or bars, plastic, or ceramic tile. Film fill is a compact plastic material, similar to a honeycomb, that causes water to flow over the fill material, creating a large wet surface that maximizes evaporation as air travels past the film surface (see Figure 11).



Figure 11  
High-Efficiency Cooling Tower Film Fill

**1.4.4 DRIFT ELIMINATORS.** The drift eliminators efficiently remove water droplets from the air and return the recovered water to the cooling tower, thereby minimizing the loss of cooling tower water. They are located in areas that are situated after the fill and water sprays and just before the area where the air exits the cooling tower (see Figures 6 and 8). Drift eliminators are also known as “mist eliminators.”

**1.4.5 WATER DISTRIBUTION AND FAN DECK.** In a cross-flow cooling tower, the hot water basin is used to distribute the warm return water flow uniformly over the tower fill (see Figure 6). In a counter-flow cooling tower, water sprays are used to distribute the warm water (see Figure 8). The fan deck supports the motor and fan of the water spray system. The stack is the structure (typically a cylinder) that encloses the fan and directs warm, humid discharge air upward and out of the cooling tower.

**1.4.6 CELL.** This is the smallest subdivision of a large cooling tower in which the fan can operate as an independent unit. A midwall casing must separate each end of the cell from the adjacent cells to ensure all air flow induced by the cell fan is drawn only through the cell fill and mist eliminator air path. Figure 7 illustrates a typical three-cell cross-flow cooling tower. Figure 9 illustrates a typical four-cell counter-flow cooling tower.

**1.5 COMMON COOLING WATER SYSTEM PROBLEMS.** Water-related problems can cause system downtime, loss of equipment efficiency, the need for capital replacement of equipment, and can increase the risk of disease from pathogenic microorganisms. An open recirculating cooling tower system has a greater potential for these problems than does a once-through cooling water system, due to the air- and water-mixing design of the open recirculating system. These problems are associated with water-caused deposits, corrosion, or microbiological organisms, and occur for various reasons:

- The cooling tower is essentially a huge air scrubber that can introduce materials such as microorganisms, gases, dust, and dirt into the circulating water, which provides an excellent growth environment for pathogenic microorganisms. These materials can contribute to the formation of deposits and cause corrosion.

- If the water is not properly treated and its quality maintained, corrosion and scale and solids deposition can occur. The potential for these problems results from the nature of the cooling system design and the operating conditions, including water evaporation, mineral concentration, and water temperatures of up to 54 °C (130 °F).
- The constant addition of makeup water results in increased quantities of mineral constituents that can form scale, deposits, and corrosion. Blowdown control and proper water treatment can minimize these problems.
- The film fill contains small water and air passages that can become plugged, thereby causing a reduction in cooling tower operational efficiency due to reduced water evaporation (see paragraph 4-1.4.3).
- Current designs for heat exchangers and cooling towers provide for more efficient operation than in the past, but unexpected water problems may occur.

**1.5.1 ENHANCED AND SUPER-ENHANCED CHILLER CONDENSER TUBING.** Recent air conditioning chiller equipment designs incorporate enhanced and super-enhanced chiller condenser tubes. Previous designs have used smooth-bored waterside condenser tubing. The enhanced tube is machined with rifled grooves that provide an increased surface area and a resultant increase in heat transfer; however, the rifled grooves and ridges tend to entrap SS (i.e., dirt, silt, sand, and old corrosion products), which are deposited from the cooling water as it passes through the tube. This deposition of material on metal surfaces can create a type of localized corrosion called “under-deposit corrosion.” This situation has resulted in numerous cases of tube failure. The super-enhanced chiller tubes have even finer grooves and ridges, making this type of tubing even more susceptible to under-deposit corrosion. (See Figures 12 and 13, which show photos of super-enhanced copper tubes.)



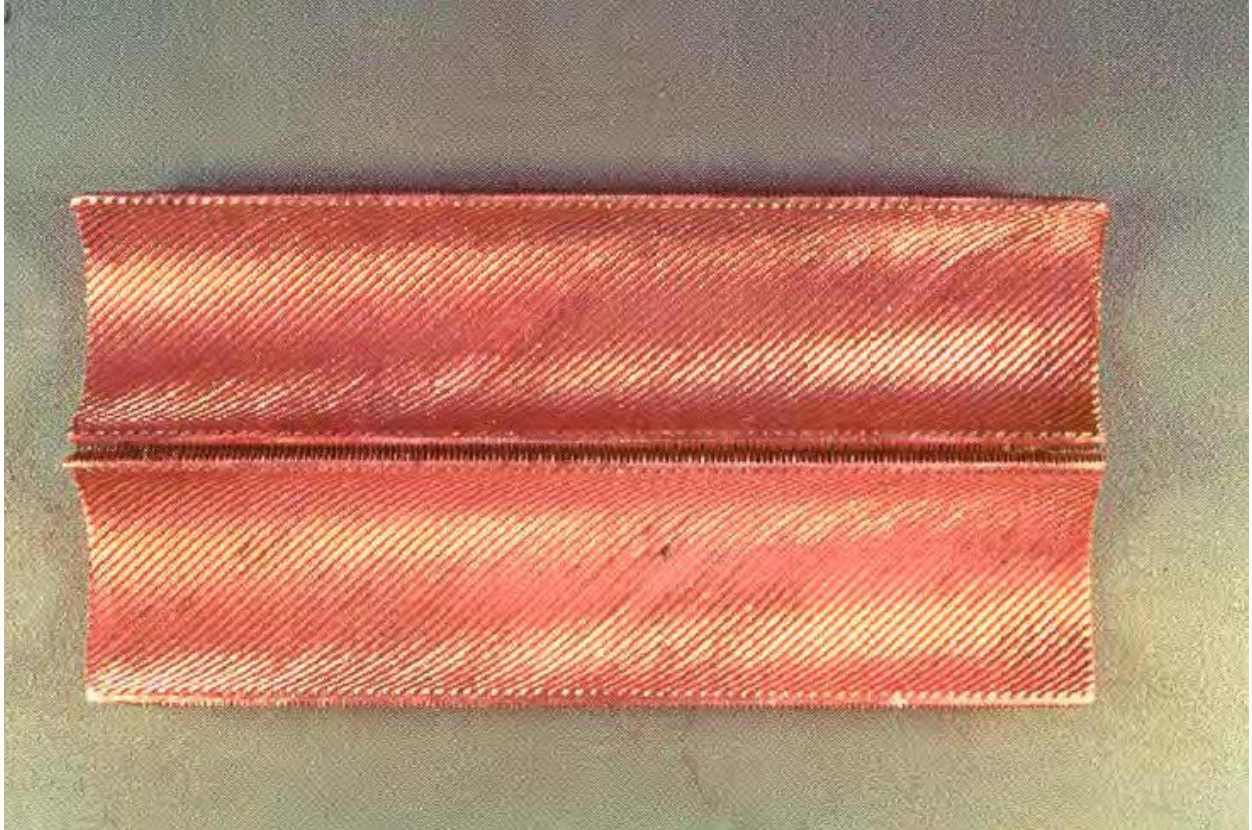


Figure 12  
Super-Enhanced Copper Tubes

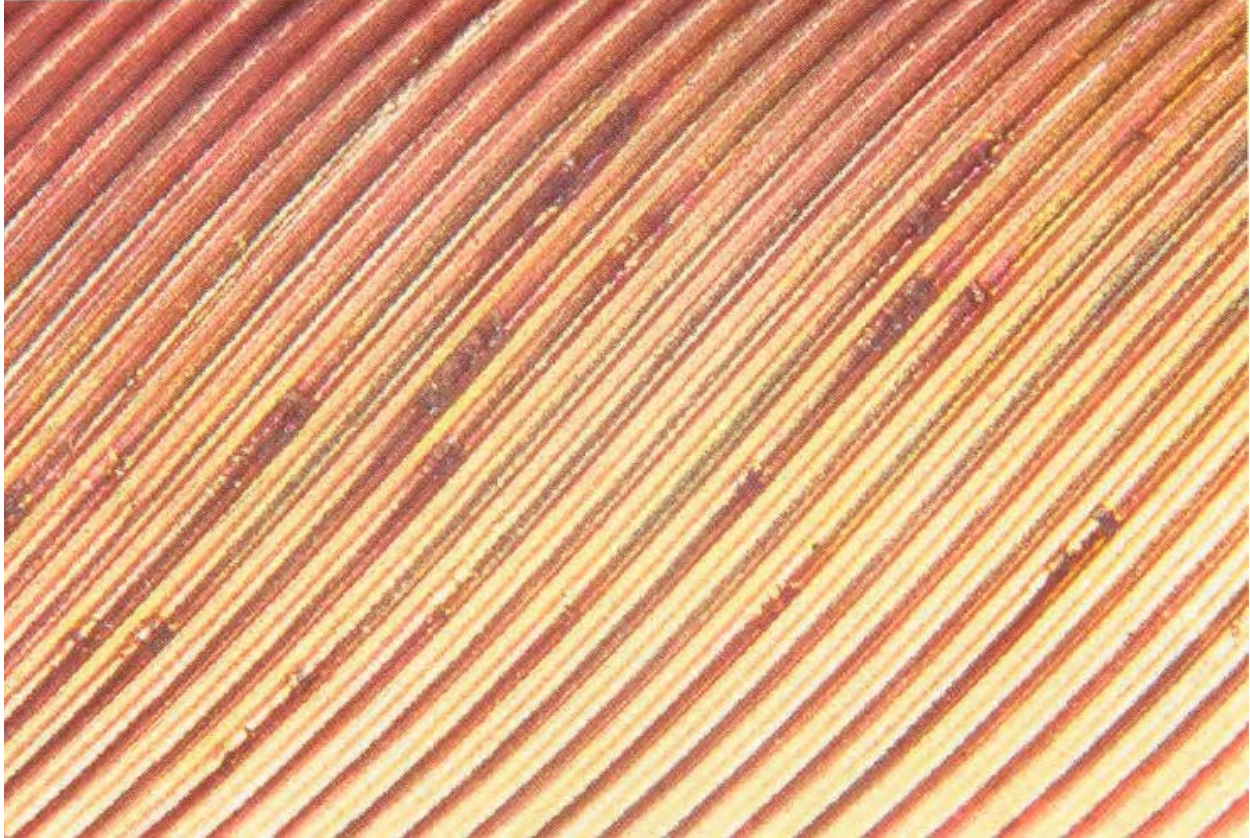


Figure 13

Close-Up of Corrosion Pitting on Super-Enhanced Copper Tube

**1.5.2 WHITE RUST.** Some cooling towers are constructed with galvanized steel components and must not be exposed to conditions of high pH (high alkalinity). The galvanizing process deposits a protective zinc coating on a mild steel metal surface, resulting in increased resistance to corrosion. Failure to avoid such exposure can result in production of “white rust” due to the corrosion of the galvanizing coating. Eventually, this corrosion process exposes the mild steel underneath, which then starts to corrode. White rust failures have been a common occurrence throughout the country, mainly with newer cooling towers. Proper protection of the galvanizing material is necessary both during startup of a new cooling tower and during normal operations. Specific water treatment chemicals are needed to provide this protection. Examples include pretreatment with a high level of orthophosphate.

**1.5.3 COOLING TOWER FILM FILL.** Small- and medium-sized cooling towers use film fill, which is a tightly packed media as compared to the splash-type fill used prevalently in the past. Film fill has a higher potential for fouling (plugging) due to adherence and entrapment of biomass and of SS (i.e., dirt, silt, and sand). The cooling capacity of a cooling tower can be reduced if the film fill is extensively fouled (see Figure 14). Instances of severe fouling have resulted in the collapse of fill into the cooling tower basin. In addition, fouling deposits in the fill can harbor pathogenic microbiological organisms such as Legionnaires' Disease.

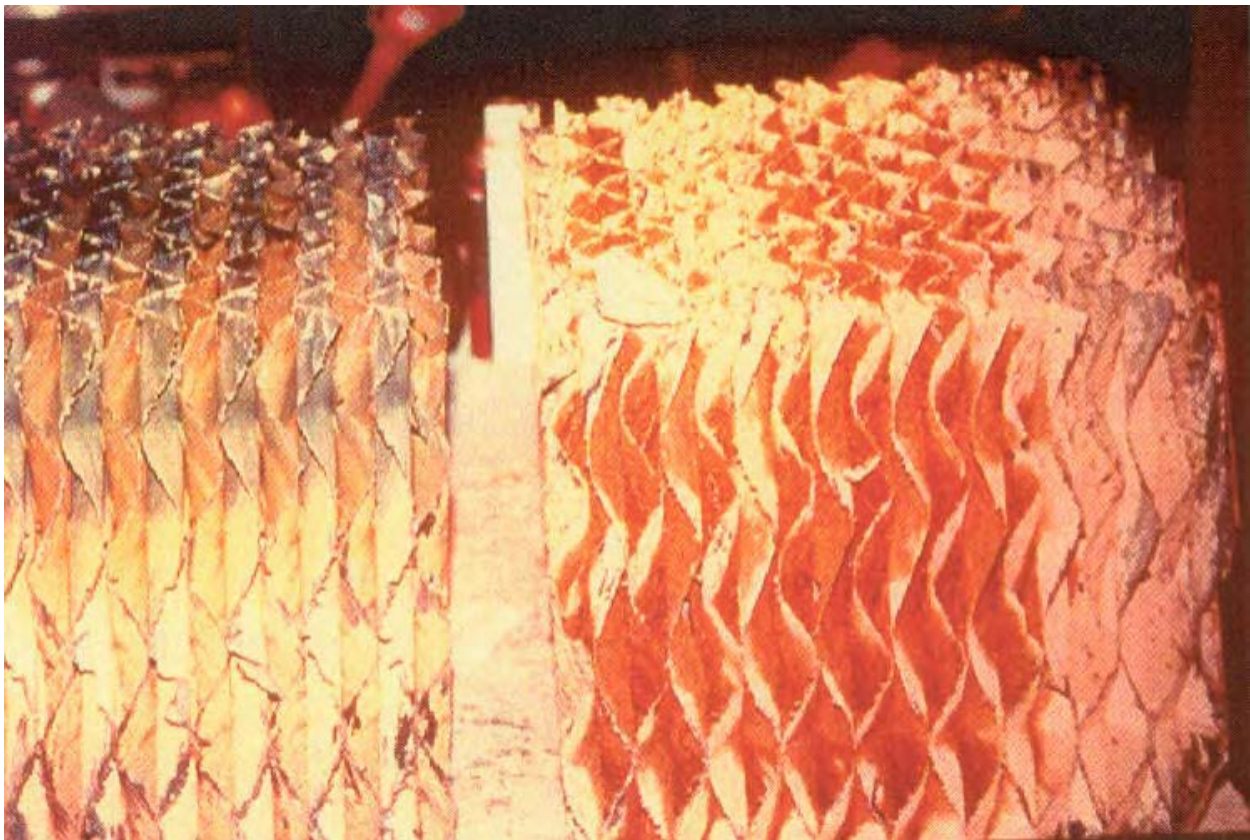


Figure 14  
Heavily Fouled Cooling Tower Film Fill

**1.5.4 LEGIONELLA BACTERIA.** This type of bacteria is the cause of Legionnaires' Disease. It can grow in cooling water systems even when a proper microbiological control program has been maintained. This bacterium can be discharged in the drift produced

from all types of cooling tower systems. If a susceptible person inhales the bacteria, the disease could possibly develop. Due to increased awareness by cooling tower operators and the water treatment industry in general, the risk of being infected by Legionella Pneumophila or other pathogenic microorganism from a cooling tower system is probably not much greater today than it was a few years ago. Still, a number of outbreaks of Legionnaires' Disease are reported each year throughout the country. See paragraph 4-4.7 for more information on controlling Legionella.

## 2. COOLING TOWER WATER CALCULATIONS

**2.1 PRINCIPLES OF COOLING TOWER SYSTEM OPERATIONS.** The function of a cooling tower is to dissipate heat from water-cooled refrigeration, air-conditioning and industrial process systems. Water is typically the heat transfer medium used to dissipate the heat. A cooling tower uses a combination of heat and mass transfer (evaporation) to cool the water flowing through the tower. Conductive heat transfer accounts for 20 to 30% of the total heat dissipated. The remaining 70 to 80% of total cooling is the result of evaporative cooling of about 1 to 2% of the recirculating water, depending on the decrease in temperature across the tower. It takes approximately 2,326,000 joules to evaporate 1 kilogram of water (1000 BTU per 1 pound of water). If this amount of heat is extracted from 454 kilograms (1000 pounds) of water, approximately 0.45 kilogram (1 pound) of water will be evaporated and the temperature will drop 0.55 oC (1 oF). If 4.5 kilograms (10 pounds) of water are evaporated, the water temperature will drop 5.5 oC (10 oF). The water lost by evaporation is replaced with makeup water. Water is also added to replace water lost through tower drift (loss of water from the tower as a fine mist), leaks in the system (unintentional blowdown), and water discharged as intentional blowdown. Water that is added to the cooling tower to replace all of these losses is known as cooling tower makeup water.

**2.1.1 RELATIONSHIP BETWEEN EVAPORATION, BLOWDOWN, AND MAKEUP.** The operation of cooling towers can be described by the relationship between evaporation, blowdown, and makeup. Makeup water must equal blowdown water plus water evaporation to maintain a constant operating water level in the system:

$$\text{EQUATION | } M = B + E \tag{1}$$

Where

M = makeup water, liters/sec (gpm)

B = blowdown, liters/sec (gpm) (all sources)

E = evaporation, liters/sec (gpm)

NOTE: Blowdown (B) includes discharge to sewer, drift loss, and any leaks from the systems.

EXAMPLE: M = 6.3 liters/sec (100 gpm)  
B = 0.63 liters/sec (100 gpm)  
E = 5.67 liters/sec (90 gpm)

**2.1.2 CYCLES OF CONCENTRATION (COC).** One of the common terms used in describing the water use efficiency of cooling tower water systems is COC. COC represents the relationship between the makeup water quantity and blowdown quantity. COC is a measure of the total amount of minerals that is concentrated in the cooling tower water relative to the amount of minerals in the makeup water or to the volume of each type of water. The higher the COC, the greater the water use efficiency. Most cooling tower systems operate with a COC of 3 to 10, where 3 represents acceptable efficiency and 10 represents very good efficiency. It has been found that the range of 5 to 7 COC represents the most cost-effective situation.

**2.1.2.1 CALCULATING COC BY VOLUME.** If both makeup and blowdown water volumes are known, COC by volume can be calculated. The term is defined as:

$$\text{EQUATION} \mid C = M / B \quad (2)$$

Where

C = COC, no units  
M = makeup water, kg/hr (gpm)  
B = blowdown losses, kg/hr (gpm)

EXAMPLE: M = 6.3 liters/sec (100 gpm)  
B = 0.63 liters/sec (10 gpm)  
C = M/B = 10

**2.1.2.2 DETERMINING COC BY WATER ANALYSES.** To determine COC, you must know the mineral content of both makeup and blowdown water. For example, you must

determine both the conductivity of the recirculating cooling tower water and the conductivity of the makeup water. (Note that the blowdown water will have the same conductivity as the recirculating water.) Conductivity is commonly measured in micromhos ( $\mu\text{mhos}$ ). You can also estimate COC by using other water quality parameters such as chlorides, silica, or sulfates. The relationship is represented by this equation:

$$\text{EQUATION} \mid C = \frac{B_{\mu\text{mhos}}}{M_{\mu\text{mhos}}} \text{ or } \frac{B_{\text{Cl}}}{M_{\text{Cl}}} \quad (3)$$

Where

$C$  = COC, no units

$B_{\mu\text{mhos}}$  = conductivity of blowdown (recirculating water), micromhos ( $\mu\text{mhos}$ )

$M_{\mu\text{mhos}}$  = conductivity of makeup water,  $\mu\text{mhos}$

$\text{Cl}$  = chlorides in blowdown, ppm

$\text{Cl}$  = chlorides in makeup water, ppm

EXAMPLE:

The measured conductivity of the blowdown (recirculating water) is 800 micromhos and the makeup is 300 micromhos.

The COC is:

$$C = \frac{\mu\text{mhos}}{\mu\text{mhos}}$$

$$C = 800/300 = 2.67$$

NOTE: The parameters of conductivity or chloride concentration are used commonly for such measurements. Other water quality parameters can be used, but sometimes with inaccurate results (i.e., calcium, magnesium, alkalinity, and silica can form deposits, meaning they drop out of solution). COC based on these parameters could be considerably less than that based on conductivity or chlorides. Similarly, chemical additions of sulfuric acid can yield higher sulfate levels than those species cycled up naturally.

**2.1.2.3 CONTROLLING COC.** A simple, sometimes overlooked rule: To increase COC, decrease blowdown; to decrease COC, increase blowdown.

**2.1.2.4 RELATIONSHIP BETWEEN COC AND MAKEUP.** COC and makeup requirements are related to the temperature drop across a cooling tower and to the recirculating rate of the tower. As shown in Figure 15, for a recirculating tower with water temperature drops of 5.5 °C (10 °F), 11 °C (20 °F), and 16.5 °C (30 °F), the makeup water requirement decreases rapidly as COC is increased to about 4 or 5, with lower incremental reductions at higher COC; therefore, COC can be adjusted (increased) to allow for reductions in water use (water conservation) and for reductions in the amount of water treatment chemicals used.

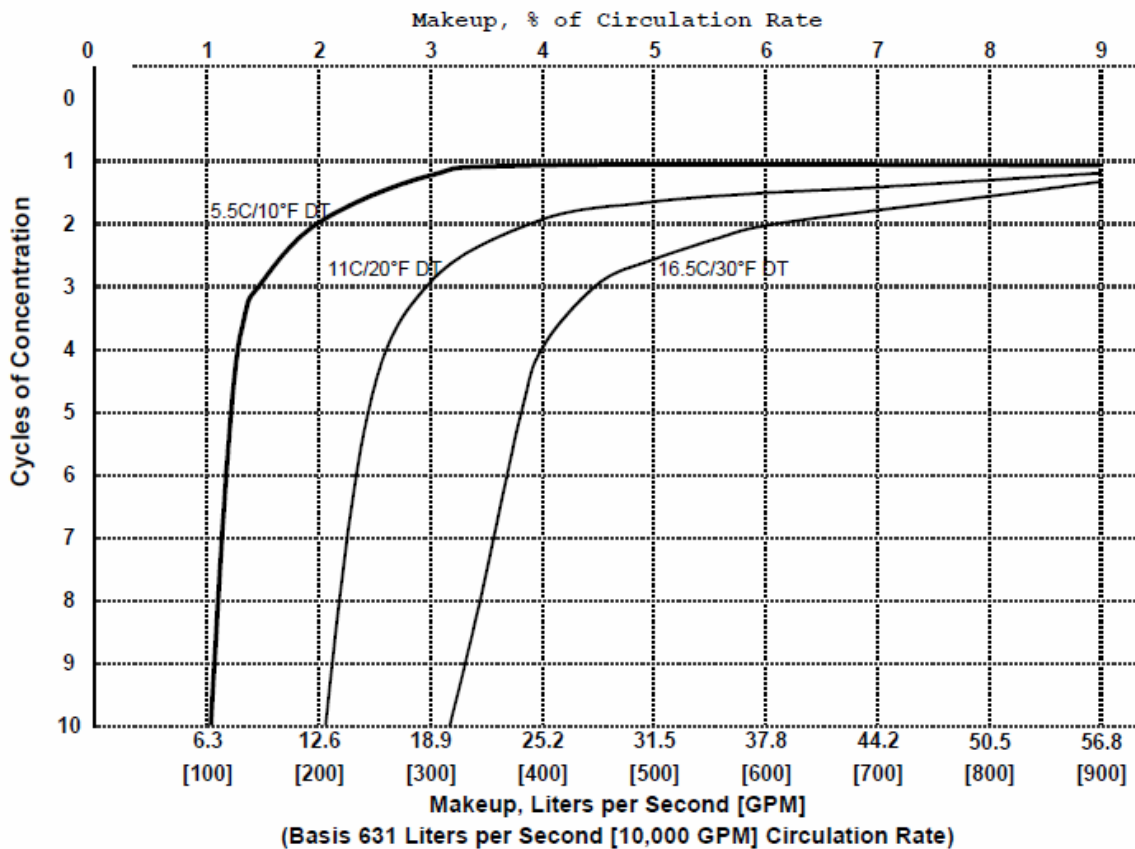


Figure 15  
Effect of COC on Makeup Requirement

**2.1.3 RELATIONSHIP BETWEEN BLOWDOWN, EVAPORATION, AND COC.** You can use the cooling water evaporation loss to calculate the blowdown rate that must be maintained to operate at a selected COC. The relationship between blowdown, evaporation, and COC is represented with this equation:



$$\text{EQUATION | } B = E / (C - 1) \tag{4}$$

Where

B = blowdown liters per day or liters per second (gpd or gpm)

E = evaporation, liters per day or liters per second (gpd or gpm)

C = COC, no units

EXAMPLE:

A cooling tower evaporates 37.8 liters per second (600 gallons per minute) and operates at 4 COC:

$$\text{EQUATION | } B = 37.8 \text{ l/sec (600 gpm)} / (4 - 1) = 12.6 \text{ l/sec (gpm)} \tag{5}$$

a) This formula is derived using data from previously presented equations:

$$(7) \quad M = B + E \quad \text{from paragraph 2.1.1 (Equation 1)}$$

$$(8) \quad C = M / B \quad \text{from paragraph 2.1.2.1 (Equation 2)}$$

$$(9) \quad C = (B + E) / B \quad \text{from Equations (7) and (8) above}$$

$$(10) \quad C = 1 + (E / B) \quad \text{rearranging Equation (9)}$$

$$(11) \quad (C - 1) = E / B \quad \text{rearranging Equation (10)}$$

$$(12) \quad B = E / (C - 1) \quad \text{rearranging Equation (11)}$$

a) If you know the quantity of evaporation, you can calculate the blowdown required for a given value of COC. You can estimate the evaporation using simple “rule of thumb” estimates:

b) For a typical recirculating cooling tower water system, approximately 1% of the recirculating rate (R) of the cooling water is evaporated for every 5.5 °C (10 °F) temperature drop in the cooling water as it passes through the tower; therefore, you may calculate the evaporation rate (E) this way:

$$\text{EQUATION | } E(\text{l/sec}) = 0.01 * R(\text{l/sec}) * \Delta T \text{ drop in } ^\circ\text{C} / 5.5 \text{ } ^\circ\text{C} \tag{13}$$

Since 0.01 / 5.5 = 0.0018, this can be condensed to:

$$\text{EQUATION | } E = R * \Delta T * 0.0018 \tag{14}$$

Or

$$\text{EQUATION | } E = R * \Delta T / 550 \tag{15}$$

NOTE: Newer cooling towers can have 0.75% of the recirculation rate evaporated for every 5.5 °C (10 °F) drop.

EXAMPLE 4-2:

- c) A cooling system operates at 315 liters per second (5000 gallons per minute). The temperature drop through the tower is 7.8 °C (14 °F). The evaporation estimate is represented by this equation:

EQUATION |

$$E = 0.01 * 315 \text{ l/sec (5000 gpm)} * 7.8 \text{ °C (14 °F)} / 5.5 \text{ °C (10 °F)} = 4.5 \text{ l/sec (70 gpm)} \quad (16)$$

Or

$$\text{EQUATION | } E = 315 * 7.8 / 550 = 4.5 \text{ l/sec (70 gpm)} \quad (17)$$

- d) For a cooling tower system serving air conditioner and chiller operations, the evaporation rate used depends on the type of chiller:
7. Approximately 20 liters per hour per kilowatt (1.5 gallons per hour per ton) for centrifugal, reciprocating, and screw-type chillers.
  8. Approximately 40 liters per hour per kilowatt (3 gallons per hour per ton) for absorption-type chillers.