PDHonline Course M121 (4 PDH)

Cooling Water Systems - An Overview of Cooling Towers

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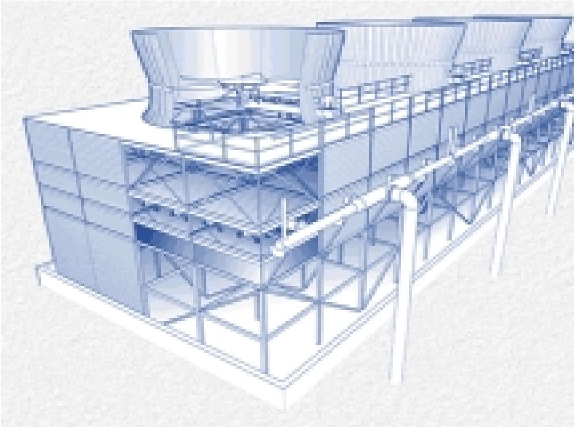
Course Content

Water is a most efficient way of dissipating unwanted heat. The most commercial buildings and industries use water to cool their HVAC and process machinery. A cooling tower is the most important piece of equipment in any industry whose primary purpose is to remove heat while minimizing water usage. The course covers 15 sections of comprehensive information on important aspects of cooling tower types, sizing, selection and performance issues.

Section 1 – Cooling System Basics

The amount of water consumed for cooling varies with the type of cooling system employed. The cooling system could be classified in three broad categories:

1. **Once through system:** In once through system, the cooling water passes through the heat exchange equipment only once. Water is simply drawn from estuary, lake or river to the process equipment/heat exchangers and discharged back to river. This system is used where large volume of cooling water is required and where the water is available in abundance. Local environment authority having jurisdiction must permit such installation as the environment issues in many states do not permit discharging hot water directly to river because of water pollution and aquatic life concerns.
2. **Dry towers** or closed re-circulation system use the same cooling water repeatedly in a continuous cycle. In dry cooling there is no direct contact of water with air. This type of cooling system consumes little or no water, but they are very costly to construct. These systems are very common where there is acute scarcity of water for instance in Middle East countries.
3. **Evaporative systems** such as wet cooling towers, cooling ponds, or spray ponds re-circulate the water. A cooling tower is a device that cools water that gets heated in process cooling. Cooling towers are provided to re-use the same water for cooling again and again rather than discharging it to the environment. The cooling tower reduces the environmental impact of water pollution and promotes water conservation.



In general, the most applications rely on the use of evaporative cooling tower systems.

Most cooling towers are designed as simple wet cooling towers, but upon occasion, a tower will be designed to operate as a combination wet-dry cooling tower. A wet-dry cooling tower adds heat to the airflow prior to discharge through the cooling tower fan stack. The discharge air is warmed above the ambient dew point to eliminate any visible plume that could cause local environmental concerns or hazards to local roadways.

Figure-1 on the right is a 3-d image of a multi-cell (4no.) mechanical draft cooling tower.

Where do we need cooling tower?

Cooling tower is essential equipment in almost all the process industries, fertilizer complexes, petrochemical industries and air conditioning systems. They represent a relatively inexpensive and dependable means of removing low grade heat from cooling water.

The figure-2 below provides a schematic arrangement of a cooling application in a process industry where the plant heat exchangers are cooled with water. The pump keeps the water re-circulation through heat exchangers where it picks up heat and distributes on to the cooling tower. The heat is released from the water through evaporation.

The cold water enters the heat exchangers for cooling. The resulting hot water from heat exchangers is sent to the cooling tower.   The cold water exits the cooling tower and is sent back to the exchangers for further cooling. The make-up water source is used to replenish around 2% of water lost to evaporation and drift.

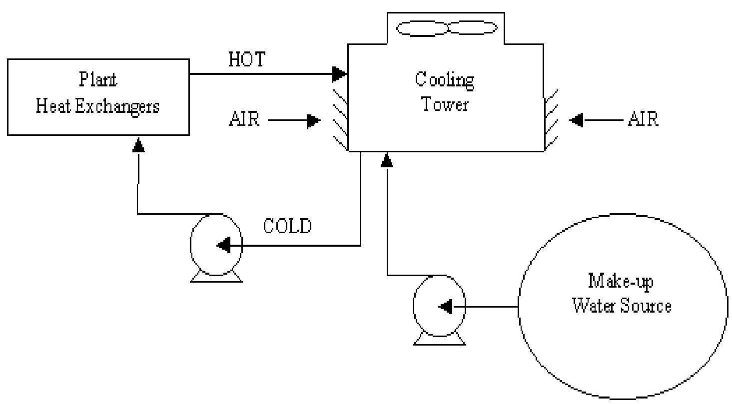


Figure 2: Closed Loop Cooling Tower System in Industry

The Figure-3 below provides a conceptual view of chilled water air-conditioning system with water-cooled condenser and cooling tower.

Here the heat is extracted from the space and expelled to the outdoors (left to right) through 5 loops of heat transfer. The chilled water is produced in the evaporator of the refrigeration cycle and is passed through a single or multiple cooling coils. The heat is rejected through a water-cooled condenser and the condenser water pump sends it to the cooling tower. The cooling tower’s fan drives air across an open flow of hot condenser water, transferring the heat to the outdoors.

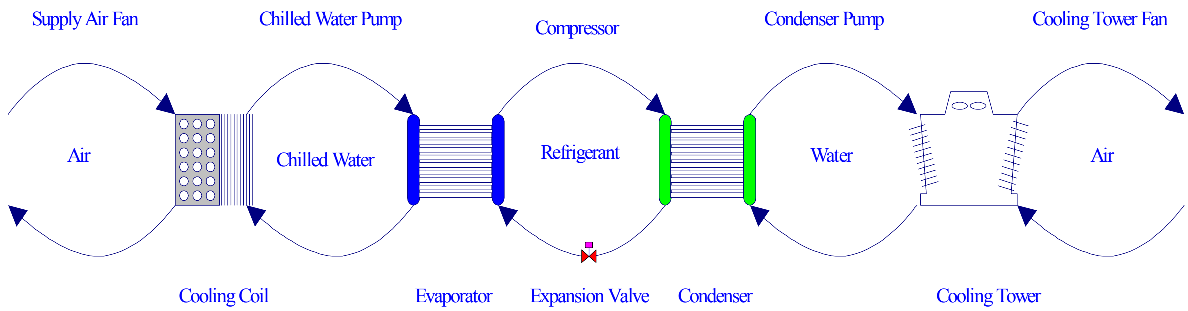


FIGURE -3
CHILLED WATER SYSTEM WITH WATER COOLED CONDENSER

How Cooling Tower Works?

Cooling towers come in all shapes and sizes. They all work on the same principle of evaporation as the means of cooling. They are designed to expose the maximum water surface to the maximum flow of air, for the largest period of time.

The hot water enters the tower at the top and is distributed within the structure in a manner that exposes a very large water surface to the air passing through.

Water distribution is accompanied by means of spray nozzles or distribution pans and by means of various types of fill media. The fill media is generally in form of open plastic mesh that increases the exposed water surface to maximise contact with air. The water trickles in droplets through the fill media.

A cooling tower blows air across the mesh to have direct contact with the falling water so that some of the water evaporates

The evaporation cools the stream of water.

Some of the water is lost to evaporation; the water is constantly added to cooling tower basin to make up the difference.

Both the evaporative and sensible heat transfer occurs as the warmer water comes in contact with the cooler air. The total heat transferred is equal to the heat of evaporation plus the sensible heat.

Evaporation results in cooling…

Imagine a drop of gasoline is put on your palm, it gets evaporated and your palm feels cold. The cooling is a result of evaporation. In cooling tower, the evaporative heat transfer occurs as part of the water gets evaporated due to cold ambient air. “Each pound of water evaporated, removes somewhere near 1000BTU’s of heat from the water that remains, thus lowering its temperature.” Evaporation occurs when the wet bulb temperature (WBT) of air is lower than the dry bulb temperature (DBT) of air.

When WBT = DBT, this condition corresponds to 100% relative humidity (RH) that implies the air is fully saturated. The air will no longer accept water and the lack of evaporation do not allow the wetted bulb to reject heat into the air by evaporation.

Higher the difference between DBT and WBT, lower is the relative humidity or drier is the air.

The lower relative humidity indicates greater capacity of air to absorb or hold water and shall result in efficient lowering of water temperatures.

Sensible Cooling…

The air temperature rises as it absorbs sensible heat from the water. This sensible heat transfer occurs if the dry bulb temperature (DBT) of air is less than the DBT of water.

In summary:

Total heat transferred = Heat of evaporation + Sensible Heat

1 lb of water evaporated takes with it 1000 BTUs of heat.

80% of cooling in cooling tower is through evaporation and the balance is through the sensible cooling.

Section 2 – Cooling Tower Performance

Before going further, it is important to understand two most critical parameters associated with cooling towers viz. the "Range" and the "Approach".

The heat load equation shall provide some answer. The basic heat transfer equation for water-cooling is

Heat load (in Btus/hr) = 500 x flow in GPM x Range in °F

Range

Range is the difference between the cooling tower water inlet and outlet temperatures. For instance a design demanding, the hot water coming @ 100 deg F and required to be cooled to 90 deg F is said to have a designed range of 10 deg F.

Approach

Where does Approach come into picture?

The above equation defines the Range. On learning this, I was asked a curious question that if the cooling tower is a heat transfer device why at all I need the mechanical refrigeration to chill the water. I will simply cool the water from 100 to 90 deg F and than again pass it to cool from 90 deg F to 80 deg F, than 80 deg F to 70 deg F and so on…. Also I can select a bigger size-cooling tower of higher range of say 30 deg F in one stroke to chill the water.

The answer to this inquisitive question is NO. The amount of cooling that you get from a cooling tower depends on the wet bulb temperature (WBT) or relative humidity (RH) of the air. Here where the other main term "Approach" comes into picture. The approach dictates the theoretical limit to the leaving cold-water temperature and is a function of ambient wet bulb temperature. Temperature Approach is the difference between the cooling tower cold-water temperature and ambient wet bulb temperature. No matter the size of the cooling tower, range or heat load, it is not possible to cool the water below the wet bulb temperature of air with evaporative air-cooling.

Though both parameters Range and the Approach should be monitored and specified, the 'Approach' is a better indicator of cooling tower performance. The approach temperatures generally fall between 5 and 20 deg F implying that the leaving CWT shall be 5 to 20 deg F above the ambient WBT no matter is quantum of heat load or the size of the cooling tower. As the selected approach is reduced, tower size increases exponentially. Neither it is economical to select a cooling tower for approaches less than 5 deg F nor do any manufacturer guarantees the performance for approaches less than 5 deg F.

Design Wet-Bulb Temperature

The Wet bulb temperature (WBT) is a site condition measured by placing a thin film of water on the bulb of a thermometer. A non-wetted thermometer reading provides ‘dry bulb’ temperature (DBT) reading.

A comparison of wet and dry bulb readings allows the relative humidity to be determined from a psychometric chart or the air properties table. The wet bulb temperature is always lower than the dry bulb value except when the air is fully saturated with water – a condition known as 100% relative humidity. This is when the wet and dry bulb temperatures are the same.

A single wet bulb reading will allow a prediction of cooling tower performance at that unique condition but the wet bulb changes throughout the day and year. Typically a wet-bulb temperature that does not exceed more than 5% of the total hours in a year is the design wet-bulb.   A value of 5% is selected because the hours in which the wet-bulb temperature exceeds this temperature are seldom consecutive and usually occur for only short periods of time. The design-wet bulb is typically determined by reviewing a weather information chart that has been prepared by taking numerous readings in a particular area over several years. ASHARE guidelines provide the consolidated design wet bulb temperature figures for almost all the geographical locations in the world.

The wet-bulb temperature that is specified is generally an ambient wet-bulb rather than an entering wet-bulb. The entering wet-bulb temperature is the value used to design the tower and may or may not be the same as the ambient wet-bulb. If the ambient wet-bulb is specified, the vendor may adjust the wet-bulb temperature he uses for sizing the tower upwards to account for any potential re-circulation.

A fact to note…

Does cooling tower dictate rate of heat transfer? …. NO

It is a myth that the size of cooling tower dictates the rate of heat transfer- it doesn’t. A cooling tower simply gives up the heat it is given. The cooling of water is proportional to the difference in enthalpies of the leaving and entering air streams. The heat given by the water falling inside the tower equals the heat gained by the air rising through the tower.

A big size cooling tower may accomplish the cooling of say 1000 GPM of water flow from 90 to 80 °F. If it is ‘small’, it might cool the 1000 GPM water from 100 to 90 °F. In either case, the heat transfer and evaporation rates are the same. The size of the cooling tower, the flow rate and the wet bulb temperature determine the inlet and outlet water temperatures- but not the difference between them.

In summary:

Range = Hot water inlet temperature (HWT) – Cold water outlet temperature (CWT)

Approach = Cold water outlet temperature (CWT) – WBT

The range, heat load, WBT and approach affect the cooling tower performance. Approach however is the paramount factor in determining the cooling tower performance. It should be noted that when the WBT falls, the leaving water temperature from the cooling tower also decreases. This is a linear relationship when flow and range are constant. With constant flow, when the heat load decreases, the range decreases. This is expressed by Heat load (Q) = 500 x water flow (GPM) x range (°F)

Section 3 – Cooling Tower Types

Cooling towers fall into two main sub-divisions: natural draft and mechanical draft.

Natural Draft Cooling Towers

1. Natural draft cooling towers are characterized by distinct shape much like a tall cylinder with a tight belt around the waist to provide stability
2. The natural draft tower designs operate on a chimney principle that allows the air movement on density differential
3. Such towers have the advantage of not requiring any fans, motors, gearboxes, etc. The tall stack insures against re-circulation of air
4. These towers use large space. Due to the tremendous size of these towers (500 ft high and 400 ft in diameter at the base) they are generally used for water flow rates above 200000 gal /min.
5. In United States, these types of towers are generally used only by utility power stations

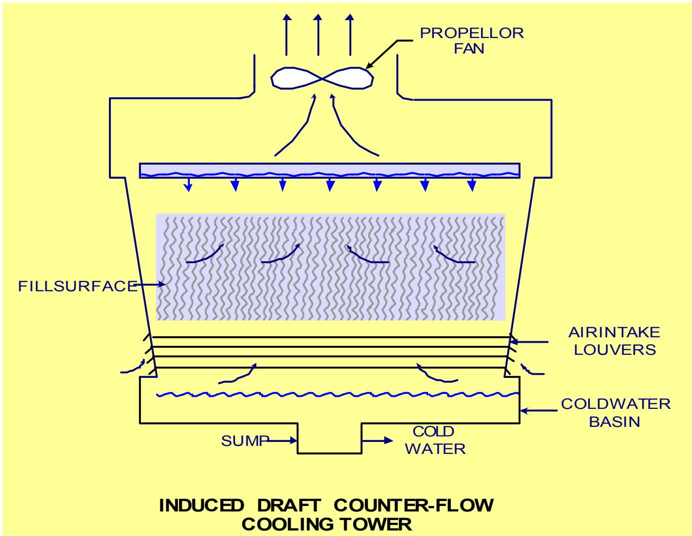
Mechanical Draft Cooling Towers

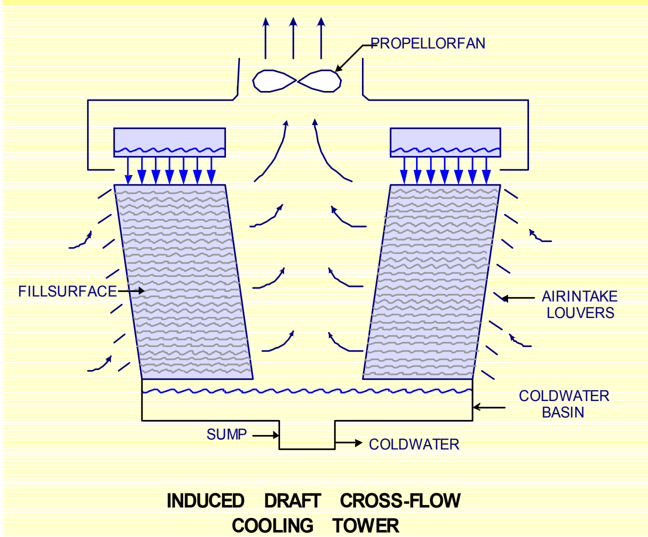
Mechanical draft cooling towers are much more widely used. These towers utilize large fans to force air through circulating water. The water falls downward over fill surfaces which help increase the contact time between the water and the air. This helps maximize heat transfer between the two.

The most HVAC and industrial cooling applications rely on the use of mechanical draft cooling towers and therefore these are further discussed.

Types of Mechanical Draft Towers:

Most mechanical draft cooling towers are available either as the counter-flow or cross-flow arrangements. The figure 4 and 5 provides a schematic arrangement and note the difference lies in the FILL arrangement.





Counter-flow Cooling Towers

In counter-current towers, air moves vertically upward through the fill, counter to the downward fall of water. Water is distributed across the fill using a system of headers, feed pipes and sprays. In majority of applications these towers are induced draft.

Cross-flow Cooling Towers

In cross-flow towers, air moves horizontally through the fill across the downward fall of water. Hot water is delivered to the hot water basin where it is distributed by gravity across the fill. These towers are generally induced draft.

Comparative Analysis (Counter-flow v/s Cross-flow)

The comparative analysis is made on the following distinctive parameters.

1. Fill Media:

Counter-flow cooling towers utilize a plastic film fill heat exchange media that reduces both pump head and horsepower costs; cross-flow towers typically utilize a splash-type heat exchanger. However, it is possible to find either type of exchange media in both types of towers.

2. Space and Size Constraints

Counter-flow towers tend to be the most compact. This is because the coldest air is in intimate contact with the entire cross section of water just before it falls into the basin. Cross-flow is also compact but require larger footprint than the counter-flow towers.

3. Operating Weight

Counter flow towers offer low operating weight - this is a major concern when replacing a cooling tower located on an existing roof structure. Care must be taken not to exceed the original structural capacities. Cross-flow operating weight is higher than the counter-flow tower.

4. Fill Arrangement

For counter flow tower, the wet deck (fill media) is encased on all the four sides. This helps prevent icing in winter operation. The prevailing winds do not directly affect the fill. Entire working system is guarded from the sun's rays and helps reduce algae growth. Air inlet louvers serve as screens to prevent debris from entering system. Cross-flow wet deck (fill) is encased on two sides only. The prevailing winds directly affect the fill and have problems of icing in winter operation.

5. Fill Support

The wet deck (fill) is supported from structural supports underneath. This prevents sagging and creates a working platform on top of the fill for service. In cross-flow generally the fill media is supported by rods. Icing and wear may deteriorate the fill making it sag, which may affect performance.

6. Operating Costs

Counter-flow tower require increased fan horsepower resulting from airflow in direct opposition to the water flow. Therefore the recurring energy costs shall be higher. Cross flow towers are popular primarily due to their operational cost savings.

7. Safety Requirements

Counter-flow towers are typically taller than other styles but do not require handrails or piping at top of tower. Cross-flow towers many a times require handrail, safety cage, & service platform per the requirements of OSHA guidelines. It is difficult to service fan drive system in cross-flow towers and these must have internal & external service platforms and ladders to reach drive systems.

8. Maintenance

Counter-flow design offers an easier maintenance design than cross-flow cooling towers. Counter-flow towers are easy to maintain, as cold-water basin is open on all sides with no restrictions from wet deck. Easily accessible cold water basin, no basin covers required. Cross-flow towers are difficult to maintain. These require frequent cleaning of hot water basin on top of tower Cross flow tower are difficult to clean at the cold water basin under wet deck because of limited access.

9. Balancing Requirements

Counter-flow does not need balancing valves to even the flow between gravity basins. For cross-flow, open gravity hot water basins require balancing valves to insure even flow and maximum performance.

10. Limitations

Counter- flow tower require airflow on all four sides for optimum performance. Cross-flow towers also have limited configurations available to fit layout. Care must be taken not to lay out more than (2) towers side by side or middle cells will be difficult to access, outer cells may have to be shut down to service inner cells.

11. Initial Cost

Counter-flow towers are typically expensive to build and have higher initial cost v/s. cross flow tower.

Forced Draft Cooling Towers

The description above pertains to the induced draft cooling arrangement where the air is drawn from the intake louvers at the bottom and is discharge thru a fan at top. In forced draft arrangement the air is blown through and the fans are located at the bottom.

The forced draft cooling towers are also in use but have certain disadvantages:

- Maintenance is high. Cold water basin is covered and difficult to access.
- Pressurized upper casing is more susceptible to water leaks than the induced draft styles.
- High fan motor horsepower requirements. Typically double that of a comparable induced draft counter-flow cooling tower.

The forced draft cooling towers find application on critical layout situations. These can be used for indoor applications and ducted to outside of the building. It has low noise v/s other cooling tower styles.

Section 4 – Cooling Tower Capacities & Availability

Mechanical draft towers are available in a large range of capacities. The nominal capacities range from approximately 15 GPM to several thousand GPM. Towers for HVAC duty are rated in nominal tons. Based on the capacity sizes, the towers can be either factory built or field erected.

Packaged Cooling Towers

Packaged towers are the one where the first or essentially all assembly is done at the manufacturer's plant. This type of cooling tower is manufactured so it can be transported easily to the job site without special trucking permits. Most heating and cooling applications (HVAC) require cooling towers sized below 10,000 GPM. Towers for HVAC duty are rated in nominal tons, based on the heat load of 15000 Btu per tone (12000 Btu cooling load plus 3000 Btu's per ton for work of compression), water flow of 3 GPM per ton, a 10° F range and HWT and CWT of 95° F and 85° F respectively.

Towers of this type usually are mass produced in factories with FRP or galvanized steel structure and casing.

Field Erected Cooling Towers

Cooling towers requiring a thermal duty beyond the capabilities of a package cooling tower are larger, requiring them to be manufactured, shipped and assembled at the site. Generally large installations require field erection with factory built assemblies for large wood and steel framed towers being put together at the jobsite. Concrete towers are also field erected. These can received architectural treatment for aesthetic purposes. These are field-erected towers and generally are used in most industrial and utility applications. Field-erected mechanical draft towers can handle flow rates from 10000 to 350000 gal /min.

Many a times, towers are constructed so that they can be ganged together to achieve the desired capacity. Thus many cooling towers are assemblies of two or more individual cooling towers or cells. Such cooling towers are referred to by the number of cells they have e.g. a five cell cooling tower. Multiple cell towers can be linear, square or round depending upon the shape of the individual cells and whether the air inlets are located on the sides or bottoms of cells.

Mechanical draft towers offer control of cooling rates in their fan diameter and speed of operation. The cooling towers often contain several areas, each with their own fan, called cells.

Section 5 – Cooling Tower Materials

Cooling tower structures are constructed using primarily three materials: wood, concrete and steel.

In early days, towers were constructed primarily of wood. In wooden towers, Californian Redwood and Douglas fir are the two most extensively used woods.

With advent of new technologies and the need for mass production, today the tower manufacturers fabricate tower components from a variety of materials. Often several materials are used to construct a cooling tower to enhance corrosion resistance, reduce maintenance, and promote reliability and long service life.

1. Lumber:

Redwood is the most preferred construction material for cooling towers because of its natural non- decay characteristics. Douglas fir is the second preferred choice. All wood used in a cooling tower must be treated with a preservative to prevent decay. Fir is prone to early de-lignification's (eating up of wood) due to water impurities and is prevented to certain extent by maintaining pH in range of 7 to 7.5. Chromate Copper Arsenate (CCA) was initially used as a preservative but because of its arsenic content, Acid Copper Chromate (ACC) has replaced it.

2. Galvanised Steel:

Simultaneous with the greater reliance on lumber, galvanized steel and various grades of stainless steel are widely used in tower construction. Galvanized Steel - G-235 has become the industry norm for packaged cooling towers. Water treatment chemicals dosed in the cooling tower basin impact the life of steel. Earlier the higher steel thickness was utilized to combat the impact of chemicals on the steel sheet but the modern designs provide optimum thickness of zinc coating to G-235 grade (or, 2.35oz. of zinc per sq. ft.) from earlier standards of G-90 (0.90 oz/sqft). Use of G-235 grade galvanized steel construction maximizes years of service at the most competitive price.

3. Stainless Steel:

Stainless Steel - Type 304 stainless steel construction is recommended for cooling towers that are to be used in a highly corrosive duty.

4. Concrete:

Larger towers generally are made of concrete. Extensive concrete construction is also used for architectural reasons- where the tower is disguised to look like or blend in with a building- or, the cooling tower is designed as a structure with a life expectancy equal to the facility it serves.

5. Fiber-Reinforced Plastic (FRP):

One advance in cooling tower construction has been the supply of cooling towers built with fiber-reinforced plastic (FRP). Fiberglass has been used in cooling tower piping, fan stacks and siding for many years with great success due to its low maintenance requirements, resistance to moisture, and material properties that allow a range of water temperatures and pH.

Currently, the fastest growing segment of the cooling tower market is structures built with FRP sections. This inert inorganic material is strong, lightweight, chemically resistant and able to handle a range of pH valves. FRP is stronger than Douglas fir and redwood, and because it is available in long lengths, it allows a cooling tower to be designed and built with a minimum number of airflow obstructions. This enhances performance and reduces the number of connections and field labor erection costs. Fire-retardant FRP can eliminate the cost of a fire protection system, which can equal 5 to 12% of the cost of a cooling tower.

Section 6 – Cooling Tower Components

The important components of the cooling tower and their function are addressed below:

1. Wet Deck or Surface or fill is the heart of cooling tower. Generally, it takes the form of PVC plastic film type surface. Most towers deck or surface employ 'Fill' to facilitate the heat transfer by maximizing water and air contact. Fill can either be splash or film type.

- With splash fill, water falls over successive layers of horizontal splash bars, continuously breaking into smaller droplets thus wetting the fill surface.
- Film fill consists of thin, closely spaced plastic surfaces over which the water spreads, forming a thin film in contact with the air. These surfaces may be flat, corrugated, honeycombed, or other patterns.

Plastic splash fill promotes better heat transfer than does wood splash fill. The film type of fill is more efficient fill and provides equal heat transfer in a smaller volume than does splash fill.

Plastics are widely used for fill, including, PVC, polypropylene and other polymers.

Treated wood splash fill is still specified for wood towers, but plastic splash fill is now widely used where water quality demands the use of wider spaced splash fill.

Film fill offer higher efficiency and is a preferred choice where the circulating water is generally free of debris. Debris could plug the fill passageways thereby requiring higher maintenance and cleaning.

2. Eliminators are used to capture water droplets entrapped in the air discharging from the cooling tower. The eliminator reduces the drift – to 0.002% -or less- of the re-circulated flow rate.

3. Spray Tree is used to distribute water over the wet deck fill. Nozzles mounted on the spray tree provide the water sprays to wet the fill. Uniform water distribution at the top of the fill is essential to achieve proper wetting of the entire fill surface. Nozzles are fabricated out of PVC, ABS, polypropylene and glass filled nylon.

4. Cold Water Basins collect cooled water at the bottom of the tower. They are an integral part of factory-assembled designs and are built in place- typically of concrete- for field-erected towers. The cold-water basin located at or near the bottom of the tower, receives the cooled water that flows down through the tower and fills. A basin usually has a sump or low point for the cold-water discharge connection. In most of the designs the cold water basin is beneath the entire fill.

5. Air Inlet Screens is the point of entry for the air entering a tower. The inlet may take up an entire side of a tower-cross-flow design- or be located low on the side or the bottom of counter-flow designs.

6. Louvers- Generally, cross-flow towers have inlet louvers to equalize airflow into the fill and retain the water within the tower. Many counter-flow tower designs do not require louvers.

7. Ladders and Handrails are necessary for large field erected cooling towers and make sense on some factory assembled designs. These are safety & maintenance accessories that are recommended per the guidelines of OSHA standards.

8. Seismic Bracing options exist in the in earthquake prone areas.

9. Fans provide the airflow for mechanical draft cooling towers. Generally, propeller fans are used on induced draft towers. Both propeller and centrifugal fans are found on forced draft models. Depending upon their size, propeller fans can either be fixed or variable pitch. A fan having non-automatic adjustable pitch blades permits the same fan to be used over a wide range of airflows at the lowest power draw. Automatic pitch blades can vary airflow in response to changing load conditions. Aluminum, FRP and hot dipped galvanized steel are commonly used fan materials.

10. Cooling Tower Bypasses are generally specified for towers installed in cold climates. The bypass is used to prevent overcooling of the water when there is little or no heat load in the system. The bypass should discharge into the tower basin as far as possible from the cooling water pump suctions. This reduces the chance of cavitations due to disturbances in the flow of water to the pump suctions.

11. Frame and casing: Many towers have structural frames that support the exterior enclosures (casings), motors, fans and other components. With some smaller designs, such as some glass fiber units, the casing may essentially be the frame.

Section 7 – Sizing Your Tower

The selection of cooling tower depends on many factors. An improperly selected cooling tower will cost you financially, causing a loss in production due to increases in circulation water temperature and increased electrical operating costs. Emphasis must be placed on properly specified and designed cooling towers that require minimal maintenance.

“Consider your design and operating conditions before specifying a cooling tower”

What affects cooling tower size?

The heat load, range, approach, and the WBT affect the cooling tower size. When three of these four quantities are held constant, tower size varies in the following manner:

1. Directly with the heat load: Tower size is directly proportional to the heat load. If heat load is doubled, the tower size doubles.

2. Inversely with the range: The size of the cooling tower varies inversely with the temperature range. The range could be maximized to minimize the size of the cooling tower and the total circulating water flow. However, this is offset by increases in the size of heat exchange equipment in the plant due to lower LMTD's. Detailed life cycle economics need to be performed to select an optimal range.

3. Inversely with the approach: Tower size varies inversely with the approach. As the selected approach is reduced, tower size increases exponentially. It is not economical to select the cooling tower approaches below 5º F.

4. Inversely with the entering WBT: At constant heat load, range and approach, the tower size varies inversely with the actual wet-bulb temperature. In essence, it would take a tower of infinite size to cool the water to the wet-bulb temperature. The reason for this is that most of the heat transfer occurs by evaporation and the air's ability to absorb moisture reduces with temperature.

“When sizing a cooling tower, the highest anticipated wet bulb should be used.”

What affects cooling tower selection?

To select a cooling tower, the water flow rate, water inlet temperature, water outlet temperature and ambient wet bulb temperatures must be known.

When selecting the cooling tower, one must determine the design heat rejection load along with the design WBT for the geographical area and desired range. Water flow is determined by the heat load and range.

Reputed tower manufacturers provide performance curves and /or computer simulations to predict the tower performance over the expected operating range. If the design heat load is close to the nominal tower capacity, consideration should be given to selecting the next larger cooling tower to ensure the tower will provide the required cold water temperature (CWT) at the design condition. This extra expense is small compared to the total cost of the cooling plant and some what lower CWT will provide operating cost savings for years to come.

Many choices and decisions are required to properly select a tower. The designer should only consider towers with CTI certified listing. At minimum, be sure your specification to cooling tower manufacturers stipulates the following:

- Flow rate (gal/min)
- Total heat rejection (BTU/hr)
- Cold water temperature (°F)
- Hot water temperature (°F)
- Design wet bulb temperature (°F)
- Elevation above sea level (ft)
- Tower type (cross-flow or counter- flow)
- Materials of construction
- Fill media choice (film, splash or antifouling)
- Water quality
- Noise limitations
- Drift loss expected
- Scope of supply. (Who is responsible for basin, external piping, electrical hook-up, etc?)
- Evaluation factors ($/kW)

The designer should only consider towers with independently certified capacities. The Cooling Tower Institute (CTI) lists towers that subscribe to their test standard STD-201. Alternately, the designer should specify a field test by an accredited independent test agency in accordance with CTI Acceptance Test Code ATC-105 or ASME PCT-23. For further details, refer www.cti.org

What affects cooling tower design?

The cooling tower manufacturers carry out the research, modeling and computer simulations to predict the tower performance. The cooling tower design is governed by a relation known as the Merkel Equation. This is more an academic area and is not of great importance to the end users. Those interested in further reading can refer to book on thermodynamics. The Merkel Equation is

$$\frac{KaV}{L} = \int_{T_2}^{T_1} \frac{dT}{h_w - h_a}$$

- Where:

KaV/L = tower characteristic

- K = mass transfer coefficient (lb water/h ft^2)

a = contact area/tower volume
V = active cooling volume/plan area
L = water rate (lb/h ft^2)
T_1 = hot water temperature (^{0}F or ^{0}C)
T_2 = cold water temperature (^{0}F or ^{0}C)
T = bulk water temperature (^{0}F or ^{0}C)
h_w = enthalpy of air-water vapor mixture at bulk water temperature (J/kg dry air or Btu/lb dry air)
h_a = enthalpy of air-water vapor mixture at wet bulb temperature (J/kg dry air or Btu/lb dry air)

Section 7 – Cooling Tower Controls

The cooling tower performance & operating efficiencies to a large extent are dependent on controls. The automatic controls many a times are necessarily provided to control the leaving cold water temperatures (CWT). The other controls include automatic adjustment of chemical feed rate to maintain water chemistry, automatic blow-down and the controls for enhancing energy conservation. The wooden cooling towers in particular also need to be provided with automatic fire suppression systems per the requirements of NFPA 214.

The CWT leaving a tower falls

- As the WBT drops
- During lean load periods in process
- During winter

Some processes can be adversely affected if the cooling water supply gets too cold. Air-conditioning centrifugal chillers for instance require a specific minimum entering condenser water temperature to prevent surging

The capacity control of the cooling tower is best achieved by modulate air flow through a cooling tower. This capacity reduction can be achieved with fan cycling, multi-speed motors, extra motors, or variable speed drives. Reducing tower airflow yields higher leaving water temperatures.

Fan cycling (turning off fan motors) works well for a multi-cell cooling tower. This is an easy capacity control method but doesn't work well when close temperature control is required resulting in frequent motor starts. Six starts per hour should be considered maximum.

Control of tower airflow can be done by varying methods:

- Starting and stopping of fans (moderate control)
- Use of 2 or 3-speed fan motors (better control)
- Use of automatic adjustable pitch fans (close control)

- Use of variable speed fans (close control)

Depending upon the method of air volume control selected, control strategies can be determined to minimise fan energy while achieving the desired control of CWT.

In the areas subjected to freezing conditions, the CWT control is an extremely important factor. In addition to the airflow control, tower basins must be heated and all exposed water piping must be insulated and heat traced. Typically, this is the range of 55 to 65° F for air-conditioning chiller.

Section 8 – Layout Considerations

The general factors and the rules of thumb associated with cooling tower layout pertain to space, weight, noise and aesthetic looks.

1. Whenever you walk behind a building and find equipment that has large quantities of water running through a plastic mesh, you will know you have found a cooling tower! Cooling towers are physically the largest footprint of equipment in an industrial facility or a commercial building. As a rule of thumb, the HVAC application for a building typically demand 0.25 sq ft of floor area per 100 sq ft of total building area. The cooling tower can be from 12 to 40 feet high.
2. When located on the roof, the building structure must support the added weight in the range of 120 to 150 lb per sq ft along the wind load stresses. If located at ground level, they are subject to vandalism and ground level dirt.
3. If tower noise affects adjacent structures, acoustic treatment may be needed. Over sizing at added first cost reduces noise level due to lower fan speeds, and can be an excellent energy saving investment since it improves cooling system performance.
4. If decorative screens are used, they must have sufficient free air so as not to interfere with good air flow.
5. Tower location is critical to take advantage of prevailing winds and avoid air bypass conditions that will penalize tower performance and increase energy use.

The cooling tower performance is largely impacted by correct installation and placement to allow free flowing airflow. Obstructions to the airflow can cause two problems:

1. Re-circulation is a result of short-circuiting of air flow. This is a phenomenon where the moist discharge air is somehow redirected back into the air inlet. The increased moisture in the air inhibits evaporation and reduces cooling capacity. The detrimental effect of increased wet bulb can be best examined on the manufacturer's selection charts. A cooling tower selected at 78 degree wet bulb is about 40% bigger than one selected at 72 degree wet bulb [@ 95 in and 85 out].
2. Starving the tower for air. Reducing the airflow inhibits the tower's ability to evaporate water and thermal capacity suffers accordingly.

Note: For the optimum cooling tower performance and enhanced safety, 0.5 to 2º F re-circulation allowance is loaded on the design wet bulb temperature. As a rule of thumb recirculation allowance of 0.5º F for towers smaller than 10000 GPM and 2º F for towers designed for more than 100,000 GPM is added to the design WBT.

Section 8 – Installation Considerations

Care must be taken in the design of cooling tower piping and fittings. Cooling tower water is highly aerated.

Cooling tower is an open circuit with all water falling into the cooling tower basin. An improper installation can lead to potential upset conditions.

Consider a cooling tower located at ground level with all the system components installed above. Such a system shall face two major potential problems:

1. On pump trip or shut off, the entire water in the piping components shall fall back to the basin and may exceed its volume. This shall result in overflowing of all the excess water. The basin may have to be over designed to hold this water to prevent overflow.
2. On restart, the sump shall run out of water before it can fill the empty piping. While the make-up valve may eventually add enough water for the system to operate, the pump may become air-bound causing cavitations.

System designer must ensure the adequate size of the basin yet not over sizing it, to minimize the drain-back of any water. An easiest approach is to locate the cooling tower as the highest element in the system. The tower should be elevated until all other system components are below the overflow level of the cooling tower except for any vertical risers to the tower inlet(s). When designing a system, the designer must perform the hydraulic analysis and calculate the amount of water the basin must accept at pump shutdown.

Section 9 – Fans, Drives and Motors

Cooling tower fan motors operate on a harsh environment of moisture laden air. These must be totally enclosed type for trouble free operation.

ODP motors should never be installed and TEFC motors should be the minimum standard.

The cooling tower motors shall be specified to meet the criteria set forth by the National Electrical Motor Association (NEMA) and UL. The cooling tower motors need not be UL listed as the smoke and debris resulting out of motor upset condition is not directed to the occupied spaces. UL listing is therefore not critical.

As a minimum, two speed fans must be specified for all cooling towers. The high and low speed allows more flexibility in the control of leaving cold water temperatures (CWT). In climates with severe winters, the fans should be reversible allowing the towers to be de-iced.

Fans are either belt driven or shaft driven through a gearbox. Belt driven units have motors located inside the tower in a high humidity environment. Shaft driven units generally have the motors located outside the tower. The large field erected or factory assembled cooling towers generally utilize gear box to restrict tip speeds and noise.

Section 10 – Pumps

The cooling water re-circulation requires at least one pump for each cooling tower. The other pump may be required for the make up water needs if the make up supply pressure is insufficient.

"Two basic parameters viz. Flow rate (in GPM) and Head (in feet) are required for specifying the right duty pump."

The flow rate is dictated by the process requirements and can be worked out per the heat load equation as listed in section 2. Total heat load and the range must be known to determine the anticipated flow rate.

The total head is the summation of static and dynamic losses within the system and is calculated as follows:

Total head =

- Net vertical lift (ft.) (typically, this is the distance between the operating level and the water inlet) Plus
- Pressure drop at the cooling tower exit through strainer mesh/outlet connection, typically 1 psi Plus
- Pressure drop in the piping to the pump (friction loss as water passes through pipe, fittings and valves) Plus
- Pressure drop from the pump to the item being cooled (essentially the discharge side friction drop as water passes through the pipe, fittings and valves) Plus
- Pressure drop through the item being cooled (figure provided by the manufacturer of the equipment) Plus
- Pressure drop from the cooled item back to the tower (discharge side friction drop as water passes through the pipe, fittings and valves to cooling tower) Plus
- Pressure drop for the tower's water distribution system (towers with pressurized header and spray nozzles will have spray pressure tabulated in CT specs typically 2 psi) Plus
- Velocity pressure (For open systems- the pressure necessary to cause the water to attain its velocity. It can be calculated as $V^2/2g$ but is typically picked from a chart)

The total head is tabulated in feet- the height of a vertical water column. Values expressed in psi are converted to feet by multiplying with 2.31.

Pump Types

The general practice is to have:

1. End suction pumps are used for up to 10 Hp sizes
2. Horizontal split casing pumps are used for sizes above 10 Hp.
3. Vertical turbine pumps are used where suction lift is high as in concrete tower basins of large field erected cooling tower.

The pump internals shall be constructed of materials that suit the water chemistry. The pumps seal must 'Viton', if ozone water treatment is used.

Section 11 – Noise and Vibration

Cooling towers generate noise due to the fan air movement, fan motor and the sound of spraying water. Large installations particularly the air-conditioning applications on the residing areas require attenuation or sound proofing.

Following recommendation could be followed to limit the objectionable noise:

- Lay equipment away from noise sensitive areas as far as possible

- Add concrete walls as barriers and apply acoustic treatment where necessary
- Consider over sizing the cooling tower, where noise level requirements is very stringent. This shall allow for slowing fan operation
- Use gear drives instead of belt drives
- Use centrifugal fan towers which are inherently quieter.
- Use attenuators on the fan discharge. These shall however add to the fan static pressure and thus requiring increase fan HP.
- Use vibration isolators to reduce impact of vibrations. As a minimum specify isolators with static deflection of 2" particularly when the cooling towers are located on the roof.

Section 12 – Cooling Water Treatment

Cooling towers are the most common method used to dissipate heat in open re-circulating cooling systems. While they save tremendous amounts of water, open re-circulating cooling systems are subject to a variety of problems.

- Evaporation increases dissolved solids concentration and subsequent corrosion and deposition tendencies
- Higher temperatures increase corrosion potential
- Longer retention time and warmer water increase the potential for microbiological growth

When water is evaporated or lost from a cooling tower, the solids and chemicals used to treat the tower remain in the system. When water is "bled" from the system, the chemicals lost through bleed must be replaced for the system to remain protected. Water lost due to intentional bleed off and evaporation is to be continuously made up to maintain a steady operation. The make up water introduces impurities in the re-circulated water.

If the quality of water is left unchecked, the system would lead to solids build up that will precipitate out of solution as scale. The four principal sources of these deposits in the case of water-cooled systems are: scale, corrosion, biological growths and sludge. These factors are important and need considerable attention to avoid damage to equipment and enhance productivity.

Water treatment is provided to keep the water quality sufficient to prevent scaling, corrosion and biological fouling that can affect normal productive operations.

In the cooling tower operations, the operators are instructed to carry out blow-down at the regular intervals or it is automatically controlled through instruments & control devices. The manual practice of carrying out blow down is non-scientific as one doesn't know whether the blow-down is really necessary to be carried out at that particular time and if it is necessary to what extent.

Lets understand an important term frequently used in cooling tower operation "Cycle of concentration" (COC). It is defined as a factor of level of impurities in the cooling water with respect to its corresponding level in the make-up water. Evaporating enough water to make the solids increase to twice their initial value is a two-fold increase in solids content. (e.g.: 80 parts/million becomes 160ppm). The newly constituted water is said to have 'two cycles of concentration'. In other words, COC is defined as the number of times the water is concentrated in the cooling tower. COC is generally determined by some very soluble ion, such as chloride in the makeup to re-circulating water. Conductivity/TDS is also used for this determination.

In general, where proper treatment practices are carried out, the total dissolved solids (TDS) of the circulating water in open circuit is not allowed exceeding 2500 ppm so that the corrosion and scaling problems are kept under control. Therefore with this concept, when the make-up water TDS is 800 ppm and maximum allowable TDS in circulating water is 2500 ppm, the system is not permitted to operate at more than 2500/800 = 3.1 cycles of concentration.

The optimum value for 'Cycles' is a bit elusive and if it is unknown the default figure is usually 5. A high value of COC leads to reduced chemical, water and sewage costs but introduces an increased risk of scale formation and visa versa. Design value of operating on a particular COC is determined specific to a service, quality of make up water and amount of chemical dosage. Once the COC is established, the water treatment controls are set into position that senses the conductivity of water. Conductivity of water increases in direct proportion to the solids concentration. The device is first used to measure the conductivity of the make-up water and then set to initiate a bleed cycle when the system conductivity reaches a value equal to the set cycles.

It is helpful to examine the water balance of the system. The amount of water that enters as make-up must be equal to the total water that exits the system or

Make-up water (M) = water lost {through evaporation (V) + bleed (B) + drift (D)}

When we ignore the insignificant drift losses

Then, M = V + B (eq.1)

Recognizing that in order to keep off from making scale, all of the solids that enter as make- up must exit as bleed, it follows that:

- M = cycles x B (eq.2)

And that:

- M = V [(cycles)/(cycles-1)] (eq.3)

Combine (eq.2) and (eq.3) to get:

- B = V/ (cycles-1) (eq.4)

The biological aspect of water treatment comes from living organisms that thrive in the re-circulated water and wetted surfaces. Bacteria, slime and algae can foul heat exchanger surfaces and in some cases attack and destroy system components. Chemical treatments address biological issues separately from scale and corrosion.

Cooling towers are also prone to health hazards. Recently, the Executive Board of the Cooling Technology Institute (CTI) approved new guidelines for control of Legionella, the bacteria associated with potentially fatal Legionnaires' disease. CTI's best practice specifies the continuous use of halogen compounds to reduce health risks associated with these bacteria.

These issues are addressed separately in another course "Cooling Water Treatment and its relevance to Energy Conservation".

Section 13 – Cooling Tower Testing

Cooling tower capacity is generally considerably very hard to quantify as it requires the accurate, simultaneous measurement of water flow, inlet and outlet water temperatures, wet bulb temperature and power consumption. It is unlikely that ideal test conditions shall be available after commissioning as nature must co-operate with wet bulb temperatures, wind velocities, etc.

Water and wet bulb temperatures do not remain constant and it is necessary to average readings- typically over one hour. The average readings are then compared against manufacturer supplied capacity data to verify thermal compliance.

The complexity of such testing is reflected in the testing costs for the test technician plus the necessary participation of the contractor and owner personnel, modifications to the piping to accommodate test measurements and the production of sufficient thermal load for testing. For this reason the field testing of cooling tower performance is seldom done and the factory assembled designs carry certification of compliance to CTI Standard STD-201. The certification stamp offered by CTI guarantees the performance by reviewing, evaluating and time testing manufacturer's submitted product offering and capacity ratings. CTI then lists those product lines that meet published ratings. The cooling tower industry has largely embraced STD-201 because it helps prevent unqualified manufacturers from enjoying undeserved sales. System designers and owners also benefit with predictable performance.

The importance of thermal performance is very critical and poor efficiencies increases economic impact on large projects such as reduced overall output from power generation facility. Large projects also tend to employ field erected cooling towers where unique designs and field assembly practices become more important.

All field erected cooling towers should be specified with a specific test and penalties for failure clearly laid-out in advance. All the certification information and field tests procedures are CTI Standard ACT-105 (Available from CTI at www.cti.org and ASME PCT-23 www.asme.org/cns)

Someone desiring a CTI approved test, only the CTI pre-approved licensed testing agencies could verify and authenticate the test results. The selected test company will provide a calibrated test instruments for temperature, flow and power measurement. Test results are submitted to CTI for review and verification and an official test result provided by CTI.

Section 14– Codes and Guides

The Cooling Tower Institute, CTI, is a non-profit organization based in Houston, TX comprised of cooling tower users, manufacturers, and related service providers. It is probably best known for its test specifications and huge library of papers addressing all of cooling tower related subjects.

The American Society of Heating, Refrigeration and Air Conditioning Engineers, ASHRAE, is an international organization which is also non profit and headquartered in Atlanta, GA. They promote standards based on extensive research and publish comprehensive books. Most of the weather data, the design wet bulb temperature, used by system designers comes from ASHRAE publications.

Within the industry, standards for cooling towers are set up by the Cooling Tower Institute (CTI). The CTI is a self-governing, non-profit technical association dedicated to the improvement of technology, design, performance and maintenance of cooling towers. When a tower is specified as a CTI code tower, the following standards become part of the specification (if applicable):

- STD-103 Redwood Lumber Specification

- ATC-105 Acceptance Test Code
- STD-111 Gear Speed Reducers
- STD-114 Douglas fir Lumber Specification
- STD-115 Southern Pine Lumber Specification
- STD-118 Inquiry and Bid Form
- STD-119 Timber Fastener Specification
- STD-127 Asbestos Cement Materials for Application on Industrial Water Cooling Towers
- STD-201 Certification Standard for Commercial Water Cooling Towers

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Section 15 – Glossary of Terms and Example

1. Heat Load: Total heat to be removed from the circulating water by the cooling tower in Btuh

2. Liquid to Gas ratio (L/G): A ratio of total mass flows of water and dry air in a cooling tower.

3. Range: Difference between the hot water temperature and cold water temperature.

4. Approach: Difference between the cold water temperature at tower outlet and the entering air wet bulb temperature.

5. Cold Water Temperature: Temperature of the water leaving the collection basin.

6. Counter-flow: Air flow direction through the fill is counter-current to that of falling water.

7. Cross-flow: Air flow direction through the fill is essentially perpendicular to that of falling water.

8. Ambient wet bulb temperature: The wet bulb temperature of air encompassing the cooling tower.

9. Entering wet bulb temperature: The Wet bulb temperature of air actually entering the tower.

10. Exhaust Wet Bulb Temperature: Wet bulb temperature of the exhaust stream of air, going out of the cooling tower.

11. Fill / Fill Sheet: Vertically arranged, closely spaced panels to spread flowing water so as to increase its surface area.

12. Hot water temperature: Temperature of the circulating water entering the cooling tower distribution system.

13. Forced Draft: Refers to the movement of air under pressure through a cooling tower (blow through type)

14. Induced Draft: Refers to the movement of air through a cooling tower by means of an induced partial vacuum (draw thru type)

15. Natural Draft: Refers to the movement of air through a cooling tower typically by the driving force of density differential.

16. Plume: The effluent mixture of heated air and water vapor (usually visible) discharged from a cooling tower.

17. Net Effective Volume: That portion of the total structural volume within which the circulating water is in intimate contact with the flowing air.

Example:

A Tower cools 1000 GPM from 95º F to 85º F at 72º F wet bulb temperature. Calculate Range, Approach, Heat rejection, Drift loss, Evaporation rate, Bleed rate and Make up water requirements.

- Range: *(HWT – CWT)* = 95 - 85 = 10º F
- Approach: *(CWT – WBT)* = 85 - 73 = 13º F
- Heat Rejection: *(Flow $_{GPM}$ X Range $_{°F}$ X 500)* = 1000 x 10 x 500 = 5,000,000 btu's/hr = 5,000 MBH)
- Typical Drift Loss: *(0.002% X Re-circulated Flow Rate)* = 0.00002 X 1000 = 0.02 GPM
- Evaporation Rate: *(Flow $_{GPM}$ X Range $_{°F}$ / 1,000)* = 1000 X 10 / 1,000 = 10 GPM
- Bleed Rate: *(Evaporation Rate $_{GPM}$ / (Cycles-1)* = 10 / (3-1) = 5 GPM
- Make-up Water Requirement: *(Evaporation Rate $_{GPM}$ X [Cycles/(Cycles-1)])* = 10 x 3/2 = 15 GPM

Course Summary

The most critical value in determining cooling tower efficiency and size is the wet bulb temperature of entering air.

Wet bulb temperature is a measurement of maximum cooling capability of air and is a function of the actual (dry bulb) temperature and moisture content (relative humidity) of the air.

Range and Approach are two most important parameters associated with cooling towers. The sizing of cooling tower varies directly as a function of heat load and inversely as range and approach.

Cooling towers sized to handle water flow below 10000 GPM are classified as factory built package towers and the sizes above this limit are generally field fabricated.

To select a cooling tower, the water flow rate, water inlet temperature, water outlet temperature and ambient wet bulb temperatures must be known.

The cooling tower could be natural draft that finds usage mainly in power generation facilities. Most of the industry, process or air-conditioning applications rely on the use of mechanical draft-cooling towers. The mechanical draft cooling towers are further classified as the counter-flow or the cross –flow type depending upon the 'Fill' arrangement and the way air comes in contact with water.

The cooling towers use wood, galvanized steel, stainless steel, concrete and fiberglass as the major fabrication materials.

The other important factors that guide the overall performance of the system include the layout & installation considerations to keep the tower free from obstructions, health hazards such as Legionella disease, water treatment, energy efficiency, environment and acoustic concerns.

The testing and performance of cooling tower is governed by the guidelines of Cooling Tower Institute (CTI) standards.