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Cooling Towers - Made Easy

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COOLING TOWERS – MADE EASY

Overview

Most industrial production processes need cooling water to operate efficiently and safely. Refineries, steel mills, petrochemical manufacturing plants, electric utilities and paper mills all rely heavily on equipment or processes that require efficient temperature control. Cooling water systems control these temperatures by transferring heat from hot process fluids into cooling water. As this happens, the cooling water itself gets hot; before it can be used again it must either be cooled or replaced by a fresh supply of cool water.

A Cooling Tower is a heat rejection device that extracts waste heat to the atmosphere by cooling a stream of hot water in the tower. This type of heat rejection is termed "evaporative" because it allows a small portion of the water being cooled to evaporate into a moving air stream and thereby provides significant cooling to the rest of that water stream. The heat that is transferred from the water stream to the air stream raises the air's temperature and its relative humidity to 100%, and this air is discharged to the atmosphere.

Types of Cooling Processes

Two basic types of water cooling processes are commonly used. One transfers the heat from warmer water to cooler air mainly by an evaporation heat-transfer process and is known as the evaporative or wet cooling. These are also termed as open systems. The other transfers the heat from warmer water to cooler air by a sensible heat-transfer process and is known as the non-evaporative or dry cooling. These are also termed as closed cooling water systems because the water does not come in contact with outside air.

Dry cooling towers operate by heat transmission through a surface that divides the working fluid from ambient air. These rely mainly on convection heat transfer to reject heat from the working fluid, rather than evaporation. The cooling takes place through air-cooled exchangers similar to radiators.

The advantages of these systems include:

1. Precise temperature control, which is critical in many process applications

2. The water loss is negligible as the water remains in a closed loop. This system consumes very little water for make up and thus water treatment costs will be less. This system is recommended where water is scarce.

3. Ability to operate at very high temperatures (200ºF) and under sub-freezing conditions using ethylene glycol, alcohol or brines.

Other variant of closed cooling system is the once through system. Here the cooling water is drawn from estuary, lake or river; used in process once and is disposed back to the source. There is no re-circulation.

Once-through cooling is usually employed when the cooling water demands are high and water is readily available in abundance. Environmental regulation of hot water discharge or concerns of aquatic life go against using this system. Local environment authority having jurisdiction must permit such installation.

Evaporative systems is a recirculation water system that accomplishes cooling by providing intimate mixing of water and air, which results in cooling primarily by evaporation. A small portion of the water being cooled is allowed to evaporate into a moving air stream to provide significant cooling to the rest of that water stream.

Water is re-circulated and reused again and again. The water evaporation is approximately 1% of the flow for each 10ºF drop in temperature. The heat from the water stream transferred to the air stream raises the air's temperature and its relative humidity to 100%, and this air is discharged to the atmosphere.

In general, the most applications rely on the use of evaporative cooling tower systems, which include wet cooling towers, cooling ponds or spray ponds.

The course covers 18 sections of comprehensive information on evaporative cooling towers and provides important aspects of cooling tower types, sizing, selection and performance issues. Let's first define few important terms for understanding this course. A detailed glossary is provided at the end of the course.

Cooling Tower Terms and Definitions

Some useful terms, commonly used in the cooling tower industry:

1. **BTU (British thermal unit) -** BTU 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.

2. **Cooling Range** - The difference in temperature between the hot water entering the tower and the cold water leaving the tower is the cooling range.

3. **Approach** - The difference between the temperature of the cold water leaving the tower and the wet- bulb temperature of the air is known as the approach. Establishment of the approach fixes the operating temperature of the tower and is a most important parameter in determining both tower size and cost.

4. **Drift** - Water droplets that are carried out of the cooling tower with the exhaust air. Drift loss does not include water lost by evaporation. Proper tower design can minimize drift loss. The drift rate is typically reduced by employing baffle-like devices, called drift eliminators, through which the air must travel after leaving the fill and spray zones of the tower.

5. **Heat Load** - The amount of heat to be removed from the circulating water within the tower. Heat load is equal to water circulation rate (gpm) times the cooling range times 500 and is expressed in BTU/hr. Heat load is also an important parameter in determining tower size and cost.

6. **Ton** - An evaporative cooling ton is 15,000 BTU's per hour. The refrigeration ton is 12000 BTU's per hour.

7. **Wet Bulb Temperature (WBT)** - The lowest temperature that water theoretically can reach by evaporation. Wet-Bulb temperature is an extremely important parameter in tower selection and design and should be measured by a psychrometer.

8. **Dry-Bulb Temperature** - The temperature of the entering or ambient air adjacent to the cooling tower as measured with a dry-bulb thermometer.

9. **Pumping Head** - The pressure required to pump the water from the tower basin, through the entire system and return to the top of the tower

10. **Makeup** - The amount of water required to replace normal losses caused by bleed off, drift, and evaporation.

11. **Bleed off** - The portion of the circulating water flow that is removed in order to maintain the amount of dissolved solids and other impurities at an acceptable level. As a result of evaporation, dissolved solids concentration will continually increase unless reduced by bleed off

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SECTION 1 – EVAPORATIVE COOLING TOWERS

An evaporative cooling tower is a heat exchanger that transfers heat from circulating water to the atmosphere. Warm water from the heat source is pumped to the top of the tower and will than flow down through plastic or wooden shells. As it falls downward across baffles, the water is broken into small droplets. Simultaneously, air is drawn in through the air inlet louvers at the base of the tower and travels upward through the wet deck fill opposite the water flow. A small portion of the water is evaporated which removes the heat from the remaining water causing it to cool down 10 to 20˚C. The water falls down into a basin and will be brought back into the production process from there. Some of the water is lost to evaporation and thus the fresh water is constantly added to cooling tower basin to make up the difference.

Cooling Tower Principle

Evaporation results in cooling…

On a warm day when you work or play hard, your body heats up, and you begin to sweat. Because your skin is more moist than the air, the sweat EVAPORATES and it ABSORBS heat from your body. By absorbing heat from your body, the temperature of your body is lowered. It is the evaporation or the change from a liquid to a vapor of the water on your skin which causes the skin to be cooled. If you stand in a breeze, you feel cooler, even though the temperature of the breeze will be the same as the temperature of still air. The breeze STEPS UP the EVAPORATION process of the sweat and more rapidly cools the body. It is not the breeze alone that makes you feel cooler. It is the increase in the rate of evaporation which makes the body feels cooler.

All cooling towers operate on the principle of removing heat from water by evaporating a small portion of the water that is recirculated through the unit. The heat that is removed is called the latent heat of vaporization. Each one pound of water that is evaporated removes approximately 1,050BTU's in the form of latent heat. The amount of heat lost by the water depends on the temperature rise of the ambient air before it leaves the tower. This means that both the dry bulb and wet bulb temperatures of the air are important. 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. This may account for 20% of the cooling.

Why Evaporative Cooling

The advantages of evaporative cooling stem from several key factors. First, evaporative cooling process use the ambient wet-bulb temperature of the entering air as the heat sink, which is typically 10°F to 30°F lower than the dry bulb, depending on the local climate. The lower the temperature of the heat sink, the more efficient will be the process.

Second, the evaporative cooling process involves both latent and sensible heat transfer (primarily latent) where a small portion of the recirculating flow is evaporated to cool the remaining water. For every pound of water evaporated into the airstream, approximately 1,050 Btu of heat is rejected. In contrast, a pound of air at standard conditions has a heat content of only 0.24 Btu/1b-°F, meaning that much greater air volume is required to reject the same heat load in air cooled (sensible only) cooling systems as compared to evaporative cooled systems.

Third, due to water's ability to efficiently transport large quantities of heat over relatively long distances, water-cooled systems allow the economical separation of the process equipment and heat rejection equipment.

Fourth, evaporative cooling towers allow direct contact between the water and the air, which is a highly efficient process. This mixing occurs in the fill, sometimes called the wet deck, which is typically comprised of sheets of thermoformed plastic. The fill provides a large amount of low-cost surface area for air and water to contact each other.

These reasons combine to explain why evaporative cooling towers are smaller and require much less fan energy than air-cooled equipment.

Summarizing:

Both the evaporative and sensible heat transfer occurs as the warmer water comes in contact with the cooler air.

1. Total heat transferred = Heat of evaporation + Sensible Heat
2. Every pound of water evaporated into the airstream allows the air to carry away approximately 1,050 Btu of energy from the process to be cooled. This value varies slightly with climate.
3. Higher the difference between DBT and WBT, lower is the relative humidity (or drier is the air) and more effective will be the cooling tower performance. A cooling tower should be installed in places where there is considerable differential between dry bulb temperature and wet bulb temperature.

SECTION 2 – COOLING TOWER PERFORMANCE

Cooling tower performance depends on four factors (1) Range; (2) Heat load; (3) Ambient wet-bulb temperature or relative humidity and (4) Approach.

Range

Range is the temperature difference between the hot water inlet and cold water outlet at the tower. For instance a design demanding, the hot water coming @ 100ºF and required to be cooled to 90ºF is said to have a range of 10ºF.

Increasing the range will reduce the capital cost and energy cost of the tower.

Heat Load

Heat load of cooling water is indicated by standard heat transfer equation:

$Q = m\ Cp\ \Delta T$

Where

- Q is heat load in Btu/hr
- m is cooling water mass in lbs/hr
- Cp is specific heat of water = 1 Btu/lb-°F
- ΔT is the inlet/outlet temperature differential in ºF

The above equation can be simplified in volumetric flow rates as

Q (in Btu/hr) = 8.33 lbs/Gallons x 60 hr/min x 1 x ΔT (ºF)

Heat Load (Btu/hr) = 500 x flow in GPM x Range in °F

Wet-bulb Temperature (WBT)

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 tower cannot cool the hot process water to a temperature any lower than the wet bulb temperature of the entering air.

The wet bulb temperature is also the dew point of the ambient air. It is not possible or practical to design a cooling tower that can provide cooling water equal to or lower than prevailing wet bulb temperature of the air. Each tower system must be specifically sized for each geographic area's prevailing summer wet bulb temperature. High efficiency mechanical draft towers cool the water to within 5 or 6°F of the wet-bulb temperature, while natural draft towers cool within 10 to 12°F.

In general, it is assumed that the ambient air wet bulb temperature, usually obtained from ASHRAE climatic design information (Tables 1B, 2B, and 3B of the 2001 Fundamentals Handbook, Chapter 26) represents the entering air wet bulb temperature. In fact, this is only true if the tower is located away from any heat sources that may elevate the local temperature. The Cooling Technology Institute, CTI, defines the ambient wet bulb temperature as that measured between 50 and 100 feet upwind of the tower, with no interfering heat sources between the point of measurement and the tower, and at an elevation of 5 feet above the tower base. Very few cooling tower installations fit this description. Therefore, for cooling tower selection, the entering wet bulb temperature, which is usually 1 or 2ºF higher than the ambient wet-bulb is specified to account for any potential recirculation.

Approach

How closely the leaving cold water temperature approaches the entering air wet bulb temperature, simply termed as the approach. *Approach* is the temperature difference between the cold water leaving the tower and ambient wet bulb temperature. If a cooling tower produces 85°F cold water when the ambient wet bulb is 78°F, then the cooling tower approach is 7°F.

Approach is the most important indicator of cooling tower performance. It dictates the theoretical limit to the leaving cold-water temperature and 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.

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.

The approach temperatures generally fall between 5 and 20ºF implying that the leaving CWT shall be 5 to 20ºF 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 5ºF nor do any manufacturer guarantees the performance for approaches less than 5ºF.

Effectiveness of Cooling Tower

For a given type of cooling tower, a closer (smaller) approach temperature indicates a more effective tower. Selecting a cooling tower with a close approach will supply the cooler water … but the capital cost and energy consumption of the tower will be higher, too. Note that *effectiveness* refers to the thermal efficiency of the cooling tower fill and the evaporative process; do not confuse this with the mechanical efficiency of the cooling tower. The mechanical efficiency refers to the fan power that's required to circulate ambient air over the cooling tower fill. Different types of cooling towers differ in their mechanical efficiencies.

A fact to note…

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

Summarizing:

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

Approach = Cold water outlet temperature (CWT) – WBT

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 are designed and manufactured in several types, with numerous sizes available in each type. With respect to drawing air through the tower, there are two types of cooling towers: (1) Natural draft and (2) Mechanical draft.

<u>Natural Draft Cooling Towers</u>

Natural-draft cooling towers use the buoyancy of the exhaust air rising in a tall chimney to provide the draft. Warm, moist air naturally rises due to the density differential to the dry, cooler outside air. Counter intuitively, more moist air is less dense than drier air at the same temperature and pressure. This moist air buoyancy produces a current of air through the tower. Note the characteristics of natural draft towers below:

1. Natural draft cooling towers rely on stack effect that allows the air movement on density differential. Many early designs just rely on prevailing winds to generate the draft of air.

2. Natural draft cooling towers are characterized by distinct shape much like a tall cylinder with a tight belt around the waist to provide stability

3. Such towers have the advantage of not requiring any fans, motors, gearboxes, etc. The tall stack insures against re-circulation of air

Although relatively inexpensive, they are usually applied only in very small sizes, and are fare more affected by adverse wind conditions. Their use on processes requiring accurate, dependable cold water temperatures is not recommended.

Another natural type of cooling tower also known as hyperbolic natural draft tower is quite dependable and predictable in its thermal performance. Typically, these towers tend to be quite large (250,000 gpm and greater) and occasionally in excess of 500 feet in height. These are used extensively in the field of electric power generation.

Mechanical Draft Cooling Towers

Mechanical draft cooling towers use either single or multiple fans to force or draw air through the circulating water. Their thermal performance is less affected by psychrometric variables and thus tends towards greater stability than the natural draft towers.

These can be categorized as forced draft (air pushing) or induced draft (draw-thru) arrangement by virtue of the location of fan.

Forced draft

In forced draft cooling towers, air is "pushed" through the tower from an inlet to an exhaust. A forced draft mechanical draft tower is a blow-through arrangement, where a blower type fan at the intake forces air through the tower. These are characterized by high air entrance velocities and low exit velocities.

The forced draft cooling towers have certain disadvantages:

1. The blower forces outside air into the tower creating high entering and low exiting air velocities. The low exiting velocity of warm moisture laden air has the tendency to get re-sucked by the blower fan. This increases the apparent wet bulb temperature, and the cooling tower ceases to give the desired approach.

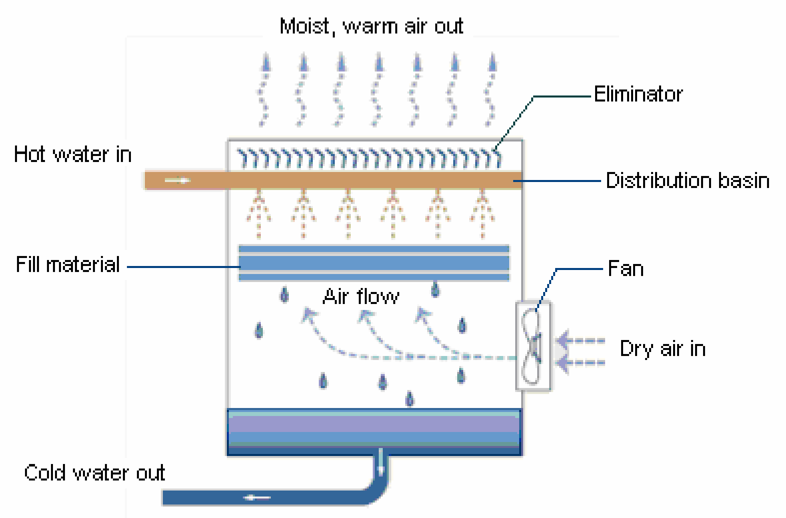
2. A Forced draft Cooling Tower can only be square or rectangular shaped. Forced draft arrangement always has a fan on the side. Due to this the cooling tower cannot be bottle shaped. Further, due to this characteristic, the water distribution system cannot be that of a sprinkler form. This results in inefficient water distribution.

3. It is difficult to maintain this type of a cooling tower because of the inaccessibility of the fills. Cold water basin is covered and difficult to access.

4. Pressurized upper casing is more susceptible to water leaks than the induced draft styles.

5. A forced draft design typically requires more motor horsepower typically double that of a comparable induced draft counter-flow cooling tower.

6. With the fan on the air intake, the fan is more susceptible to sever icing with resultant imbalance when moving air laden with either natural or recirculated moisture.



Forced Draft Cooling Tower

Usually forced draft towers are equipped with centrifugal blower type fans which although require more horsepower than propeller type fans, have the advantage of being able to operate against high static pressures. Therefore they can be installed indoors in more confined spaces or within a specifically designed enclosure that provides significant separation between intake and discharge locations to minimize recirculation.

Induced draft

An induced draft mechanical draft tower is a draw-through arrangement, where a fan located at the discharge end pulls air through tower. The fan *induces* hot moist air out the discharge. This produces low entering and high exiting air velocities, reducing the possibility of *recirculation* in which discharged air flows back into the air intake. When compared to forced draft cooling towers, induced draft towers have following advantages:

1. Recirculation tendency is less a problem. The air that is thrown out from the top of the Cooling Tower has no chance of getting back into the Cooling Tower. The push of the fan adds to the upward thrust of the warm air.

2. The induced draught can be square as well as round. The distribution system is that of a sprinkler which is considered to be the most efficient water distribution system.

3. Noise level is very low, because the fan and motor are placed on the top of the Cooling Tower. They are not in level with the observer

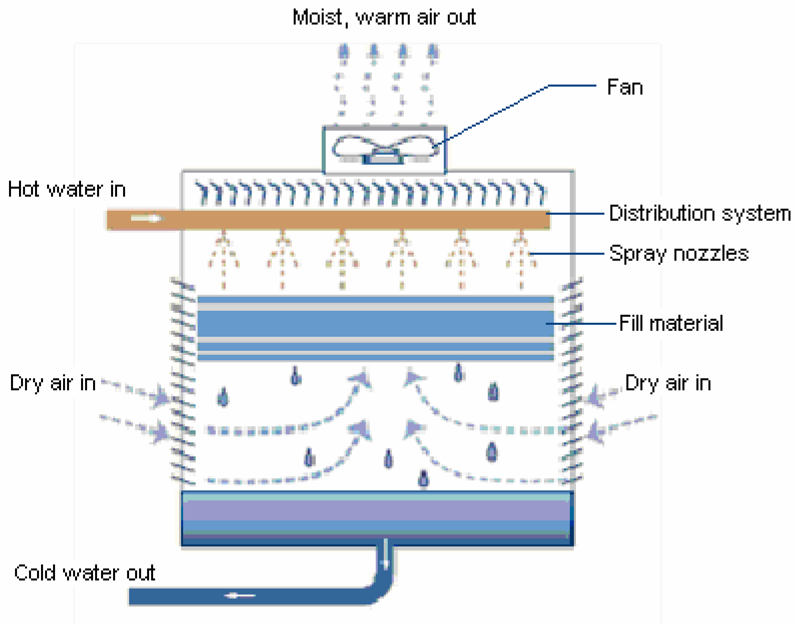
4. A forced draft Cooling Tower cannot be a Cross-flow type model. An induced draught can be either Cross-flow or Counter-flow.

5. The parts of this type of cooling tower are easily accessible and there is no problem in their maintenance.

Types of Induced Draft Tower

Induced draft cooling towers are characterized as Cross-flow and Counter-flow designs, by virtue of air-to-water flow arrangement. The difference lies in the FILL arrangement.

<u>Counter-flow Cooling Towers</u>

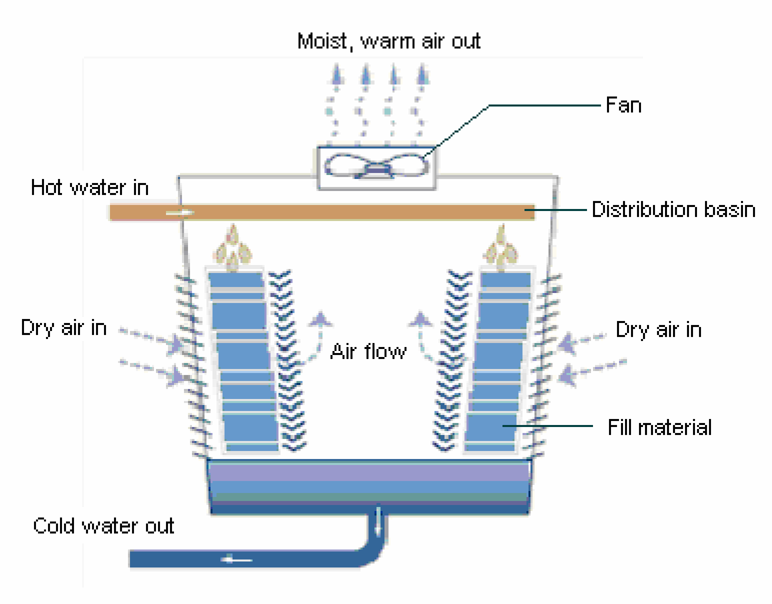


Counterflow Type Design

In a counter-flow induced draft cooling towers, air travels vertically across the fill sheet, opposite to the downward motion of the water. Air enters an open area beneath the fill media and is then drawn up vertically. The water is sprayed through pressurized nozzles and flows downward through the fill, opposite to the air flow.

Cross-flow Cooling Towers

In Cross-flow induced draft cooling towers, air enters one or more vertical faces of the cooling tower and moves horizontally through the fill material. Water drops by gravity and the air pass through the water flow into an open plenum area. A shallow pan type elevated basin is used to distribute hot water over the tower fill by means of orifices in the basin floor. The application obviates the need for a pressure-spray distribution system and relies on gravity distribution.



Crossflow Type Design

Crossflow towers are also sub-classified by the number of fill banks and air inlets that are served by each fan. The tower indicated in schematic above is a double-flow tower because the fan is inducing air through two inlets and across two banks of fill.

The surface enclosing the top structure of an induced draft cooling tower, exclusive of the distribution basins on a crossflow tower is called Fan deck.

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

What is Common to both designs?

1. Both are generally induced flow arrangement although counter-flow design is available in forced flow arrangement too.
2. The interaction of the air and water flow allows a partial equalization and evaporation of water.
3. Both are generally draw-thru arrangement where a fan *induces* hot moist air out the discharge.
4. Both produces low entering and high exiting air velocities, reducing the possibility of *recirculation.*

What is Different in Cross-flow and Counter-flow designs?

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 tower is compact and have smaller footprint, but these tend to be taller than Cross-flow models, require more pump head and utilize more fan power than their cross-flow counterparts. The physically higher size also demands taller architectural screens. Cross-flow cooling towers have larger foot print area because of the cavity which is to be left between the fan and the fills.

3. **Dimensional references**

   For cross-flow towers, length is always perpendicular to the direction of air flow through the fill (air travel), or from casing to casing. For counter-flow towers, length is always parallel to the long dimension of a multi-cell tower, and parallel to the intended direction of cellular extension on single-cell towers

4. **Spray Pattern (Water Distribution)**

   Counter-flow towers use pressurized spray systems that is considered to be the most efficient method of water distribution in a cooling tower. No sprinkler distribution is possible in a cross-flow cooling tower.

5. **Operating Weight**

   Counter-flow towers have low operating weight and thus find greater acceptability at roof locations. Cross-flow operating weight is higher than the counter-flow tower.

6. **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. A cross-flow cooling tower where two opposed fill banks are served by a common air plenum is termed double flow arrangement.

7. **Fill Support**

In counter-flow design, 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 design, the fill media is generally supported by rods. Icing and wear may deteriorate the fill making it sag, which may affect performance.

8. **Operating Efficiency**

Counter-flow cooling towers are 25% more efficient than cross-flow type. The reason being that as the air is being sucked from the lower part of the cooling tower, it rises upwards, gets warmer and when it reaches the top, it is hottest at that point. Since the water is flowing in the downward, it is the hottest at the top. Thus hottest of air meets the hottest of water and evaporation is more and thus the cooling is more.

In this case a cross-flow tower, air that passes the water, is not capable to pass waters at different temperatures. Thus the level of cooling in this case is less.

9. **Operation in Freeze Climates**

Counter-flow tower's configuration tends to confine ice formation to areas of greatest structural strength, however, it is also the most difficult to de-ice. This is because their straight sided shape reduces the opportunity for direct warm water contact with a major ice formation, requiring more frequent fan reversal. Cross-flow towers have an inwardly sloping air inlet face which assures continuous contact of warm water with critical areas and with only occasional fan reversal, promotes rapid de-icing.

10. **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.

11. **Maintenance**

Counter-flow towers are easy to maintain at cold-water basin level because this is open on all sides with no restrictions from wet deck. Cross-flow tower are difficult to clean at the cold water basin under wet deck because of limited access.

12. **Balancing Requirements**

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

13. **Limitations**

Counter- flow tower require airflow on all four sides for optimum performance. 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.

14. **Initial Cost**

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

SECTION 4 - COOLING TOWER CAPACITIES & AVAILABILITY

Mechanical draft towers are available in a large range of capacities. The nominal capacities range from approximately 15 gallons per minute (GPM) to several thousand GPM. 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 point of manufacture, whereupon they are shipped to the site in as few sections as the mode of transportation will permit. Towers of this type usually are mass produced in factories with FRP or galvanized steel structure and casing.

Package towers are typically used in air-conditioning and small industrial cooling applications requiring flow rates below 10000 GPM. Large office buildings, hospitals, schools typically use one or multiple cooling towers as part of their air conditioning systems.

Cooling Towers for HVAC duty are usually described by their tons of cooling capacity. The cooling capacity indicates the rate at which the cooling tower can transfer heat. One ton of cooling is equal to 12,000 BTUs (British thermal units) per hour, or 200 BTUs per minute. The heat rejected from an air conditioning system equals about 1.25 times the net refrigeration effect. Therefore the *equivalent ton* on the cooling tower side actually rejects about 15,000 Btu/hour (12000 Btu cooling load plus 3000 Btu's per ton for work of compression). Cooling tower capacities at commercial, industrial, or institutional facilities typically range from as little as 50 tons to as much as 1,000 tons or more. Large facilities may be equipped with several large cooling towers.

Where water is scarce, HVAC chillers can be air-cooled. However, water-cooled chillers are normally more energy efficient than air-cooled chillers due to heat rejection to tower water at near wet-bulb temperatures. Air-cooled chillers reject heat near to the dry-bulb temperature, and thus have lower average effectiveness.

Note that, a cooling tower is an auxiliary cooling device – it doesn't cool the building directly – but rather it helps other air-conditioning (chiller) equipment do that job.

Field Erected Cooling Towers

Field erected towers are those on which the primary construction activity takes place at the site of ultimate use. These are generally manufactured and/or assembled at jobsite making use of framed structures. All large towers are prefabricated, piece marked and shipped to the site for final assembly. Erection supervision for final assembly is usually provided by the cooling tower manufacturer.

The field erected cooling towers are typically specified with very high thermal duties demanding water flow rates ranging from 10000 to 350000 GPM.

The field-erected towers are generally used in most industrial and utility applications such as power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food processing plants, semi-conductor plants, and other industrial facilities. To give an example, the circulation rate of cooling water in a typical 700 MW coal-fired power plant with a cooling tower amounts to about 71,600 cubic meters an hour (315,000 U.S. gallons per minute) and the circulating water requires a supply water make-up rate of perhaps 5 percent (i.e., 3,600 cubic meters an hour). A typical large refinery processing 40,000 metric tonnes of crude oil per day (300,000 barrels per day) circulates about 80,000 cubic meters of water per hour through its cooling tower system.

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.

SECTION 5 - COOLING TOWER MATERIALS

Cooling tower structures are constructed using variety of materials. While package cooling tower are generally constructed with fiberglass, galvanized steel (or stainless steel in special situations), many possibilities exist for field-erected structures. Field-erected towers can be constructed of Douglas fir, redwood, fiberglass, steel or concrete. Each material has advantages and disadvantages.

1. **Wood -** In early days, towers were constructed primarily of Redwood because of its natural tendency to inhibit decay. As the Redwood resources diminished, Douglas-Fir come into existence. Douglas-Fir however supports the growth and proliferation of micro-organisms causing rapid diglinification (eating of wood). Various methods of pressure treatment and incising are used to prevent micro-organisms attack to wood, which includes CCA and ACC treatment. Chromate Copper Arsenate (CCA) was initially used as a preservative but because of its arsenic content, Acid Copper Chromate (ACC) has replaced it. Irrespective of any treatment, the leaching of chemicals is still a concern to the environment and sometimes extensive additional water treatment of blowdown and tower sediment is needed. Some drawbacks of wooden towers are stated below:

   - The wooden structure is less durable and the life expectance of is low. Delignification (eating of wood) is controlled by adjusting pH strictly between 7 and 7.5
   - The drift losses are over 1%.
   - Tower has a larger footprint and need more space when compared to other alternatives.
   - Algae formation is a continuous problem in this type of Cooling Tower.
   - The wooden structure is less durable.
   - Wooden tower usually use large concrete tank that involves more cost, time and labor.

- Since these towers are extremely heavy, they have to be installed on ground only.
- The nozzles on the wooden tower consume a significant amount of pressure head, which result in pressure drop.
- Wood can be damaged by excessive levels of free chlorine and is sensitive to prolonged exposure to excessively hot water. Design hot water temperature should be limited to 140°F or should be controlled to that level by use of a cold water by-pass.

2. **Galvanized Steel –** The most cost-effective material of construction for packaged towers is G-235 hot dip galvanized steel, from both structural and corrosion resistance standpoint. G-235 is the heaviest mill galvanizing commercially available, and offers a substantial amount of protection as compared to the lighter zinc thicknesses in use several decades ago, providing reliable corrosion protection for most HVAC and industrial system water chemistries. The most common upgrade from G-235 galvanized steel is Type 304 stainless steel. Parts that are submerged during operation and/or at shutdown can benefit the most by upgrading to stainless steel.

   **Note that the G-235 designation refers to 2.35 ounces of zinc per square foot (717 g per m^2) of the steel sheet.*

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

4. **Concrete Towers -** Larger field erected towers for power plant and refinery applications are constructed of concrete. Concrete towers will last more than 40 years, but they are the most expensive to build. Because of their cost, they represent only 2 to 3% of all field-erected towers. Sometimes 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.

   Circulating water in want of calcium (quantified by a negative Saturation Index) can be corrosive to concrete components, in which case the concrete gives up a portion of its calcium content in an effort to “neutralize” the water. Chemical treatment of the circulating water should be aimed at maintaining a slightly positive Saturation Index.

5. **Fibre-reinforced Plastic (FRP) Towers -** Currently, the fastest growing segment of the cooling tower market is structures built with pultruded FRP sections. The capability of plastics to be

moulded into single parts of complex shape and dimensions is a distinct advantage, particularly for close tolerance components such as fan blades and fan cylinders. This inert inorganic material is strong, lightweight, chemically resistant and able to handle a range of pH values. 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.

Note that for the cooling towers erected over a concrete basin, height is measured from the elevation of the basin curb. "Nominal" heights are usually measured to the fan deck elevation, not including the height of the fan cylinder. Heights for towers on which a wood, steel, or plastic basin is included within the manufacturer's scope of supply are generally measured from the lowermost point of the basin, and are usually overall of the tower.

SECTION 6 – COMPONENTS OF A COOLING TOWER

The average life of a cooling tower is estimated at approximately 20 years and well-maintained towers often can operate well beyond that. Most towers are designed such that air moving components and heat transfer media can be replaced when necessary, often resulting in higher unit performance as technological advances occur in the industry. The key to longevity is keeping the base structure of the tower usable, especially the cold water basin. The important components of the cooling tower are grouped in three categories 1) structural components, 2) mechanical components and 3) electrical components.

Structural Components

The structural components of the cooling tower include cold water basin, framework, water distribution system, fan deck, fan cylinders, mechanical equipment supports, fill, drift eliminators, casing and louvers.

1) **Cold Water Basin:** The cooling tower basins serves two fundamentally important functions of 1) collecting the cold water following its transit of the tower and 2) acting as the tower's primary foundation. 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.

   Typical materials for basins include wood, steel, plastic, concrete or coated metals. Plastic basins generally are limited to small towers for structural reasons, while steel basins can be used on all sizes. Steel basins may be of carbon steel (galvanized or painted) or stainless steel, and of either bolted or welded construction. If bolted, joints must be gasketed and sealed leak tight. Light-weight, corrosion-resistant fibreglass reinforced polyester (FRP) also is popular for casing panels for corrosion resistance and lighter weight. Concrete basins for large wood or steel framed field erected cooling towers are usually designed and built by the purchaser, utilizing the dimensional and load information provided by the manufacturer.

The basin must be deep enough to provide sufficient hydraulic head for proper water flow into the sump(s) and to accept the transient water and potential backflow at pump shutdown. Beyond this, the basin may be made deep enough to hold a reserve in case of interrupted make-up water supply to stabilize water temperatures under highly variable loads.

<u>As a general rule, the basin should be sized to hold three times the rate of circulation in gallons per minute.</u>

2) **Basin Sumps and Screens:** Sumps for towers with wood or steel basins are normally designed and furnished by manufacturer. Concrete sumps provided by owner, should be designed for water entrance velocities of less than 3 ft/sec and should be sufficient depth to satisfy pump suction head requirements. Screens are usually required to prevent debris and should be maximum ½" square mesh, sized for 1 ft/sec net velocity through the open area of the screen. Screens should be held in place by channels imbedded in the sump walls to allow for easy removal.

3) **Tower Framework:** Factory assembled towers predominate in steel construction whereas the most commonly used material for the framework of field erected towers is wood and concrete with steel utilized infrequently to conform to a local building code. In large wood towers, the columns are normally spaced on 4' x8' or 6' x 6' canters. These bay sizes have evolved over the years of experience and have proved the best to properly support the fill, drift eliminator and louver modules, as well as to keep lumber sizes to those that are readily available.

   A uniform wind load design of 30 lbs per sq-ft is standard with higher values either dictated or advisable in some areas. Earthquake loads, if applicable shall be in accordance with zones defined in Uniform Building Code.

4) **Packing Materials:** Packing materials (splash bars, fills) are used to enhance performance of cooling tower by providing increased surface area between air and water.

- Splash Fills- Splash fills breaks up the water and interrupts its vertical progress, by causing it to cascade through successive offset levels of parallel splash bars. The splashing causes the water to disperse into droplets thereby increasing the contact of water and air. Treated wood splash bars is still specified for wood towers, but plastic splash fill promotes better heat transfer and is now widely used where water quality demands the use of wider spaced splash fill. Splash fill is characterized by reduced air pressure losses and is not conducive to clogging.

- Film Fills – Film fill causes the water to spread into a thin film, flowing over large vertical areas, to promote maximum exposure to the air flow. Film fill is typically made of corrugated plastic sheets that have been joined into blocks that have a honeycombed appearance. Hot water falling onto the distribution deck forms a surface film as it channels through the fill down to the cooling tower basin. Plastics are widely used for fill, including, PVC, polypropylene and other polymers. 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.

5) **Hot Water Distribution System:** Those parts of a tower beginning with the inlet connection which distribute the hot circulating water within the tower to the points where it contacts the air for effective cooling. May include headers, laterals branch arms, nozzles, distribution basins, and flow-regulating devices. Nozzles are fabricated out of PVC, ABS, polypropylene and glass filled nylon. Water enters through a removable wave suppressor splash box. A typical supply piping arrangement, applicable to multi-cell crossflow or counterflow towers positions the supply line adjacent to the long side of the tower and running the full length. Vertical risers (one per cell) connect the supply line to the manufacturer's inlet connections at the elevation of the tower's distribution system. Valves are usually installed in these risers to isolate individual cells when needed.

6) **Air Inlet Screens:** An Air inlet screen 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. Install coarse mesh screens over the air intake components of the cooling tower to reduce the ingress of leaves and coarse debris.

7) **Fan Deck:** The fan deck is considered a part of the tower structure acting as a diaphragm for transmitting dead and live loads to the tower framing. It also provides a platform for the support of the fan cylinders, as well as an access way to the mechanical equipment and water distribution system.

8) **Fan Cylinders:** The fan cylinder affects the proper flow of air through the tower. The essence of a well designed fan cylinder incorporates an eased inlet to promote smooth flow of air to the fan, minimum fan blade tip clearance, a smooth profile below and above the fan, sufficient structural strength to main a stable plan and profile and sufficient height to prevent recirculation and protect operating personnel. FRP because of its formability, strength, relatively light weight, stability and resistance to water and weathering is the preferred material for this application.

9) **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.

10) **Drift Eliminators:** An assembly of baffles or labyrinth passages through which the air passes prior to its exit from the tower, for the purpose of removing entrained water droplets from the exhaust air. The eliminator reduces the drift – to 0.002% -or less- to 0.0005% of the circulating water flow. Generally the drift eliminators are PVC type, 10 mil minimum sheet thicknesses with 25 mil minimum PVC stiffeners, UV protected, capable of supporting weight of maintenance workers without damage to top surface.

11) **Casing:** A Cooling tower casing acts to contain water within the tower, provide an air plenum for the fan, and transmit the wind loads to the tower framework. It must have diaphragm strength, be watertight and corrosion resistant.

12) **Ladders & Handrails:** Ladders and Handrails for tower access are necessary for large field erected cooling towers and make sense on some factory assembled designs. A hot dip galvanized steel access door and ladder is necessary in each cell for internal access to fill from the fan deck level. These are safety & maintenance accessories that are recommended per the guidelines of OSHA standards. Seismic Bracing options exist in the in earthquake prone areas.

13) **Cooling Tower Bypasses:** 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.

Mechanical Components

Mechanical components basic to the operation of the cooling towers are fans, speed reducers, drive shafts and water flow control valves.

1) **Cooling Tower Fan:** Fans provide the airflow for mechanical draft cooling towers. Generally, propeller fans driven through v-belts are used. These are protected with a belt guard, or with drive shafts and gear boxes. Depending upon their size, propeller fans can either be fixed or adjustable 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.

2) **Speed Reducers:** Cooling tower fans are operated at a very low RPM that seldom coincides with the most efficient speed of the driver (motor). This dictates that a speed reduction and power transmission unit of some sort be situated between motor and the fan. Speed reduction is generally accomplished either by differential gears of positive engagement or by differential pulleys (sheaves) connected through V-belts. Typically, gear reduction units are applied through a wide range of horse power ratings from the very large down to as little as 5 hp. V-belts are usually applied at ratings of 50 hp or less.

3) **Drive Shaft:** The drive shaft transmits power from the output shaft of the motor to the input shaft of the gear reducer. Because the drive shaft operates within the tower, it must be highly corrosion resistant (generally stainless steel). It is very important that drive shafts be properly balanced. Imbalance not only causes tower vibration, but also induces higher loads and excessive wear on the mechanical equipment couple to the shaft.

4) **Valves:** Valves are used to control and regulate the flow through the water lines serving the tower. Valves utilized for cooling tower application include stop valves, flow control valves and make-up regulator valves. Stop valves are usually the gate or butterfly type. Because flow control valves are customarily supplied with crossflow towers, stop valves are not normally considered mandatory in their case.

Electrical Components

1) **Electric Motors:** Electric motors used to drive fan on the mechanical draft cooling towers must be capable of reliable operation under extremely adverse conditions of high humidity. Two basic types of motor enclosures are “open” and “totally enclosed”. The open motor circulates external air inside the enclosure for cooling whereas totally enclosed motor prevents outside air from entering the enclosure. Open motors are further classified as drip proof, splash proof and weather protected – the distinction between them being the degree of protection provided against falling or air-borne

water gaining access to live and rotating parts. Drip proof motor is NOT recommended in cooling tower applications.

Totally enclosed motors are recommended cooling tower applications as these are more resilient to fumes, dust, sand, snow and high humidity conditions. These can provide a high quality installation either in or out of the air stream.

2) **Motor Service Factor:** The service factor of a motor is indication of its maximum allowable continuous power output, as compared to its nameplate rating. A 1.0 service factor motor should not be operated beyond its rated horse power at design ambient conditions, whereas a 1.15 service factor motor will accept a load 15 percent in excess of its nameplate rating. Use of 1.15 service factor motor is recommended for cooling tower fan loads at or near nominal horse power ratings.

3) **Motor Insulation:** Insulation is categorized by classes – A, B, F and H commonly used in USA with class A carrying the lowest temperature rating and class H the highest. Class B insulation are designed for a maximum altitude of 3300 feet and a maximum ambient temperature of 40°C. Class F insulation is used for higher altitudes as well as higher ambient, and is gaining increased use as a means of improving service factor of a motor of given frame size.

4) **Motor Torques:** Normal torque motors perform satisfactorily for cooling tower applications and high starting torque motors are not recommended for cooling tower drives.

5) **Motor Controls and Protective Devices:** Controllers serves to start and stop the fan motor and to protect it from overload or power supply failure. In addition various protective devices such as safety switches, circuit breakers, disconnect switch, manual and magnetic starters, enclosures must be as per the applicable electrical codes.

SECTION 7 – SIZING YOUR TOWER

Four fundamental factors affect tower size: heat load, range, approach, and ambient wet-bulb temperature. If three of these factors remain constant, then changing the fourth factor will affect tower size in the following way:

1. <u>Tower size varies directly and linearly with the heat rejection load</u>. If the heat rejection is to be doubled, the tower size will double.

2. Tower size varies inversely with range. For a given heat rejection duty, higher range will reduce the circulating water flow rate. Lower water flow rate in turn will demand lower surface area for heat transfer and reduce the size of the cooling tower. Lower circulating flow rate will also reduce the pumping horsepower. 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. It is not economical to select range higher than 20ºF.

3. Tower size varies inversely with 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. Tower size varies inversely with wet-bulb temperature. The effect of wet-bulb temperature is similar to approach. 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 parameters are needed for tower selection?

As a minimum, four parameters 1) the heat load from the process, 2) water inlet temperature, 3) water outlet temperature and 4) ambient wet bulb temperatures must be known. For instance the recirculation water flow rate is determined by the heat load and range using following equation:

$$H = Btu/\min = \frac{(\Delta T_{°F})(R_{gal})(8.33lb)(1Btu)}{(\min)(gal)(lb/°F)} \quad \text{--------------------} \quad \text{Equation (1)}$$

Where

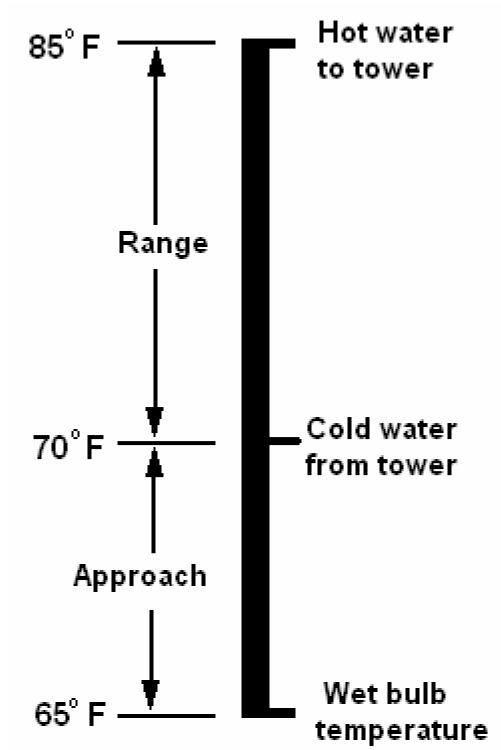
- Heat load (H) is the heat rejection load from the process or is heat absorbed by the cooling water system which must be rejected in the cooling tower expressed in Btu/min.

- Cooling range (ΔT) of a cooling tower is the difference between the entering and leaving temperatures expressed in deg F.

- Recirculation (R) rate is the water flow over the tower in gallons per minute.

- British Thermal Unit (Btu) is the heat required to raise the temperature of one pound of water one º F.

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. Figure below shows a sample representative graphic, depicting the relationship of range and approach as the heat load is applied to the tower.



Note that although the combination of range and gpm is fixed by the heat load in accordance with the Equation (1) above, approach (difference between cold water temperature and entering wet bulb temperature) is fixed by the size and efficiency of the cooling tower. A large tower of average efficiency will deliver cold water at a temperature which approaches a given wet bulb temperature no closer than a somewhat smaller tower having significantly better efficiency.

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.

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

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 8 – COOLING TOWER CAPACITY CONTROLS

One may think, that lower water temperature from cooling tower dictates the effectiveness of the cooling tower. Yes this is true; however, 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.

It is very important to maintain close control on the cooling tower during winter operation. In order to provide a margin of safety, a minimum leaving water temperature of 45°F is recommended.

Regardless of what type of capacity control is utilized, a full flow bypass may be required. If the cooling load is to be maintained below 30% of the full winter capacity, then a full flow bypass valve should be incorporated. This valve serves to divert water from the tower hot water distribution system to the cold basin. Alternatively, reducing tower airflow yields higher leaving water temperatures. Few other control options are listed below:

1. **Fan cycling**- The capacity control of the cooling tower is best achieved by modulating air flow through a cooling tower. Fan cycling may be achieved by simple ON-OFF control, Variable Speed Drives and using 2 or 3 speed motors.

    - Fan On-Off control 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. It results in frequent motor starts; six starts per hour should be considered maximum.

    - Variable frequency drives allows the fans to run at a nearly infinite range of speeds to match the unit capacity to the system load. During periods of reduced load and low ambient temperatures, a thermostat senses the temperature of water unloaded by the tower and provides signal to variable frequency drive of fan to lower the speed.

    - 2 or 3 Speed Motor – This method also relies on reducing speed like variable speed control, but the difference lies on the step reduction of motor speed. For instance the motor speed can be reduced to 100%, 75% and 50% for 3-speed control. Two speed motors are often a preferred method for capacity control. 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.

2. **Inlet Air Damper Control-** Thermostatically operated dampers are incorporated into the tower to control the air volume; as the load decreases, the damper closes and restricts airflow through the unit.

3. **Water volume sprayed-** Capacity of a tower is related to the flow rate of water passing through the equipment. A modulating valve regulates the amount of water sprayed in relation to load fluctuations. Another method involves spray pump thermostatically stopping spraying water as the load decreases and restarting the pump when greater cooling capacity is needed.

Other controls

The other controls include automatic adjustment of chemical feed rate to maintain water chemistry, automatic blow-down and the controls for enhancing energy conservation.

1. **Vibration Control** - An electronic vibration switch with weatherproof housing is recommended to protect mechanical equipment against excessive damage due to a malfunction of rotating members. Vibration switch shall be provided with a time delay device (manually adjustable) that ignores start-up and transient vibration shocks. Should ice build up occur on the fan or fan parts, the resultant vibration would be detected before fan failure could occur.

2. **Electronic Water Level Control** – An electronic water level switch is recommended. This package replaces the standard mechanical make-up valve and float assembly thus eliminating the problem of ice formation and blockage of this component. It provides very accurate control of the basin water level and does not require field adjustment – even under widely varying operating conditions.

3. **Lubrication Control** - An oil level switch is recommended to provide protection for sudden loss of oil or low oil level in the gear reducer.

4. **Fire Detection** - The wooden cooling towers in particular also need to be provided with automatic fire suppression systems per the requirements of NFPA 214.

5. **Freeze Control-** In the areas subjected to freezing conditions, the CWT control is an extremely important factor. All external piping that does not drain must be heat traced and insulted. This includes water circulation pumps, riser pipes, and any accessories (including the stand pipe associated with an optional electronic water level control package). A remote sump located in an indoor heated space is an excellent way to prevent a problem with basin water freezing during idle

or no load conditions. A second alternative would be to provide basin heaters that are designed to maintain the sump water temperature at 40ºF.

Summarizing, 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)

SECTION 9 – LAYOUT CONSIDERATIONS

Two key factors affecting cooling tower performance: First airflow is important as it propagate heat transfer i.e. with more air available; there is greater potential for heat transfer to occur. The other is entering wet bulb temperature. Technically, wet bulb temperature is important because any increase in entering air wet bulb temperature will increase the minimum temperature to which a tower can perform, and thus, lower its cooling capacity.

Cooling tower layout, where and how a tower is sited, can significantly impact both its airflow and entering air wet bulb temperature. Obstructions to the airflow can cause two problems:

1. **Recirculation** is a result of short-circuiting of air flow. Recirculation occurs when tower's moist discharge (exhaust plume) is somehow redirected back into the air intake. For example, if a tower is located close to the windward or even leeward side of a taller building, wall, or other structure, the potential exists for plume travel downward causing moist air to be drawn to the tower air inlets. The moist air can effectively increase the tower entering air wet bulb temperature, thereby reducing the tower capacity - a mere two degree Fahrenheit increase in entering wet bulb temperature can decrease tower capacity 12 to 16% — As an example, a cooling tower selected at 78ºF wet bulb needs to be about 40% bigger than one selected at 72ºF wet bulb [@ 95°F cold water inlet and 85°F outlet] for equivalent performance. 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.

The potential for recirculation is primarily related to wind force and direction, with recirculation tending to increase as wind velocity increases. For that reason, accepted codes under which cooling towers are tested for thermal performance limit wind velocity during the test to 10 mph.

Although wind is the primary cause of recirculation, several other aspects such as cooling tower shape, air obstructions, orientation with prevailing wind, air discharge velocity, tower siting and orientation etc. play important role in its reduction and control.

2. **Starving** the tower for air. Cooling tower installation with intake facing too close to the wall or any other obstruction will experience airflow restrictions, which will inhibit the tower's ability to evaporate water and thermal capacity suffers accordingly. For example, a tower with an air intake too close to a solid wall would be starved of air; this would result in less evaporation and thereby into reduced tower capacity.

Every effort should be made to provide the least possible restriction to the free flow of air to the tower. The performance and efficiency of every cooling tower, large or small, is depended upon the quantity and thermal quality of the entering air. If the equipment is next to a wall, precipitation from the tower can cause building wall paint to peel, gutters to rust, or icicles to form. Cooling towers are physically the largest footprint of equipment in an industrial facility or a commercial building. Due to the size impediments of cooling towers, most are stored outside with ample room for air flow. Proper location of the cooling tower is essential to its satisfactory operation. Note the following recommendations-

1. Select an open site having an unobstructed air supply and free air motion. Minimum horizontal separation distance between cooling towers and outdoor air intakes, and other areas where people may be exposed should be considered. The draft revision of ASHRAE-62, 1989R, recommends a minimum separation of 15 feet between cooling tower and building intake.

2. Cooling towers should be installed such that its discharge is at an elevation equal to or greater than that of adjacent structures. This allows the exhaust to be carried over the adjacent structure, thus minimizing the potential for re-entrainment. It is easily accomplished by simply raising the tower, and the installing contractor can provide supporting steel to elevate the tower to any desired height. An alternate tactic is to incorporate a tower exhaust stack up to or beyond the level of adjacent structures.

3. Interference from other equipment, especially other towers, can raise the local wet bulb temperature from ½ ºF to as much as 8ºF above the ambient wet bulb temperature, depending on the size (in

terms of both dimension and capacity) of the tower. This is particularly true if these are low velocity exhausts. In order to maintain the separation of air streams and to avoid air restrictions and recirculation, as a general rule of thumb, the well or enclosure should have a gross plan area that is at least 2.5 to 3.0 times that of the tower.

4. Building vents and air intakes can substantially affect tower performance. Consideration should also be give to ensure that the discharge air from the cooling tower is not directed into a building vent or intake louver

5. Do not locate the cooling tower near heat-generating equipment, exhaust vents or pipes which could interfere with the temperature of inlet air and raise the ambient wet-bulb temperature to the cooling tower.

6. Do not install a canopy or roof of any kind over the cooling tower that would deflect discharge air back down around the cooling tower and cause recirculation of the discharge air back into the blowers.

7. 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.

8. Often enclosures are specified to shield them from view, but enclosures can restrict airflow. In these cases, instead of flowing horizontally into the tower intakes, the necessary air will be drawn from above, from spaces between tower intakes and the adjacent enclosure. If decorative screens are used, they must have sufficient free air so as not to interfere with good air flow.

Purchaser must give attention to the distance of the tower from the heat load, and the effect of that distance on piping and wiring costs; noise or vibration may create a problem, which can be expensive to correct after the fact; drift or fogging may be objectionable, if the tower is located too close to an area that is sensitive to dampness or spotting; also easy access and adequate working space should be provided on all sides of the tower to facilitate repair and maintenance work.

SECTION 10 – INSTALLATION CONSIDERATIONS

To assure optimum performance, the following recommendations should be followed as closely as possible.

1. The cooling tower should be installed on a continuous firm, smooth and level concrete, steel or wood foundation. The tower must be anchored to the foundation with ¼" guy wires using the four U-bolts provided at the op o the cooling tower shell.

2. The complete mechanical assembly for each cell shall be supported by a rigid, unitized torque tube base that is galvanized steel construction and that prevents misalignment between the motor and the gear reducer. The support shall be heavy wall tubular steel with heavy platforms and structural outriggers to transmit loads to the tower structure.

3. The sump tank should be large enough to fill the entire recirculation system without danger of pump cavitation and/or overflow. A cooling tower located at ground level with all the system components installed above shall face two major potential problems:

   - On pump 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.

   - 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. As a general rule, the tank should be sized to hold three times the rate of circulation in gallons per minute.

4. All supply and return piping must be independently supported. Spacing for piping and service access should be considered when positioning the cooling tower. Also to insure an adequate positive suction head, the pump should be located below the bottom of the cooling tower sump.

5. The inlet and discharge ducting should be screened to prevent foreign objects from entering.

6. Should prevailing winds blow into a horizontal discharge, it is recommended that a suitable windbreak be installed several feet away.

7. The tank should be provided with properly sized overflow, makeup, drain and suction connections. When a sump tank is used, the cooling tower should be located high enough above it to allow free cold water gravity drain.

8. When the cooling tower is located outdoors, adequate measures including the use of heat tracing tape and insulation should be considered to protect outdoor water lines from freezing.

9. On multiple tower installations, pipe sizing should balance pressure drops to provide equal inlet pressures. Equalizing fittings can be provided in cooling tower sumps and are available as an option from the factory. Each unit should be valved separately to allow for flow balance or isolation from service.

10. An inlet pressure gauge should be installed immediately before the cooling tower inlet connection.

11. The makeup connection should be provided with a float valve and ball assembly for proper water level control.

12. The overflow connection should include an elbow with extension pipe that drops below the water level in the tower sump. Never block overflow connection. Water should be allowed to flow freely without obstruction.

13. The outlet connections for pump suction applications are provided with a vortex breaker. Note for gravity flow applications, a vortex breaker is not required or provided. A vent pipe or bleed valve should be installed at the highest elbow of the piping system; to prevent air locks and insure free flow of water. Air locks can cause gravy flow restriction resulting in excessive water accumulation and eventual overflow of the cooling tower.

14. The outlet, makeup and overflow connections are notched at the outer ridge and should be held in position with the notch at 12 o'clock. This is to insure proper position of the vortex breaker, float valve, assembly and overflow extension which are internal and not visible from the exterior of the cooling tower.

15. PVC bulkhead connections must be held steady and in their factory-installed positions when the connecting piping is being installed.

SECTION 11 – FANS, DRIVES and MOTORS

Cooling tower components operate in a moisture laden air. Generally speaking, the interior temperature of cooling tower is 100º F at 100% RH. Under these conditions, the drive components particularly the fan motors, gear drives must be totally enclosed type for trouble free operation.

1. **Speed Reducers** - The speed reducer shall be rated in accordance with practices of the American Gear Manufacturer's Association (AGMA), using a cooling tower service factor of greater than 2. Life-span of bearing for input shaft, intermediate shaft bearings shall be 50,000 hours or more (L10 life*) and bearing for output shaft bearing shall be 100,000 hours or more (L10 life*). * L10 life defines the basic rated life (When 90% of a group of identical bearings will exceed this life when rotated at the same speed and under the same load and operating conditions). Rating shall also be in accordance with CTI STD-111. Gear reducers shall be of the spiral bevel, single (or double) reduction type. The gear reducer shall be bolted to a stainless steel base plate which in turn is bolted to the cooling tower structure. Saddle or bracket type mounting shall not be permitted.

2. **Fan Assembly** - The complete fan assembly (fan and mounting) shall be designed to give maximum fan efficiency and long life when handling saturated air at high velocities. Fan shall be of an adjustable multi-blade design with a minimum of six (6) blades rotating at a tip speed of less than 11,000 FPM. The large field erected or factory assembled cooling towers generally utilize gear box to restrict tip speeds and noise. The fan blades shall preferably be fibreglass reinforced epoxy (FRE). Fan hub shall be of HDG steel plate construction. Provide non-corrosive metal spacer sleeve to prevent fan from dropping onto gear reducer in the event of shaft bushing failure.

3. **Drive Connection** - The motor shall be mounted outside the air stream. The drive shaft shall be all stainless steel, full-floating type, with non-lubricated flexible couplings at both ends. Each drive shaft coupling shall be provided with a stainless steel guard, to prevent damage to surrounding equipment in case of shaft failure. Composite type drive shaft tubes are permitted.

4. **Fan Motors** - Motor shall be NEMA standard, totally enclosed fan cooled (TEFC enclosure), Class F insulation, suitable for corrosive duty. Open drip proof (ODP) motors should NEVER be installed for cooling tower duty. Motor shall be suitable for across line starting. Motor shall be mounted to a stainless steel base plate, bolted securely to the fan deck. 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.

5. **Exhaust Fan Stacks** - Exhaust fan stack shall be constructed of composite FRP panels by the cooling tower manufacturer. For fan stacks less than 6' high, easily removable aluminium fan screen shall be provided for safety as a standard.

SECTION 12 – WATER DISTRIBUTION PUMPS

Each cooling tower requires at least one pump for water recirculation and other may be required for the makeup 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.

Flow Estimation

The flow rate is dictated by the process requirements and can be worked out per the heat load equation below:

Heat Load (Btu/hr) = 500 x flow in GPM x Range in °F

Or

Flow (GPM) = Heat Load (Btu/hr) / [500 x Range (ºF)]

Where

Range is the inlet and outlet temperature differential of cooling water. For a given heat load, higher is the range lower shall be the flow requirement and therefore the pump capacity.

Head Estimation

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)

+

Pressure drop at the cooling tower exit through strainer mesh/outlet connection, typically 1 psi

+

Pressure drop in the piping to the pump (friction loss as water passes through pipe, fittings and valves)

+

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)

+

Pressure drop through the item being cooled (figure provided by the manufacturer of the equipment)

+

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)

+

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)

+

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.

Pipe Sizing

The pipeline transporting tower to a process should be sized so it does not compromise the available pump pressure. This line should also be sized to overcome pressure drops resulting from friction losses in the pipes and fittings. Pipe pressure drop is a function of fluid viscosity and water flow velocity. When a line is undersized, the fluid moves through the pipes at a high velocity, which creates noise and hastens the corrosive process. A bigger pump, which requires more energy, is needed to overcome the flow resistance of an undersized pipe. Over sizing is OK from energy conservation point of view; however, an economical point must be evaluated as the oversized pipes, will add to an unnecessary expense and also reduce the flow velocity to the point at which the transport line does not deliver the proper amount of water at the correct speed. Over sizing will also allows sediment or suspended materials to settle in the pipe and eventually clog them.

SECTION 13 – NOISE AND VIBRATION

Cooling tower noise is the sound energy emitted by a cooling tower and heard (recorded) at a given distance and direction. The sound is generated by the impact of falling water, by the movement of air by fans, the fan blades moving in the structure, and the motors, gearboxes or drive belts.

In order to identify and evaluate an objectionable component of a broad band of sound, the sound pressure levels at various frequencies must be known. The instrument utilized to measure the sound pressure levels with the specific octave bands of frequencies is known as an Octave Band Analyzer.

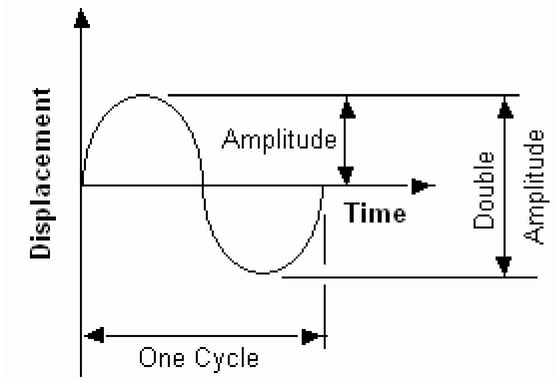
The measurement of the sound pressure levels is expressed in terms of decibels (dB). Being a wave from, sound also has a frequency characteristic which is expressed in Hertz (cycles per second). Knowing sound pressure levels and frequencies, the character of a give sound may be analyzed. For broad qualification, an overall sound level that summarizes the sound pressure levels throughout the range of frequencies may be used. This overall measurement is commonly converted to an A-scale weighted level (dBA), which represents the human ear's perception of the measure sound level.

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
- A tower with a single-side air entry can be oriented such that the air entry side is directed away from the sound sensitive area.
- Consider over sizing the cooling tower, where noise level requirements is very stringent. This can reduce the fan speed required for a given thermal duty.
- A variety of low sound, high-efficiency axial fans are available. These fans use wider chord fan blades and/or more fan blades to allow the fan to move the required air at a slower rotational speed, thus lowering the sound level.
- Use attenuators on the fan discharge. These will however add to the fan static pressure, lower the airflow and increase the power consumption. The system designer must ensure that the manufacturer's ratings are adjusted to account for any decrease in thermal performance from this reduction in airflow, and verify that the ratings with the low sound fans and/or attenuation are CTI certified as may be required by the applicable energy codes.
- Use gear drives instead of belt drives
- Variable frequency drives (VFDs) also can be used to provide sound control. VFDs allow soft start of the fans, followed by a gentle ramping up and down of the fan speed in line with the load requirement.

Vibration Isolation

In a cooling tower, disturbing frequencies can exist due to the motor speed, drive shaft speed, fan speed, blade passing frequency and their respective harmonics. The energy level imparted to the cooling tower and its components by the forces of vibration must be limited by the manufacturer to that which will not adversely affect the operating life of the equipment.



Displacement vs time in simple harmonic motion

Allowable energy levels are usually established by determining safe allowable double amplitude (Ad) of vibration at some common fundamental frequency (f) and applying it in the following formula for peak velocity in simple harmonic motion:

v = π x f x Ad

Where

- v = maximum allowable velocity (energy level) [inches/sec]
- f = Number of cycles per unit time [cycles per sec (cps)]
- Ad = Double amplitude of vibration [inches/cycle]

Customarily, a reference frequency (f) of 30 cps typical of an 1800 rpm motor is chosen, at which point allowable double amplitude of vibration Ad of 0.005 inches (5mils) might be found acceptable. The equation above establishes the basic allowable maximum velocity of vibration to be:

v = 3.14 x 30 x 0.005 = 0.471 inches per second

Equation can not be transposed to solve for allowable double amplitudes at other frequencies found in the normal mechanical equipment of a cooling tower, as follows:

Ad = 0.471 / (π x f) = 0.150/ f

For an eight bladed fan turning at 120 rpm, the blade passing frequency would be 120/60 x 8 = 16 cps. At this frequency, the maximum allowable velocity of vibration would not be exceeded if the double amplitude (Ad) were 0.150/16 = 0.009 inches (9 mils), and the energy level imparted to the cooling tower would be no greater than that represented by a double amplitude of 5 mils at 30 cps.

Most common isolation devices used for cooling tower applications are springs and synthetic rubber, quite often in combination. Vibration isolation systems are rated in terms of efficiency or transmissibility. *For a specific isolation system and deflection, isolation efficiency increases with the frequency of the disturbance. Thus if the vibration isolation system for a given machine is designed for the lowest disturbing frequency at an acceptable efficiency, the isolation efficiency for higher speed elements in the same machine will be greater.* Generally speaking, an isolation efficiency of 80% at motor rotation frequency will provide an acceptable degree of isolation in critical situations.

A vibration isolation switch is essential for big towers to prevent damage that can result from mechanical equipment malfunction or failure. The switch functions when a predetermined vibration level is exceeded, causing power to be removed from the fan motor.

SECTION 14 – COOLING TOWER WATER BALANCE

The purpose of a cooling tower is to transfer heat from the cooling water to the air by evaporation. Evaporation takes heat away from the recirculating water in the water vapour that is produced. The latent heat of evaporation of approximately 1050 Btu per pound of water evaporated generally accounts for 80-100% of the heat rejected by the cooling tower, with 20% or less being removed as sensible heat through air contact with hotter water.

As a rule of thumb, for each 10ºF that the circulated water needs to be cooled, one percent of the cooling water is evaporated in the cooling tower. The following example uses this relationship to estimate the evaporation rates for various circulated cooling water temperature reductions.

Evaporation Rate	**=**	Recirculation Flow Rate	**x**	Range (warm water temperature – desired cooling temperature)	**x**	0.01/10ºF (1% evaporation per each 10ºF temperature reduction)

Example

A cooling tower system circulates water at the rate of 1,000 gallons per minute (gpm) and the cooling tower needs to cool the warmed water exiting the heat exchanger from 90ºF to 80ºF degrees (or reduce the temperature of the water by 10ºF). Determine evaporation rate.

Evaporation Rate = 1000 GPM x (90ºF – 80ºF) x 0.01/10 = 10 GPM

Therefore, for the given 1,000 GPM circulated water, 10 GPM needs to be evaporated to reduce the warm water from 90ºF to 80ºF.

To give a prospective of water evaporated, the table below shows the gallons of water evaporated daily, monthly, and yearly; to achieve 10ºF, 20ºF, and 30ºF changes in water temperature.

Cooling Tower Evaporation at 10 intervals at 1000 GPM Circulation Rate

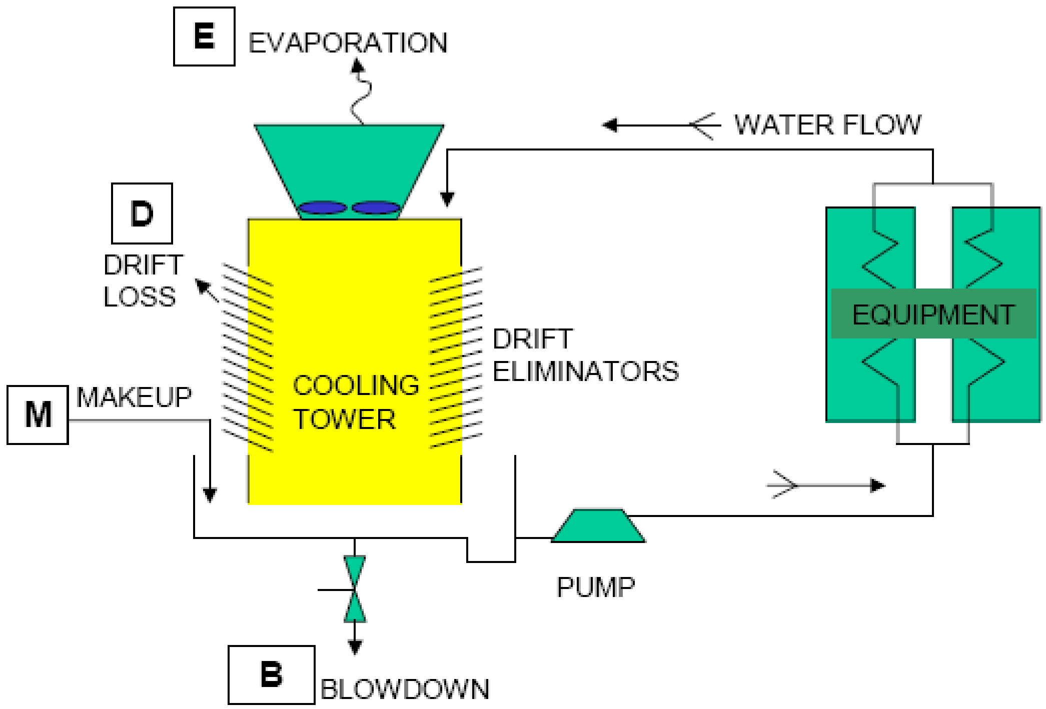
Temperature Reduction	Water Evaporated		
	Per Minute	Per Day	Per Year
10ºF	10 GAL	14,400 GAL	5,256,000 GAL
20ºF	20 GAL	28,800 GAL	10,512,000 GAL
30ºF	30 GAL	43,200 GAL	15,768,000 GAL

* System operates 24 hrs/day; 365 days a year

Makeup Water

We have learnt that it takes about 1% evaporation per each 10ºF temperature reduction. In the process of evaporation at the tower, only pure water is discharged into the atmosphere as water vapor. All the hardness and other dissolved solids of the water are left behind.

The schematic below highlight the water use of a typical cooling tower.



Pure water vapor is lost from the systems by evaporation (E), leaving behind all of the solids present in the recirculation water (R). The concentration of dissolved minerals eventually builds up and tends to increase beyond acceptable levels leading to 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

To stay below this maximum acceptable concentration and to maintain the tower's water balance, new water needs to be added to the cooling tower called makeup water [M] and a portion of the concentrated cooling tower water needs to be discharged from the cooling tower called blowdown or bleed [B]. Blowdown (B) is the controlled discharge of recirculating water to waste that is necessary to limit the amount of solids and biological matter in the cooling tower by removing a portion of the concentrated solids. Some water is also lost by droplets being carried out with the exhaust air called Drift [D] which is usually 0.01 -0.3% of the recirculation rate for a mechanical draft tower. The lower drift loss at 0.01 % is common for a modern tower.

It is helpful to examine the water balance of the system. The amount of water that enters as makeup [M] must be equal to the total water that exits the system or Makeup [M] is the sum of evaporation [E], blowdown, [B], drifts [D] and any leakage [L] to maintain a steady water level.

M = E + B + D + L

Note that

- Blowdown (B) is controlled discharge of recirculating water
- Drift (D) is the recirculating water entrained in the air flow discharged to the atmosphere. This is 0.01 -0.3% of the recirculation rate for a mechanical draft tower. The lower drift loss at 0.01 % is common for a modern tower
- Leakage (L) is the unintentional loss of water

Usually water volume losses due to leaks and drift are insignificant. Ignoring leaks and drift, the makeup water equation is

M = E + B

SECTION 15 – COOLING WATER TREATMENT

The makeup water used in cooling systems contains dissolved minerals, suspended solids, debris, bacteria and other impurities. Among other dissolved solids, water contains calcium and magnesium salts -- commonly referred to as "Hardness." These salts have only limited solubility -- that is, only a certain amount will be soluble in a given volume of water. Water is capable of dissolving a wide variety of solids and gases in infinite combinations and amounts. As the water continues to circulate throughout the system, the contaminants begin to concentrate.

There is another problem with cooling towers; this occurs when air is brought into intimate contact with the cooling water as it passes over the cooling tower. Because of pollution, the air contains a wide variety of impurities -- both solids and gases. As it passes through the water in a cooling tower, the air is effectively "scrubbed," and the impurities are transferred to the water. Thus, the dirt picked up from the air along with precipitated Hardness and suspended solids make up the major cooling tower water contaminants.

Another problem results when the moist surfaces of the tower are exposed to sunlight. This promotes the growth of algae, bacteria and fungal slime. Large masses of slime or algae growth can accumulate rapidly, causing clogging, reduced flow, and reduced heat transfer. This "fouling" must be prevented.

The operating efficiency of a cooling tower system is adversely affected by scaling, corrosion and organic fouling. Effective cooling water operation and treatment can prevent such an occurrence.

A major objective of a cooling tower treatment program is to keep the water quality sufficient to prevent scaling, corrosion and biological fouling that can affect normal productive operations. The problem of water impurity is controlled in two ways:

1) By introduction of chemicals, which prevent the dissolved solids from precipitating as scale...and which prevent corrosion

2) By bleed-off, which limits the solids concentration at a level which can be successfully handled by chemical treatment

Cycles of Concentration

Material balance for a cooling system is essential in order to detect fouling or precipitation and to determine treatment chemical feed rates. One way of evaluating how efficiently a cooling tower is using water is to compare the dissolved solids concentration in the make-up and the blow-down. Cycles of concentration (COC) is defined as the ratio of the concentration of dissolved solids (i.e., chlorides, sulfates, etc.) in the recirculating water to the concentration found in the entering makeup water. The higher the COC, the lower the bleed rate required. 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’.

The cycles of concentration (COC) are determined by dividing the makeup by the wastage [M/W].

1. Makeup [M] = water losses evaporation [E] + blowdown [B] + drift [D] + leakage [L]

2. Waste [W] = blowdown [B] + drift [D] + leakage [L]

3. Cycles of concentration [COC] = makeup / wastage or

   COC = [E+B+D + L]/ [B + D + L]

All values are expressed in GPM.

Neglecting small leakage and drift loss

COC = [E+B]/ [B]

The higher the cycles of concentration, the more efficient its water use. When the cycle of concentration is left at one (i.e. not concentrated), all water left in the tower after evaporation needs to be removed as blowdown. This is called single pass or once-through cooling and is prohibited in many states especially where potable water is used.

Bleed-Off

The amount of blowdown water wasted in cooling tower depends on hardness of the circulating water. To maintain the cooling system water at a specific number of cycles of concentration, a regulated rate of bleed-off of tower water must occur. If the cycle of concentration is increased, only a portion of water is discharged as blowdown and the rest is recirculated with more new water to make up for the water loss in the blowdown. At three cycles of concentration, bleed-off is one-third of the makeup water volume. At four cycles of concentration, the bleed-off rate is one-fourth the makeup water, etc. The balance of the makeup (not leaving the system via the bleed-off drain) is evaporative loss. The actual rate of evaporation is easily computed. If two of the following factors are known this equation can be completed. The following equations quantify the relationships of blowdown, evaporation, and the cycles of concentration based on mass balancing:

COC = [E+B]/ [B]

COC = E/B + 1

COC – 1 = E/B

B = E / [COC – 1]

Thus, Bleed Rate: ***(Evaporation Rate*** $_{GPM}$ ***/ (Cycles-1)***

Also

Makeup Volume = Blowdown Volume + Evaporation Volume

M = B + E

M = E / [COC – 1] + E

M = E x [COC / (COC – 1)]

Thus, Make-up Water: ***(Evaporation Rate*** $_{GPM}$ ***X [Cycles/ (Cycles-1)])***

In Field COC Determination

In lab, COC is generally determined by some very soluble ion, such as chloride in the makeup to re-circulating water. To measure cycles of concentration, the chloride content of the tower water and the chloride content of the raw water are compared as follows:

$$\text{Cycles of Concentration} = \frac{\text{tower water chloride}}{\text{raw water chloride}}$$

For example, if the chloride content of the tower water is 120ppm and the raw water chloride is 40ppm, the cooling tower system is operating at three (3) cycles of concentration.

EXAMPLE:

Chloride tests have shown three cycles of concentration. Bleed has been measured at the rate of 8 GPM. Therefore:

B = E / (COC-1)

E = B x (COC -1)

E = 8 x 2

E = 16

And we can say that evaporation is 16 GPM and makeup (E + B) = 24 GPM.

If the rate of evaporation never fluctuated, there would be no need to change the rate of bleed-off. But more water evaporates at 2:00 p.m. on a hot day than at midnight on the same day. All three factors of tower management (evaporation - bleed - makeup) change as the "demand" increases or decreases.

Care must be used to pick a constituent that is not affected by treatment chemicals or contaminants and that is also stable. Chloride is the most accurate titration to use for this purpose because:

1) Chloride is present in all raw water.

2) Chloride is the most soluble of the dissolved solids in water, and the last to precipitate; therefore, no other solid will concentrate more. This assures the accuracy of your measurement.

3) No chloride is used in our treatment compounds; therefore, the titrations are not influenced by the presence of chemical treatment.

In field application, conductivity/TDS is normally used for determining bleed-off frequency. Conductivity of water increases in direct proportion to the solids concentration. In field application, electronic conductive meter is used to measure the conductivity (TDS) of the make-up water and then set to initiate a bleed cycle when the system conductivity (TDS) reaches a value equal to the set cycles. Where proper treatment practices are carried out, the total dissolved solids (TDS) of the circulating water in open circuit is not allowed exceeding 2500ppm so that the corrosion and scaling problems are kept under control. Therefore with this concept, when the make-up water TDS is 800ppm and maximum allowable TDS in circulating water is 2500ppm, the system is not permitted to operate at more than 2500/800 = 3.1 cycles of concentration.

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.

Chemical Treatment

1) <u>Scale Prevention</u> – The principle scale forming ingredient in cooling water is calcium carbonate, which has a solubility of about 15 ppm and is formed by the decomposition of calcium bicarbonate. The maximum amount of calcium bicarbonate that can be held in solution depends upon the temperature and the free carbon dioxide content of the water. Raising the temperature or reducing the free carbon dioxide at the point of equilibrium, will result in the deposition of scale.

   Scale is prevented by controlling blowdown to keep the concentration of soluble and scale forming solids below a limit. The amount of blowdown water wasted in cooling tower depends on hardness of the circulating water. Softening the make up water with lime and soda ash, zeolite or some of the several phosphates keep scale formation in control.

   If agents (such as sulfuric acid) are added to convert a portion of the calcium bicarbonate to calcium sulfate, the resultant concentration of calcium sulfate should not be allowed to exceed 1200 ppm (expressed as $CaCO_3$). Otherwise sulfate scale may begin to form, which is very dense and quite difficult to remove. The other chemicals used are organic phosphates, polyphosphates, and polymer compounds.

2) Corrosion Control – The metals utilized in a cooling tower are susceptible to corrosion in varying degrees. Since most water system corrosion occurs as a result of electrolytic action, an increase in the dissolved solids increases the conductivity and the corrosion potential. This is particularly true of the chloride and sulfate ions. Therefore, blowdown is a very useful tool in the fight against corrosion. Also, corrosion must be overcome by chemically neutralizing the acidity which has been picked up by air pollution, or which is present in the makeup water. The common corrosion inhibiters used for cooling water treatment are:

Chromates, Nitrites, Orthophosphates, and Silicates --- all anodic type

Bicarbonates, Metal cations, Polyphosphates ----all cathodic type

3) Control of Biological Growth - Organic fouling and algae formation in cooling tower is controlled by adding chlorine, copper sulphate, potassium permanganate etc. to the circulating water. Chlorine is one of the most widely used, cost effective biocides and is available in liquid, gaseous or solid form. Its effectiveness is increased when used with non-oxidizing biocides and biological dispersants. Ozone is now a day widely used to curb microbial growth.

4) Foaming and Discoloration – Heavy foaming can sometimes occur when a new tower is put into operation. This type of foaming usually subsides after a relatively short operating period. Persistent foaming can be caused by the concentrations of certain combination of the circualting water with foam causing compounds. This type of foaming is often alleviated by increasing the rate of blowdown. In extreme cases, foam depressant chemicals must be added to the system.

Cooling Water Conservation

Increasing the cycles of concentration to optimize water use is the most common water conservation measure for cooling towers.

Determining the optimum value for ‘Cycles’ is a bit elusive and is a balancing act between the reduced chemical, water, and sewage costs at higher cycles of concentration versus the increased risk of scale formation. Usually, cooling towers using makeup water with the least amount of solids should be operated at the higher cycles of concentration. If it is unknown the default figure is usually 5.

Note that a high value of COC leads to reduced chemical, water and sewage costs but introduces an increased risk of scale formation and the analysis of the water quality in the cooling tower becomes more critical.

Example

Example below illustrates water savings from increasing the cycles of concentration.

A cooling tower system circulates water at the rate of 1,000gpm and the cooling tower needs to cool the warmed water exiting the heat exchanger from 90ºF to 80ºF degrees (or reduce the temperature of the water by 10ºF). The cooling tower currently operates at 2 COC. How much water can be saved by increasing the cycles of concentration to 3, 4, 6 and 10?

We have learnt -

1. Bleed Rate: *(Evaporation Rate $_{GPM}$ / (Cycles-1)*
2. Make-up Water Requirement: *(Evaporation Rate $_{GPM}$ X [Cycles/(Cycles-1)])*

Cooling Tower Water Use

(1000gpm circulating rate, 10ºF Temperature Reduction)

COC	Evaporation @ 1% for 10ºF range	Blowdown [E ÷ (COC-1)]	Water Added to System (Gallons)			%age water saved
			Per min	Per day	Per year	
2	10 gpm	10 gpm	20 gpm	28,800	10,512,000	-
4	10 gpm	3.3 gpm	13.3 gpm	19,152	6,990,480	33.5%
6	10 gpm	2.0 gpm	12 gpm	17,280	6,207,200	41%
10	10 gpm	1.1 gpm	11.1 gpm	15,984	5,834,160	44.5%

Reduction in Treatment Chemical Costs

The 1,000 gpm cooling system evaluated in the examples above can be expected to use 8,761 pounds of treatment chemicals per year at two cycles of concentration. By reducing the amount of makeup water, fewer pounds of treatment chemicals are required. Increasing the cycles of concentration from two to four could save $7,338 per year in chemical costs; increasing the cycles of concentration from two to six could save $8,980 per year. (Assumes chemical costs at $2.50/lb, and maintenance of 100 ppm treatment in the cooling tower water.)

SECTION 16 – COOLING TOWER OPERATION IN FREEZING WEATHER

Cooling towers used in freezing climates are prone to ice formation, which may jeopardize the operations. Unacceptable ice can be categorized as either a significant amount of ice that has formed on the fill thus obstructing the heat transfer or excessive ice in a support region which may threaten the tower structure. There are three potential causes for ice formation:

Causes:

1) The potential of ice varies directly with the quantity of air flowing through the tower. Reducing the air flow retards the formation of ice.

2) Where air flow is uncontrolled, the potential for ice formation varies inversely with the heat load imposed on the tower. A reduced heat load increases the probability that unacceptable ice will form.

3) The potential for ice varies inversely with the amount of water flowing over the fill. A reduced pumping rate increases the likelihood of unacceptable ice formation.

Remedies:

Air-Side Control - Reducing the air flow rate not only helps in retarding the formation of ice but also helps in reduction or elimination of ice already formed. Single speed fans afford the least opportunity for airflow variation. Two speed fan motors offer better operating flexibility and should be the minimum mandatory requirement for towers used in freezing climates. Best ice control is achieved by the use of automatic variable pitch (AVP) fans or use of variable speed fan motors. Ultimately, severe ice formation may require that the fans be reversed for a period of time. This causes the falling water pattern to be shifted outward, bringing a deluge of relatively warm water in contact with ice formations for rapid melting. This reverse mode is recommended only for short duration due to possibility of ice formation on the fan cylinders, fan blades and mechanical equipment.

Water-Side Control – Since the potential for freezing on the fill depends so much upon the incoming water temperature, provision for total water by-pass directly into the cold water basin is advisable on mechanical draft towers and mandatory on natural draft towers (due to absence of air control). By-pass mode should be continued until the total water inventory (including that in the basin) reaches an acceptable level of usually 80°F. Modulation of by-pass whereby a portion of water is allowed to continue over the fill should be discouraged unless very fine air-side control is maintained and 2) the water distribution system has the capability to concentrate water flow to the outboard portions of the fill.

Prevention of Basin Freezing

Cooling tower installations particularly those undergo periods of shutdown (night time, weekends, holidays, interims of schedule or unscheduled maintenance etc) are susceptible to freezing the cold water basin, as well all exposed piping. Several effective methods are utilized to prevent freezing, among which are the following:

1) **System Draining** – Entire system draining may be considered for small installations, particularly those on which the cooling tower represents the highest point of the circulating water system. Off course don’t forget to check the local environmental codes. The exposed portions of the piping must be traced with electric heating cable.

2) **Indoor Tank Method** – This method, also referred to as “dry basin operation” allows water in the tower’s cold water basin to drain continuously into an indoor storage tank.

3) **Electric Immersion Heater Method** – Determine the potential heat loss from the basin taking into account the volume of water, ambient temperature and wind velocity and estimate the size of immersion heater from the formula: Heater kW = Heat loss (Btu/hr) / 3412 (Btu/hr per kWh).

4) **Steam Heating Method** – Steam, if available, may be utilized to supply heat to an inoperative basin. It may be injected directly into the basin water thorough a commercially available steam muffler or condensate may be recovered by the use of a closed pipe loop installed in the basin.

5) **By-pass Circulation Method** – Running water never freezes. By-pass lines are utilized to create a circulation loop independent of both the main pump and the cooling tower distribution system. This is one of the better schemes for any installation, regardless of size, because it protects not only the cooling tower basin, but the exposed piping as well.

SECTION 17 – COOLING TOWER TESTING

Evaluation of cooling tower performance is based on cooling of a specified quantity of water through a given range and to a specified temperature approach to the wet-bulb or dry-bulb temperature for which the tower is designed. 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. Because exact design conditions are rarely experienced in operation, estimated performance curves are frequently prepared for a specific installation, and provide a means for comparing the measured performance with design conditions.

For this reason, the performance testing of small factory assembled cooling towers is seldom done. These designs just carry certification of compliance to CTI Standard STD-201D. Certification is important, since even small deviations from the expected design have a substantial impact on the system over time. For instance, a cooling tower that is 20% deficient elevates the leaving water temperature by approximately 2.5°F. Typically, this higher water temperature will result in 6% more energy. For instance in HVAC applications, a 500-ton chiller with energy rating of 2197 kW during peak conditions, this penalty translates into approximately 17 kW of additional energy usage. The certification stamp offered by CTI guarantees the performance by reviewing, evaluating and time testing manufacturer’s submitted product offering and capacity 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.

Field Erected Cooling Tower Performance

Large projects use field erected cooling towers where unique designs and field assembly practices necessitates performance testing. All field erected cooling towers should be specified with a specific test and penalties for failure clearly laid-out in advance. The performance testing is based on the criteria set forth by Acceptance Test Code (ATC-105) published by the Cooling Technology Institute

(CTI) and by American Society of Mechanical Engineers (ASME) Power Test Code for Atmospheric Cooling Equipment (PTC-23).

Testing Parameters

Test data required for the performance evaluation of a mechanical draft cooling tower includes: water flow rate, hot and cold water temperatures, entering wet bulb temperature, fan power and wind speed. The testing of a natural draft tower must also include the dry-bulb temperature but, of course, omits the need for fan power data. Make-up and blowdown water quantities and temperatures, as well as any miscellaneous water sources may need to be measured, depending upon their effect upon the aforementioned primary variables. Most testing done today is conducted using data acquisition systems to measure the temperatures.

1) Temperature Measurements – Air temperatures include both the wet bulb and dry bulb temperatures. Wet bulb temperatures should be measured with mechanically aspirated psychrometers, although sling type psychrometers do afford an alternate accurate means of measuring this variable. All precautions stated in ASME or CTI Test Codes must be exercised. Dry bulb temperatures are measured with thermometers, RTDs, or thermistors. It is also very important to recognize the difference between an ambient and entering wet bulb test. Both ASME and CTI recommend that towers be sized and tested based on entering wet bulb temperatures. The entering wet bulb temperature attempts to measure the average temperature of all the air entering the tower regardless of its source. Should mercury-in-glass thermometers be utilized, the major difference is that less data will be taken and the parameters will typically be measured sequentially.

2) Water Temperature – Water temperatures are measured with thermometers, RTDs or thermistors. The hot water temperature is normally taken in the distribution basin (cross-flow towers) or in a tap in the piping carrying water to the tower. The cold water temperatures from the tower can vary considerably throughout the collection basin, therefore, care must be taken to select a point of measurement where thorough mixing has occurred. The pump discharge is generally considered to be satisfactory location.

3) Flow Measurements - To measure the water flow rate, a pitot tube traverse of the piping carrying water to the tower is the most preferred method. Other acceptable means for flow measurements include the orifice plate, venture tube and flow nozzle, all of which also require laboratory calibration.

4) Power Measurements - A wattmeter is used to measure pump and fan input power on mechanical draft tower systems up to 600 volts. Above 600 volts alternate means must be identified.

In addition, any other factor affecting the towers operation or the data taken must be accounted for. Examples may include pump discharge pressure, make-up flow and temperature, blow-down flow and temperature, auxiliary streams entering the collection basin, etc.

Operating Conditions during Test

Current ASME and CTI Test Codes suggest the following limitations to variations from design to be observed during testing:

Water Rate	±10% of design
Cooling Range	±20% of design
Heat Load	±20% of design
Wet-bulb Temperature	±10°F of design (CTI Test Code)
	+5°F, -15°F of design (ASME Test Code)
Dry-bulb Temperature	±20°F of design
Wind Velocity	generally less than 10 mph
Fan Power	±10% of design

There will be times when operating or atmospheric conditions will not permit a test to be performed within above limits. While it is preferable to comply with all these limitations, it is not always possible. Testing, however, can proceed by mutual agreement among responsible test parties, provided test conditions are covered by the manufacturer's performance curves.

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.

For details refer to CTI at www.cti.org and ASME PCT-23 www.asme.org/cns

SECTION 18- 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

SECTION 19 – EXAMPLE

A Tower cools 1000 GPM from 95º F to 85º F at 72º F wet bulb temperature and operates at 3 cycles of concentration. Calculate Range, Approach, Heat rejection, Drift loss, Evaporation rate, Bleed rate and Make up water requirements.

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

Course Summary

Evaporative water-cooled systems, whether open or closed-circuit, are the best overall heat rejection solution for most installations. These systems offer design flexibility, save energy, and conserve resources while protecting and respecting the environment.

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.

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. The cooling tower industry continues to develop innovative products and services to meet the evolving needs of new and existing facilities.

GLOSSARY

The following terms are commonly used in cooling tower science, many of which are unique to the cooling tower industry:

1) **ACFM** - The actual volumetric flow rate of air-vapor mixture, cubic feet of air moved per minute. Unit: cu ft per min

2) **Air Horsepower** - The power output developed by a fan in moving a given air rate against a given resistance. Unit: hp. Symbol: AHP

3) **Air Inlet** - Opening in a cooling tower through which air enters; sometimes referred to as the louvered face on induced draft towers.

4) **Air Rate** - Mass flow of dry air per square foot of cross - sectional area in the tower's heat transfer region per hour. Unit: lb per sq ft per hr. Symbol: G'.(See Total Air Rate).

5) **Air Travel** - Distance which air travels in its passage through the fill. Measured vertically on counter-flow towers and horizontally on cross-flow towers. Unit: ft.

6) **Air Velocity** - Velocity of air-vapor mixture through a specific region of the tower (i.e. the fan). Unit: ft per min. Symbol: V

7) **Ambient Wet-Bulb Temperature** - The wet-bulb temperature of the air encompassing a cooling tower not including any temperature contribution by the tower itself. Generally measured upwind of a tower in a number of locations sufficient to account for all extraneous sources of heat. Unit: °F. Symbol: AWB

8) **Approach** - Difference between the cold water temperature and either the ambient or entering wet-bulb temperature. (CW-EWB=A) Unit: ºF

9) **Atmospheric** - Refers to the movement of air through a cooling tower purely by natural means, or by the aspirating effect of water flow.

10) **Automatic Variable-Pitch Fan** - A propeller type fan whose hub incorporates a mechanism which enables the fan blades to be re-pitched simultaneously and automatically. They are used on cooling towers and air-cooled heat exchangers to trim capacity and/or conserve energy.

11) **Basin** - See "Collection Basin" and "Distribution Basin".

12) **Basin Curb** - Top level of the cold water basin retaining wall; usually the datum from which pumping head and various elevations of the tower are measured.

13) **Bay** - The area between adjacent transverse and longitudinal framing bents.

14) **Bent** - A transverse or longitudinal line of structural framework composed of columns, girts, ties, and diagonal bracing members.

15) **Bleed-Off** or **Blowdown** - Water discharged from the system to control concentrations of salts or other impurities in the circulating water. Units % of circulating water rate or gpm.

16) **Blower** - A squirrel-cage (centrifugal) type fan; usually applied for operation at higher-than-normal static pressures.

17) **Blow-out -** Water droplets blown out of the cooling tower by wind, generally at the air inlet openings. Water may also be lost, in the absence of wind, through splashing or misting. Devices such as wind screens, louvers, splash deflectors and water diverters are used to limit these losses.

18) **Brake Horsepower** - The actual power output of a motor, turbine, or engine. Unit: hp. Symbol: bhp.

19) **BTU (British Thermal Unit)** - The amount of heat gain (or loss) required to raise (or lower) the temperature of one pound of water one degree (1º) F

20) **Capacity** - The amount of water (gpm) that a cooling tower will cool through a specified range, at a specified approach and wet-bulb temperature. Unit: gpm.

21) **Casing** - Exterior enclosing wall of a tower exclusive of the louvers.

22) **Cell** - Smallest tower subdivision which can function as an independent unit with regard to air and water flow; it is bounded by either exterior walls or partition walls. Each cell may have one or more fans and one or more distribution systems.

23) **CFM** - The volumetric flow rate of air-vapor mixture, cubic feet of air moved per minute. Unit: cu ft per min.

24) **Chimney** - See "Shell".

25) **Circulating Water Rate** - Quantity of hot water entering the cooling tower. Unit: gpm.

26) **Cold Water Temperature** - Temperature of the water leaving the collection basin, exclusive of any temperature effects incurred by the addition of make-up and/or the removal of blowdown. Unit: °F. Symbol: CW.

27) **Collection Basin** - Vessel below and integral with the tower where water is transiently collected and directed to the sump or pump suction line.

28) **Counter-flow** - Air flow direction through the fill is countercurrent to that of the falling water.

29) **Crossflow** - Air flow direction through the fill is essentially perpendicular to that of the falling water.

30) **Distribution Basin** - Shallow pan-type elevated basin used to distribute hot water over the tower fill by means of orifices in the basin floor. Application is normally limited to crossflow towers.

31) **Distribution System** - Those parts of a tower beginning with the inlet connection which distribute the hot circulating water within the tower to the points where it contacts the air for effective cooling. May include headers, laterals branch arms, nozzles, distribution basins, and flow-regulating devices.

32) **Double-Flow** - A crossflow cooling tower where two opposed fill banks are served by a common air plenum.

33) **Drift** - Circulating water lost from the tower as liquid droplets entrained in the exhaust air stream. Units: % of circulating water rate or gpm.

34) **Drift Eliminators** - An assembly of baffles or labyrinth passages through which the air passes prior to its exit from the tower, for the purpose of removing entrained water droplets from the exhaust air.

35) **Driver** - Primary drive for the fan drive assembly.

36) **Dry-Bulb Temperature** - The temperature of the entering or ambient air adjacent to the cooling tower as measured with a dry-bulb thermometer. Unit: ºF. Symbol: DB.

37) **Entering Wet-Bulb Temperature** - The wet-bulb temperature of the air actually entering the tower, including any effects of recirculation. In testing, the average of multiple readings taken at the air inlets to establish a true entering wet-bulb temperature. Unit ºF. Symbol: EWB.

38) **Evaluation** - A determination of the total cost of owning a cooling tower for a specific period of time. Includes first cost of tower and attendant devices, cost of operation, cost of maintenance and/or repair, cost of land use, cost of financing, etc., all normalized to a specific point in time.

39) **Evaporation Loss** - Water evaporated from the circulating water into the air stream in the cooling process. Units: % of circulating water rate or gpm.-

40) **Exhaust (Exit) Wet-Bulb Temperature** - See "Leaving Wet-Bulb Temperature".

41) **Fan Cylinder** - Cylindrical or venturi-shaped structure in which a propeller fan operates. Sometimes referred to as a fan "stack" on larger towers.

42) **Fan Deck** - Surface enclosing the top structure of an induced draft cooling tower, exclusive of the distribution basins on a crossflow tower.

43) **Fan Pitch** - The angle which the blades of a propeller fan make with the plane of rotation, measured at a prescribed point on each blade. Unit: degrees.

44) **Fan Scroll** - Convolute housing in which a centrifugal (blower) fan operates.

45) **Fill** - That portion of a cooling tower which constitutes its primary heat transfer surface. Sometimes referred to as "packing".

46) **Fill Cube -** (1) Counterflow: The amount of fill required in a volume one bay long by one bay wide by an air travel high. Unit: cu ft. (2) Crossflow: The amount of fill required in a volume one bay long by an air travel wide by one story high. Unit: cu ft.

47) **Fill Deck** - One of a succession of horizontal layers of splash bars utilized in a splash-filled cooling tower. The number of fill decks constituting overall fill height, as well as the number of splash bars incorporated within each fill deck, establishes the effective primary heat transfer surface.

48) **Fill Sheet** - One of a succession of vertically-arranged, closely-spaced panels over which flowing water spreads to offer maximum surface exposure to the air in a film-filled cooling tower. Sheets

may be flat, requiring spacers for consistent separation; or they may be formed into corrugated, chevron, and other patterns whose protrusions provide proper spacing, and whose convolutions provide increased heat-transfer capability.

49) **Film-Filled** - Descriptive of a cooling tower in which film-type fill is utilized for the primary heat-transfer surface.

50) **Float Valve** - A valve which is mechanically actuated by a float. Utilized on many cooling towers to control make-up water supply.

51) **Flow-Control Valves** - Manually controlled valves which are used to balance flow of incoming water to all sections of the tower.

52) **Flume** - A trough which may be either totally enclosed, or open at the top. Flumes are sometimes used in cooling towers for primary supply of water to various sections of the distribution system.

53) **Fogging** - A reference to the visibility and path of the effluent air stream after having exited the cooling tower. If visible and close to the ground it is referred to as "fog". If elevated it is normally called the "plume".

54) **Forced Draft** - Refers to the movement of air under pressure through a cooling tower. Fans of forced draft towers are located at the air inlets to "force" air through the tower.

55) **Heat Load** - Total heat to be removed from the circulating water by the cooling tower per unit time. Units: Btu per min. or Btu per hr.

56) **Height** - On cooling towers erected over a concrete basin, height is measured from the elevation of the basin curb. "Nominal" heights are usually measured to the fan deck elevation, not including the height of the fan cylinder. Heights for towers on which a wood, steel, or plastic basin, is included within the manufacturer's scope of supply are generally measured from the lowermost point of the basin, and are usually overall of the tower. Unit: ft.

57) **Horsepower** - The power output of a motor, turbine, or engine (also see Brake Horsepower). Unit: hp. Symbol: hp.

58) **Hot Water Temperature** - Temperature of circulating water entering the cooling tower's distribution system. Unit: F. Symbol: HW.

59) **Hydrogen Ion Concentration** - See "pH".

60) **Induced Draft** - Refers to the movement of air through a cooling tower by means of an induced partial vacuum. Fans of induced draft towers are located at the air discharges to "draw" air through the tower.

61) **Inlet Wet-Bulb Temperature** - See "Entering Wet-Bulb Temperature".

62) **Interference** - The thermal contamination of a tower's inlet air by an external heat source. (i.e. the discharge plume of another cooling tower.)

63) **Leaching -** The loss of wood preservative chemicals by the washing action of the water flowing through a wood structure cooling tower.

64) **Leaving Wet-Bulb Temperature** - Wet-bulb temperature of the air discharged from a cooling tower. Unit: F. Symbol: LWB.

65) **Length** - For crossflow towers, length is always perpendicular to the direction of air flow through the fill (air travel), or from casing to casing. For counterflow towers, length is always parallel to the long dimension of a multi-cell tower, and parallel to the intended direction of cellular extension on single-cell towers. Unit: ft.

66) **Liquid-to-Gas Ratio** - A ratio of the total mass flows of water and dry air in a cooling tower. (See Total Air Rate & Total Water Rate) Unit: lb per lb. Symbol: L/G.

67) **Longitudinal** - Pertaining to occurrences in the direction of tower length.

68) **Louvers** - Blade or passage type assemblies installed at the air inlet face of a cooling tower to control water splashout and/or promote uniform air flow through the fill. In the case of film-type crossflow fill, they may be integrally molded to the fill sheets.

69) **Make-Up** - Water added to the circulating water system to replace water lost by evaporation, drift, windage, blowdown, and leakage. Units: % of circulating water rate or gpm.

70) **Mechanical Draft** - Refers to the movement of air through a cooling tower by means of a fan or other mechanical device.

71) **Module** - A preassembled portion or section of a cooling tower cell. On larger factory-assembled towers two or more shipped modules may require joining to make a cell.

72) **Natural Draft** - Refers to the movement of air through a cooling tower purely by natural means. Typically, by the driving force of a density differential.

73) **Net Effective Volume** - That portion of the total structural volume within which the circulating water is in intimate contact with the flowing air. Unit: cu ft.

74) **Noise -** Sound energy emitted by a cooling tower and heard (recorded) at a given distance and direction. The sound is generated by the impact of falling water, by the movement of air by fans, the fan blades moving in the structure, and the motors, gearboxes or drive belts.

75) **Nozzle** - A device used for controlled distribution of water in a cooling tower. Nozzles are designed to deliver water in a spray pattern either by pressure or by gravity flow.

76) **Packing** - See "Fill".

77) **Partition** - An interior wall subdividing the tower into cells or into separate fan plenum chambers. Partitions may also be selectively installed to reduce windage water loss.

78) **Performance** - See "Capacity".

79) **pH** - A scale for expressing acidity or alkalinity of the circulating or make-up water. A pH below 7.0 indicates acidity and above 7.0 indicates alkalinity. A pH of 7.0 indicates neutral water.

80) **Pitot Tube** - An instrument that operates on the principle of differential pressures and is used to measure fluid flow.

81) **Plenum Chamber -** The enclosed space between the drift eliminators and the fan in induced draft towers, or the enclosed space between the fan and the fill in forced draft towers.

82) **Plume** - The stream of saturated exhaust air leaving the cooling tower. The plume is visible when water vapor it contains condenses in contact with cooler ambient air, like the saturated air in one's breath fogs on a cold day. Under certain conditions, a cooling tower plume may present fogging or icing hazards to its surroundings. Note that the water evaporated in the cooling process is "pure" water, in contrast to the very small percentage of drift droplets or water blown out of the air inlets.

83) **Psychrometer** - An instrument incorporating both a dry-bulb and a wet-bulb thermometer, by which simultaneous dry-bulb and wet-bulb temperature readings can be taken.

84) **Pump Head** - See "Tower Pumping Head".

85) **Range** - Difference between the hot water temperature and the cold water temperature (HW - CW = R) Unit: F.

86) **Recirculation** - Describes a condition in which a portion of the tower's discharge air re-enters the air inlets along with the fresh air. Its effect is an elevation of the average entering wet-bulb temperature compared to the ambient.

87) **Riser** - Piping which connects the circulating water supply line, from the level of the base of the tower or the supply header, to the tower's distribution system. Shell - The chimney-like structure, usually hyperbolic in cross-section, utilized to induce air flow through a natural draft tower. Sometimes referred to as a "stack" or "veil".

88) **Speed Reducer** - A mechanical device incorporated between the driver and the fan of a mechanical draft tower, designed to reduce the speed of the driver to an optimum speed for the fan. The use of geared reduction units predominates in the cooling tower industry, although smaller towers will utilize differential pulleys and V-belts for the transmission of relatively low power.

89) **Splash Bar** - One of a succession of equally-spaced horizontal bars comprising the splash surface of a fill deck in a splash-filled cooling tower. Splash bars may be flat, or may be formed into a shaped cross-section for improved structural rigidity and/or improved heat transfer capability. When flat, they are sometimes referred to as "slats" or "lath".

90) **Splash-Filled** - Descriptive of a cooling tower in which splash-type fill is used for the primary heat transfer surface.

91) **Spray-Filled** - Descriptive of a cooling tower which has no fill, with water-to-air contact depending entirely upon the water break-up and pattern afforded by pressure spray nozzles.

92) **Stack** - An extended fan cylinder whose primary purpose is to achieve elevation of the discharge plume.

93) **Stack Effect** - Descriptive of the capability of a tower shell or extended fan cylinder to induce air (or aid in its induction) through a cooling tower.

94) **Standard Air** - Air having a density of 0.075 lb per cu ft; essentially equivalent to 70ºF dry air at 29.92 in Hg barometric pressure.

95) **Story** - The vertical dimension between successive levels of horizontal framework ties, girts, joists, or beams. Story dimensions vary depending upon the size and strength characteristics of the framework material used. Unit: ft.

96) **Sump** - A depressed chamber either below or alongside (but contiguous to) the collection basin, into which the water flows to facilitate pump suction. Sumps may also be designed as collection points for silt and sludge to aid in cleaning.

97) **Total Air Rate** - Total mass flow of dry air per hour through the tower. Unit: lb per hr. Symbol: G.

98) **Total Water Rate** - Total mass flow of water per hour through the tower. Unit: lb per hr. Symbol: L.

99) **Tower Pumping Head** - The static lift from the elevation of the basin curb to the centerline elevation of the distribution system inlet plus the total pressure (converted to ft of water) necessary at that point to effect proper distribution of the water to its point of contact with the air. Unit: ft of water.

100) **Transverse** - Pertaining to occurrences in the direction of tower width.

101) **Velocity Recovery Fan Cylinder** - A fan cylinder on which the discharge portion is extended in height and outwardly flared. Its effect is to decrease the total head differential across the fan, resulting in either an increase in air rate at constant horsepower, or a decrease in horsepower at constant air rate.

102) **Water Loading** - Circulating water rate per horizontal square foot of fill plan area of the cooling tower. Unit: gpm per sq ft.

103) **Water Rate** - Mass flow of water per square foot of fill plan area of the cooling tower per hour. Unit: lb per sq ft per hr. Symbol: L.

104) **Wet-Bulb Temperature** - The temperature of the entering or ambient air adjacent to the cooling tower as measured with a wet-bulb thermometer. Unit: F. Symbol: WB.

105) **Wet-Bulb Thermometer** - A thermometer whose bulb is encased within a wetted wick.

106) **Windage** - Water lost from the tower because of the effects of wind. Sometimes called "blowout".

107) **Wind Load** - The load imposed upon a structure by a wind blowing against its surface. Unit: lb per sq ft.