KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	KLM Technology Group www.klmtechgroup.com	Page : 1 of 52 Rev: 01 July 2011
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	**COOLING TOWER SELECTION AND SIZING (ENGINEERING DESIGN GUIDELINE)**	Author: Viska Mulyandasari Checked by: Karl Kolmetz

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INTRODUCTION

Scope

This design guideline assists engineers to understand the basic principles of cooling towers. Cooling towers are commonly used to remove excess heat that is generated in places such as power stations, chemical plants and even domestically in air conditioning units. This equipment has recently developed into an important part of many chemical plants. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water.

Cooling towers might be classified into several types based on the air draft and based on the flow pattern. Each type of cooling tower has its own advantages and disadvantages; thus the proper selection is needed based on the system operation. Besides, the material selection of cooling tower is also important. Cooling towers tends to be corrosive since it always has direct contact with the water. Proper material selection or additional water treatment is then needed to keep the cooling tower safe.

Some theories are needed to be understood before an engineer start to sizing a cooling tower. Cooling tower process is generally related with vapor pressure of water and humidity. Those theories are briefly described in this guideline to provide the basic understanding of its calculation. Cooling tower sizing can simply be done by graphical methods. Some additional calculation such as water make-up, fan and pump horsepower calculations are also explained in this guideline.

Cooling Tower

Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Cooling towers make use of evaporation whereby some of the water is evaporated into a moving air stream and subsequently discharged into the atmosphere. As a result, the remainder of the water is cooled down significantly.

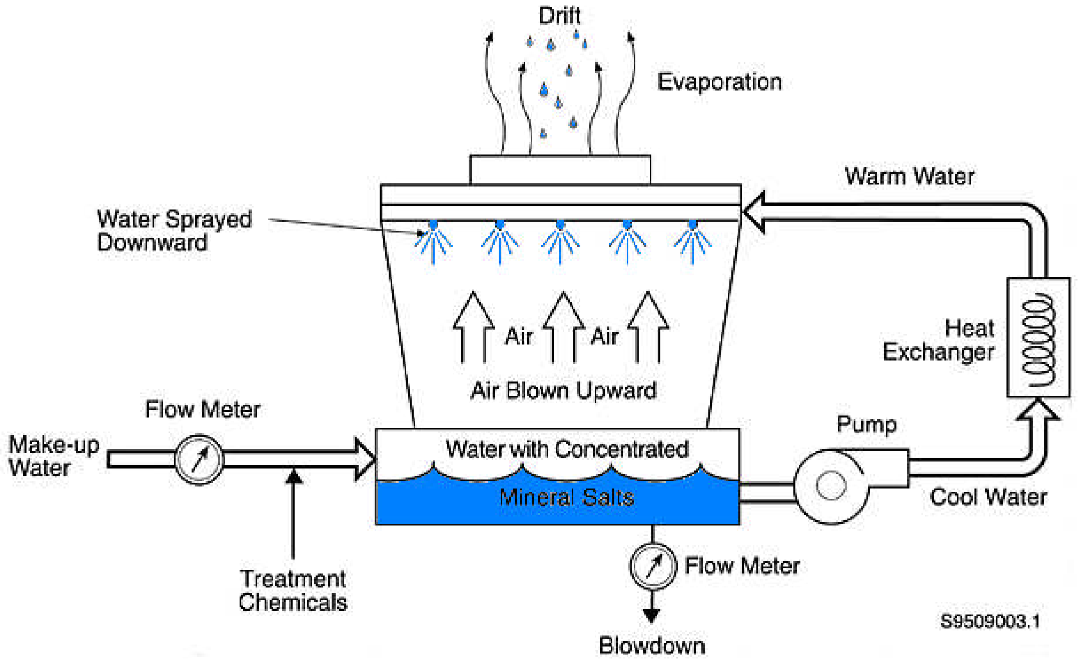

Fig 1. Schematic diagram of a cooling water system

There are several important factors that govern the operation of cooling tower:

- The dry-bulb and wet-bulb temperatures of the air
- The temperature of warm water
- The efficiency of contact between air and water in terms of the volumetric mass transfer coefficient and the contact time between the air and the water
- The uniformity of distribution of the phases within the tower
- The air pressure drop
- The desired temperature of the cooled water

Air might enter the tower driven by a density gradient (natural draft), might be pushed into the tower (forced draft) at the base or drawn into the tower (induced draft) assisted by a fan. Several types of cooling towers have been designed on the basis of the above factors and operating strategies.

The cooling tower might be classified into several types, but they are broadly categorized by following considerations:

1. Whether there is direct or indirect contact
2. The mechanism used to provide the required airflow
3. The relative flow paths of air and water
4. The primary materials of construction
5. the type of heat transfer media applied
6. The tower's physical shape

General classification of cooling tower is pictured below:

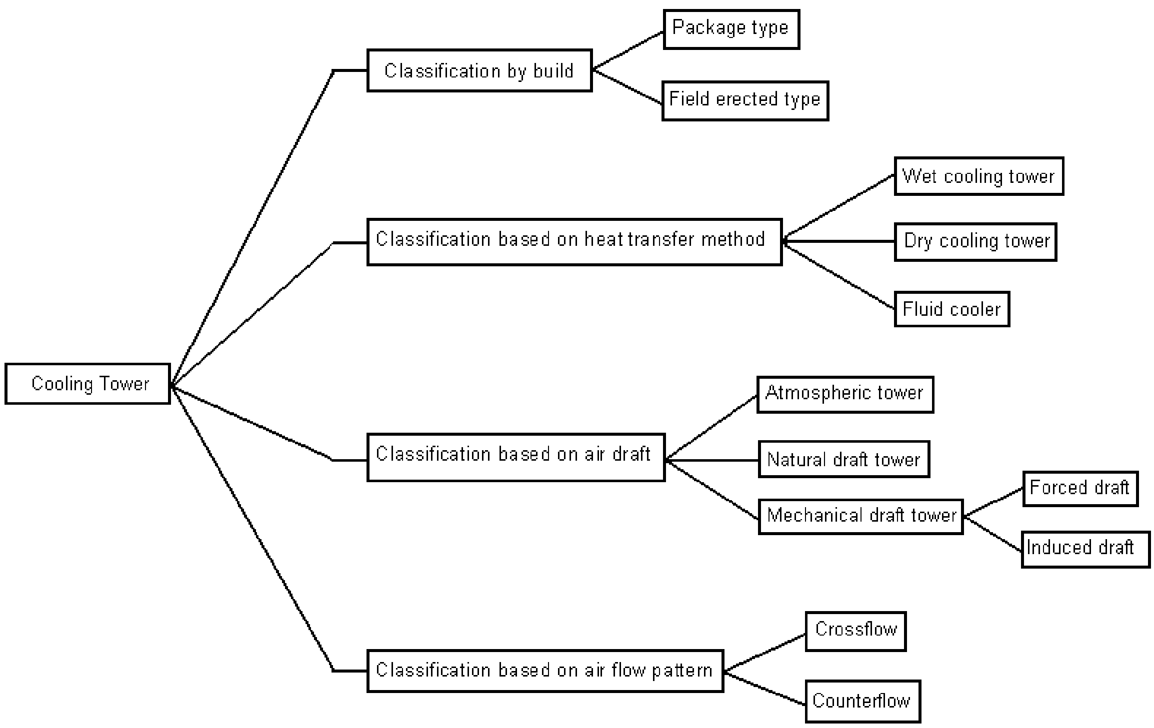

Fig 2. Classifications of cooling towers

Classification by build

Package Type

This type of cooling towers is preassembled and can be simply transported on trucks as they are compact machines. The capacity of package type towers are limited and for that reason, they are usually preferred by facilities with low heat rejection requirements such as food processing plants, textile plants, buildings like hospitals, hotels, malls, chemical processing plants, automotive factories etc. Due to the intensive use in domestic areas, sound level control is a relatively more important issue for package type cooling towers.

Field Erected Type

Field erected type cooling towers are usually preferred for power plants, steel processing plants, petroleum refineries, and petrochemical plants. These towers are larger in size compared to the package type cooling towers.

Classification based on heat transfer method

Wet Cooling Tower

This type of cooling tower operates based on evaporation principle. The working fluid and the evaporated fluid (usually water) are one and the same. In a wet cooling tower, the warm water can be cooled to a temperature lower than the ambient air dry-bulb temperature, if the air is relatively dry.

Dry Cooling Tower

This tower operates by heat transfer through a surface that separates the working fluid from ambient air, such as in a tube to air heat exchanger, utilizing convective heat transfer. Dry cooling tower does not use evaporation.

Fluid Cooler

This tower passes the working fluid through a tube bundle, upon which clean water is sprayed and a fan-induced draft applied. The resulting heat transfer performance is much closer to that of a wet cooling tower, with the advantage provided by a dry cooler of protecting the working fluid from environmental exposure and contamination.

Classification based on air draft

Atmospheric Tower

An atmospheric tower consist of a big rectangular chamber with two opposite louvered walls. The tower is packed with a suitable tower fill. Atmospheric air enters the tower through the louvers driven by its own velocity. An atmospheric tower is cheap but inefficient. Its performance largely depends upon the direction and velocity of wind.

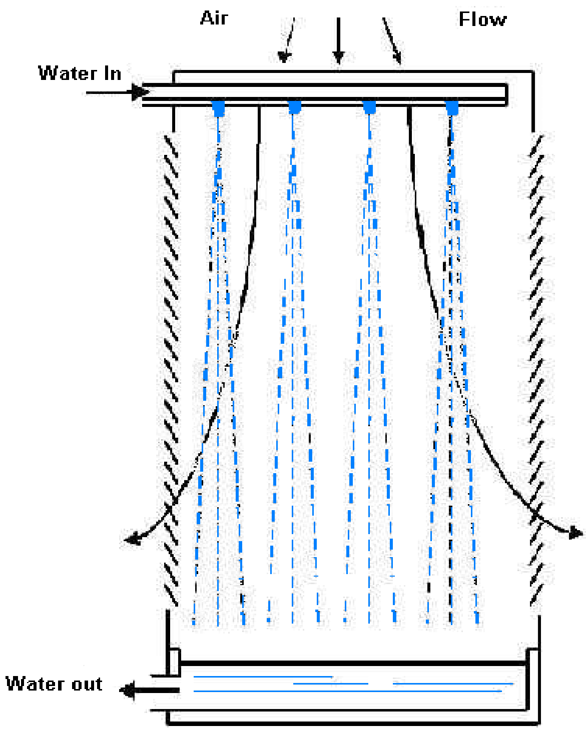

Fig 3. Atmospheric cooling tower

Natural Draft Tower

The natural draft or hyperbolic cooling tower makes use of the difference in temperature between the ambient air and the hotter air inside the tower. As hot air moves upwards through the tower (because hot air rises), fresh cool air is drawn into the tower through an air inlet at the bottom.

A natural draft tower is so called because natural flow of air occurs through the tower. Two factors are responsible for creating the natural draft:

- a rise in temperature and humidity of air in the column reduces its density, and
- the wind velocity at the tower bottom.

Due to the layout of the tower, no fan is required and there is almost no circulation of hot air that could affect the performance. But in some cases, a few fans are installed at the bottom to enhance the air flow rate. This type of tower is called 'fan-assisted' natural draft tower.

The hyperbolic shape is made because of the following reasons:

- more packing can be fitted in the bigger area at the bottom of the shell;
- the entering air gets smoothly directed towards the centre because of the shape of the wall, producing a strong upward draft;
- greater structural strength and stability of the shell is provided by this shape.

The pressure drop across the tower is low and the air velocity above the packing may vary from 1-1.5 m/s. The concrete tower is supported on a set of reinforced concrete columns. Concrete is used for the tower shell with a height of up to 200 m. These cooling towers are mostly only for large heat duties because large concrete structures are expensive.

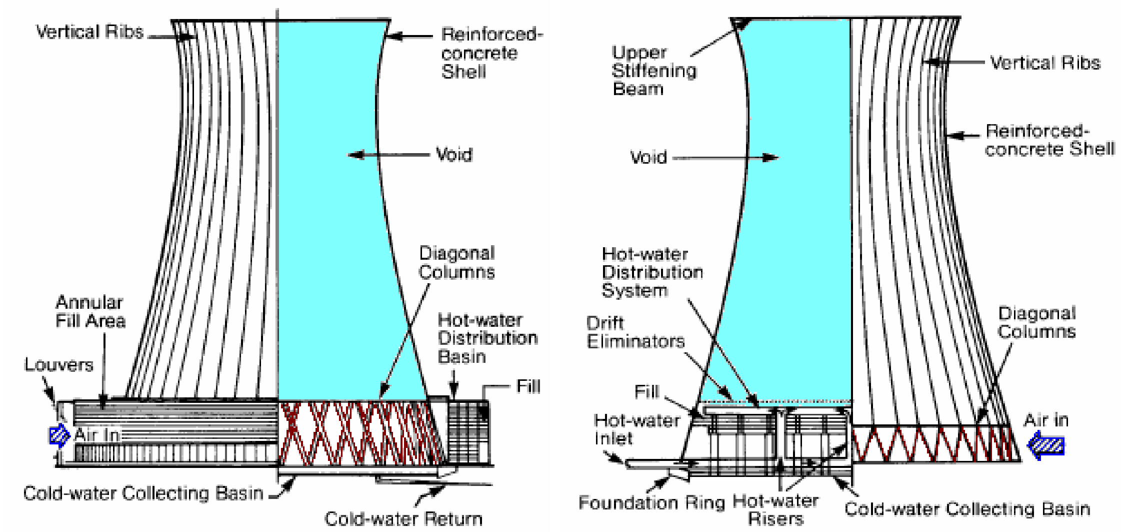

Fig 4 (a) Cross flow and (b) counter flow natural draft cooling tower

Mechanical Draft Cooling Tower

Because of their huge shape, construction difficulties and cost, natural draft towers have been replaced by mechanical draft towers in many installations. Mechanical draft towers have large fans to force or draw air through circulated water. The water falls downwards over fill surfaces, which helps increase the contact time between the water and the air. Cooling rates of mechanical draft towers depend upon various parameters; such as fan diameter and speed of operation, fills for system resistance, etc.

There are two different classes of mechanical draft cooling towers:

a. Forced draft

It has one or more fans located at the tower bottom to push air into the tower. During operation, the fan forces air at a low velocity horizontally through the packing and then vertically against the downward flow of the water that occurs on either side of the fan. The drift eliminators located at the top of the tower remove water entrained in the air. Vibration and noise are minimal since the rotating equipment is built on a solid foundation. The fans handle mostly dry air, greatly reducing erosion and water condensation problems.

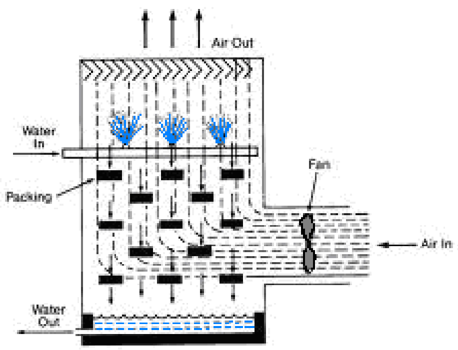

Fig 5. Forced draft cooling tower

b. Induced draft

A mechanical draft tower with a fan at the discharge which 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.

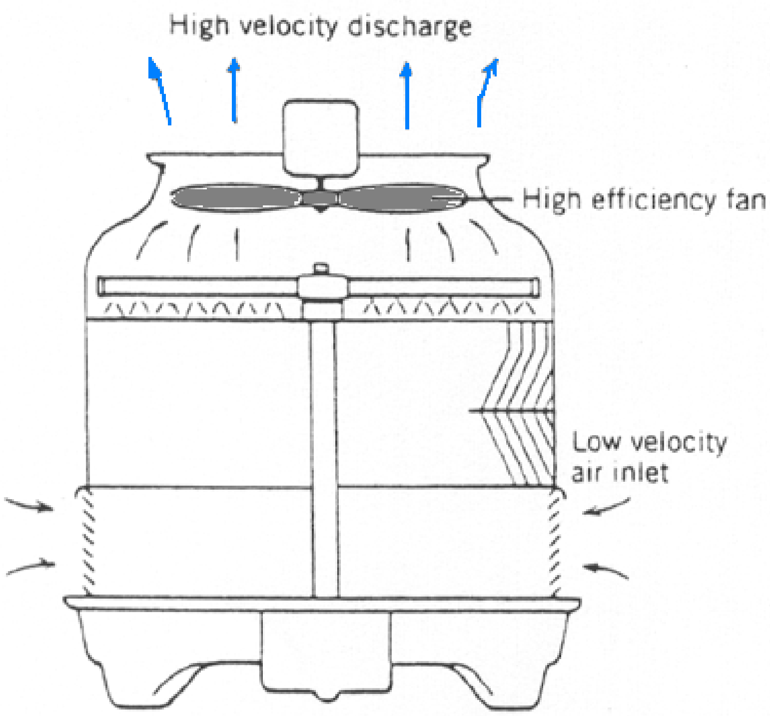

Fig 6. Induced draft cooling tower

Classification based on air flow pattern

Crossflow

Crossflow is a design in which the air flow is directed perpendicular to the water flow. Air flow enters one or more vertical faces of the cooling tower to meet the fill material. Water flows (perpendicular to the air) through the fill by gravity. The air continues through the fill and thus past the water flow into an open plenum area. A distribution or hot water basin consisting of a deep pan with holes or nozzles in the bottom is utilized in a crossflow tower. Gravity distributes the water through the nozzles uniformly across the fill material.

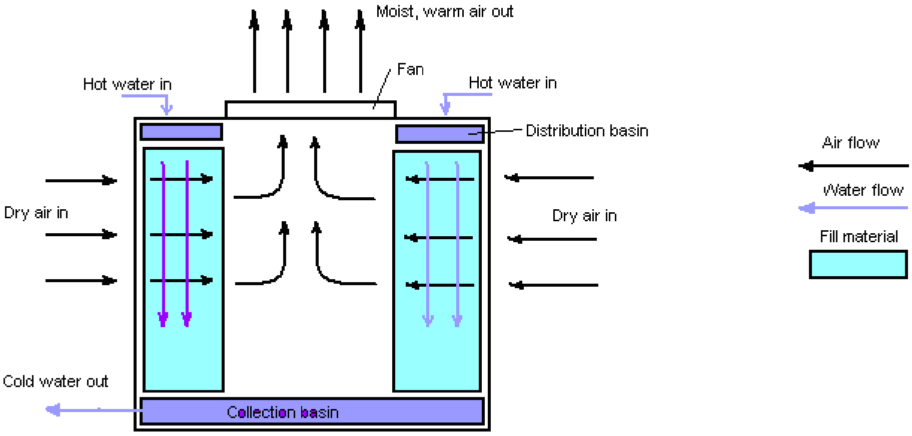

Fig 7. Crossflow type design

Counterflow

In a counterflow design the air flow is directly opposite to the water flow (see diagram below). Air flow first 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.

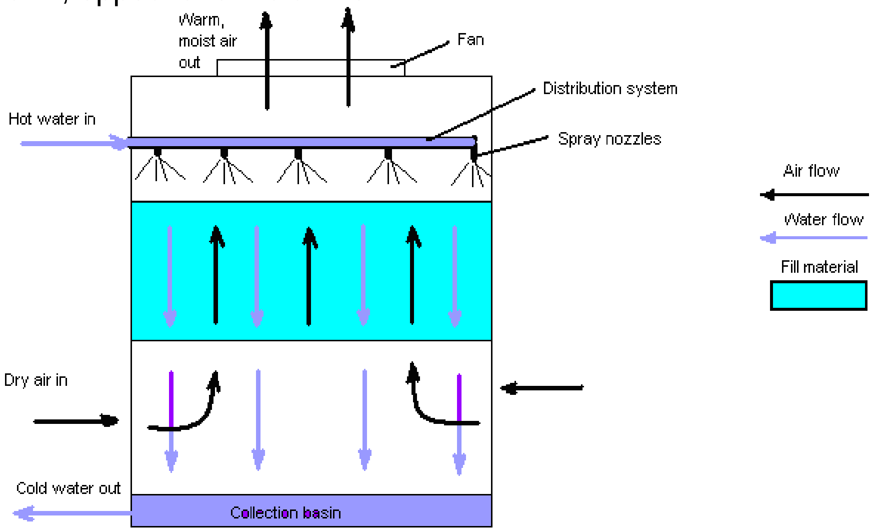

Fig 8. Counterflow type design

GENERAL DESIGN CONSIDERATION

Components of A Cooling Tower

Structural Components [1]

Most cooling systems are very vulnerable to corrosion. They contain a wide variety of metals and circulate warm water at relatively high linear velocities. Both of these factors accelerate the corrosion process. Deposits in the system caused by silt, dirt, debris, scale and bacteria, along with various gases, solids and other matter dissolved in the water all serve to compound the problem. Even a slight change in the cooling water pH level can cause a rapid increase in corrosion. Open recirculating systems are particularly corrosive because of their oxygen-enriched environment.

The structural components of cooling tower such as: 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 cold water basin has two fundamentally important functions: collecting the cold water following its transit of the tower, and acting as the tower's primary foundation.

2. Tower framework

   The most commonly used materials for the framework of field-erected towers are fiberglass, wood, and concrete, with steel utilized infrequently to conform to a local building code, or to satisfy a specific preference.

3. Water distribution system

   Lines might be buried to minimize problem of thrust loading, thermal expansion and freezing; or elevated to minimize cost of installation and repair. In either case, the risers to the tower inlet must be externally supported, independent of the tower structure and piping.

4. 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 accessway to the mechanical equipment and water distribution system. Fan deck materials are customarily compatible with the tower framework.

5. Fan cylinder

   Fan cylinder directly affects the proper flow of air through the tower. Its efficiencies can be severely reduced by a poorly designed fan cylinder, or significantly enhanced by a well-designed one.

6. Mechanical equipment supports

   Customary material for the unitized supports is carbon steel, hot-dip galvanized after fabrication, with stainless steel construction available at significant additional cost.

7. Fill (heat transfer surface)

   Fill (heat transfer surface) is able to promote both the maximum contact surface and the maximum contact time between air and water determines the efficiency of the tower. The two basic fill classifications are splash type and film type.
   Splash type fill breaks up the water, and interrupts its vertical progress, by causing it to cascade through successive offset levels of parallel splash bars. It is characterized by reduced air pressure losses, and is not conducive to logging. However, it is very sensitive to inadequate support.
   Film type fill causes the water to spread into a thin film, flowing over large vertical areas, to promote maximum exposure to the air flow. It has capability to provide more effective cooling capacity within the same amount of space, but is extremely sensitive to poor water distribution.

8. Drift eliminator

   Drift eliminators remove entrained water from the discharge air by causing it to make sudden changes in direction. The resulting centrifugal force separates the drops of water from air, depositing them on the eliminator surface, from which they flow back into the tower.
   Eliminator are normally classified by the number of directional changes or "passes", with an increase in the number of passes usually accompanied by an increase in pressure drop.

9. Casing

   A cooling tower casing acts to contain water within the tower, provide an air plenum for the fan, and transmit wind loads to the tower framework. It must have diaphragm strength, be watertight and corrosion resistant, have fire retardant qualities, and also resist weathering.

10. Louvers

Every well-designed crossflow tower is equipped with inlet louvers, whereas counterflow towers are only occasionally required to have louvers. Their purpose is to retain circulating water within the confines of the tower, as well as to equalize air flow into the fill.

Mechanical Components [1]

1. Fans

Cooling tower fans must move large volumes of air efficiently, and with minimum vibration. The materials of manufacture must not only be compatible with their design, but must also be capable of withstanding the corrosive effects of the environment in which the fans are required to operate.

a. Propeller fans: They have ability to move vast quantities of air at the relatively low static pressure encountered. They are comparatively inexpensive, may be used on any size tower, and can develop high overall efficiencies; but their application naturally tends to be limited by the number of projects of sufficient size to warrant their consideration.
b. Automatic variable-pitch fans: They are able to vary airflow through the tower in response to a changing load or ambient condition.
c. Centrifugal fans: They are usually used on cooling towers designed for indoor installations; their capability to operate against relatively high static pressures makes them particularly suitable for that type of application. However, their inability to handle large volumes of air, and their characteristically high input horsepower requirement limits their use to relatively small applications.

All propeller type fans operate in accordance with common laws:

- The capacity varies directly as the speed ratio, and directly as the pitch angle of the blades relative to the plane of rotation.
- The static pressure varies as the square of the capacity ratio.
- The fan horsepower varies as the cube of the capacity ratio.
- At constant capacity, the fan horsepower and static pressure vary directly with air density.

2. Speed reducers

The optimum speed of a cooling tower fan seldom coincides with the most efficient speed of the driver (motor); thus a speed reduction or power transmission unit is needed between the motor and the fan.

3. Drive shafts

   The driveshafts transmit power from the output shaft of the motor to the input shaft of gear reduction units.

4. Valves

   Valves are used to control and regulate flow through the water lines serving the tower. Valves utilized for cooling tower application include:

   a. Stop valves: They are used on both counterflow and crossflow towers to regulate flow in multiple-riser towers, and to stop flow in a particular riser for cell maintenance.
   b. Flow-control valves: They are considered to discharge to the atmosphere, and essentially as the end-of-line valves.
   c. Make-up valves: These are valves utilized to automatically replenish the normal water losses from the system.

Electrical Components [1]

1. Motors

   Electric motors are used almost exclusively to drive the fans on mechanical draft cooling towers, and they must be capable of reliable operation under extremely adverse conditions.

2. Motor controls

   Motor controls serve to start and stop the fan motor and to protect it from overload or power supply failure, thereby helping assure continuous reliable cooling tower operation. They are not routinely supplied as a part of the cooling tower contract but, because of their importance to the system, the need for adequate consideration in the selection and wiring of these components cannot be overstressed.

3. Wiring system

   The wiring system design must consider pertinent data on the available voltage (its actual value, as well as its stability), length of lines from the power supply to the motor, and the motor horsepower requirements.

Tower materials

Originally, cooling towers were constructed primarily with wood, including the frame, casing, louvers, fill and cold-water basin. Sometimes the cold-water basin was made of concrete. Today, manufacturers use a variety of materials to construct cooling towers. Materials are chosen to enhance corrosion resistance, reduce maintenance, and promote reliability and long service life. Galvanized steel, various grades of stainless steel, glass fiber, and concrete are widely used in tower construction, as well as aluminum and plastics for some components.

1. Frame and casing

   Wooden towers are still available, but many components are made of different materials, such as the casing around the wooden framework of glass fiber, the inlet air louvers of glass fiber, the fill of plastic and the cold-water basin of steel. Many towers (casings and basins) are constructed of galvanized steel or, where a corrosive atmosphere is a problem, the tower and/or the basis are made of stainless steel. Larger towers sometimes are made of concrete. Glass fiber is also widely used for cooling tower casings and basins, because they extend the life of the cooling tower and provide protection against harmful chemicals.

2. Fill

   Plastics are widely used for fill, including PVC, polypropylene, and other polymers. When water conditions require the use of splash fill, treated wood splash fill is still used in wooden towers, but plastic splash fill is also widely used. Because of greater heat transfer efficiency, film fill is chosen for applications where the circulating water is generally free of debris that could block the fill passageways.

3. Nozzles

   Plastics are also widely used for nozzles. Many nozzles are made of PVC, ABS, polypropylene, and glass-filled nylon.

4. Fans

   Aluminum, glass fiber and hot-dipped galvanized steel are commonly used as fan materials. Centrifugal fans are often fabricated from galvanized steel. Propeller fans are made from galvanized steel, aluminum, or molded glass fiber reinforced plastic.

Cooling Tower Design Consideration

Once a tower characteristic has been established between the plant engineer and the manufacturer, the manufacturer must design a tower that matches the value. The required tower size will be a function of:

1. Cooling range
2. Approach to wet bulb temperature
3. Mass flow rate of water
4. Wet bulb temperature
5. Air velocity through tower or individual tower cell
6. Tower height

Other design characteristics to consider are fan horsepower, pump horsepower, make-up water source, fogging abatement, and drift eliminator.

Operation Considerations

1. Water make-up

   Water losses include evaporation, drift (water entrained in discharge vapor), and blowdown (water released to discard solids). Drift losses are estimated to be between 0.1 and 0.2% of water supply.

2. Cold weather operation

   Even during cold weather months, the plant engineer should maintain the design water flow rate and heat load in each cell of the cooling tower. If less water is needed due to temperature changes (i.e. the water is colder), one or more cells should be turned off to maintain the design flow in the other cells.

   The water in the base of the tower should be maintained between 60 and 70^{o}F by adjusting air volume if necessary. Usual practice is to run the fans at half speed or turn them off during colder months to maintain this temperature range.

Improving Energy Efficiency of Cooling Towers

The most important options to improve energy efficiency of cooling towers are:

1. Follow manufacturer's recommended clearances around cooling towers and relocate or modify structures that interfere with the air intake or exhaust
2. Optimize cooling tower fan blade angle on a seasonal and/or load basis

3. Correct excessive and/or uneven fan blade tip clearance and poor fan balance
4. In old counter-flow cooling towers, replace old spray type nozzles with new square spray nozzles that do not clog
5. Replace splash bars with self-extinguishing PVC cellular film fill
6. Install nozzles that spray in a more uniform water pattern
7. Clean plugged cooling tower distribution nozzles regularly
8. Balance flow to cooling tower hot water basins
9. Cover hot water basins to minimize algae growth that contributes to fouling
10. Optimize the blow down flow rate, taking into account the cycles of concentration (COC) limit
11. Replace slat type drift eliminators with low-pressure drop, self-extinguishing PVC cellular units
12. Restrict flows through large loads to design values
13. Keep the cooling water temperature to a minimum level by (a) segregating high heat loads like furnaces, air compressors, DG sets and (b) isolating cooling towers from sensitive applications like A/C plants, condensers of captive power plant etc.

    Note: A 1^oC cooling water temperature increase may increase the A/C compressor electricity consumption by 2.7%. A 1^oC drop in cooling water temperature can give a heat rate saving of 5 kCal/kWh in a thermal power plant
14. Monitor approach, effectiveness and cooling capacity to continuously optimize the cooling tower performance, but consider seasonal variations and side variations
15. Monitor liquid to gas ratio and cooling water flow rates and amend these depending on the design values and seasonal variations. For example: increase water loads during summer and times when approach is high and increase air flow during monsoon times and when approach is low.
16. Consider COC improvement measures for water savings
17. Consider energy efficient fibre reinforced plastic blade adoption for fan energy savings
18. Control cooling tower fans based on exit water temperatures especially in small units
19. Check cooling water pumps regularly to maximize their efficiency

Tower Problems

By their very design, open recirculating cooling systems are prime candidates for contamination problems. As the cooling water evaporates, contaminants are allowed to concentrate in the system. Contaminants enter the system either through the makeup water or from the air via the cooling tower. If left untreated, high concentrations of impurities in open recirculating systems can lead to a number of serious problems, including:

1. Scale

   The most serious side effect of scale formation is reduced heat transfer efficiency. Loss of heat transfer efficiency can cause reduced production or higher fuel cost. If heat transfer falls below the critical level. the entire system may need to be shut down and cleaned. Unscheduled downtime can obviously cost thousands of dollars in lost production and increased maintenance. Once scale becomes a serious threat to efficiency or continued operation, mechanical or chemical cleaning is necessary.

   In most cases, mineral scale is a silent thief of plant profitability. Even minute amounts of scale can provide enough insulation to affect heat transfer and profitability severely.

   Scale in cooling water systems is mainly composed of inorganic mineral compounds such as calcium carbonate (which is most common), magnesium silicate, calcium phosphate and iron oxide. These minerals are dissolved in the water, but if left to concentrate uncontrolled, they will precipitate. Scale occurs first in heat transfer areas but can form even on supply piping. Many factors affect the formation of scale, such as the mineral concentration in the cooling water, water temperature, pH, availability of nucleation sites (the point of initial crystal formation) and the time allowed for scale formation to begin after nucleation occurs.

   Dissolved mineral salts are inversely temperature soluble. The higher the temperature, the lower their solubility. The most critical factors for scale formation are pH, scaling ion concentration and temperature. Consequently, most open recirculating systems operate in a saturated state. because the scaling ions are highly concentrated. Precipitation is prevented under these conditions by the addition of a scale inhibitor.

2. Fouling

   Waterborne contaminants enter cooling systems from both external and internal sources. Though filtered and clarified, makeup water may still hold particles of silt. clay, sand and other substances. The cooling tower constantly scrubs dirt and dust from the air, adding more contaminants to the cooling water. Corrosion by-products, microbiological growth and process leaks all add to the waterborne fouling potential in a cooling system.

The solids agglomerate as they collide with each other in the water. As more and more solids adhere, the low water velocity, laminar flow, and rough metal surfaces within the heat exchangers allow the masses of solids to settle out, deposit onto the metal. and form deposits. These deposits reduce heat transfer efficiency, provide sites for underdeposit corrosion, and threaten system reliability. Waterborne fouling can be controlled by a combination of mechanical and chemical programs

3. Microbiological growth

Cooling water systems are ideal spots for microscopic organisms to grow. "Bugs" thrive on water, energy and chemical nutrients that exist in various parts of most cooling water systems. Generally, a temperature range of 70-1 40º F (21-60 ^{o}C) and a pH range of 6-9 provide the perfect environment for microbial growth. Bacteria, algae and fungi are the most common microbes that can cause serious damage to cooling water systems. Microbiological fouling can cause:

- Energy losses
- Reduced heat transfer efficiency
- Increased corrosion and pitting
- Loss of tower efficiency
- Wood decay and loss of structural integrity of the cooling tower

4. Corrosion

Corrosion is the breakdown of metal in the presence of water, air and other metals. The process reflects the natural tendency of most manufactured process metals to recombine with oxygen and return to their natural (oxide) states. Corrosion is a particularly serious problem in industrial cooling water systems because it can reduce cooling efficiency, increase operating costs, destroy equipment and products and ultimately threaten plant shutdown.

Most cooling systems are very vulnerable to corrosion. They contain a wide variety of metals and circulate warm water at relatively high linear velocities. Both of these factors accelerate the corrosion process. Deposits in the system caused by silt, dirt, debris, scale and bacteria, along with various gases, solids and other matter dissolved in the water all serve to compound the problem. Even a slight change in the cooling water pH level can cause a rapid increase in corrosion. Open recirculating systems are particularly corrosive because of their oxygen-enriched environment.

Table 1. Typical Problems and Trouble Shooting for Cooling Towers

Problem/ Difficulty	Possible Causes	Remedies/Rectifying Action
Excessive absorbed current/electrical load	1. Voltage Reduction	Check the voltage
	2a. Incorrect angle of axial fan blades	Adjust the blade angle
	2b. Loose belts on centrifugal fans (or speed reducers)	Check belt tightness
	3. Overloading owing to excessive air flow-fill has minimum water loading per m^2 of tower section	Regulate the water flow by means of the valve
	4. Low ambient air temperature	The motor is cooled proportionately and hence delivers more than name plate power
Drift/carry-over of water outside the unit	1. Uneven operation of spray nozzles	Adjust the nozzle orientation and eliminate any dirt
	2. Blockage of the fill pack	Eliminate any dirt in the top of the fill
	3. Defective or displaced droplet eliminators	Replace or realign the eliminators
	4. Excessive circulating water flow (possibly owing to too high pumping head)	Adjust the water flow-rate by means of the regulating valves. Check for absence of damage to the fill
Loss of water from basins/pans	1. Float-valve not at correct level	Adjust the make-up valve
	2. Lack of equalising connections	Equalise the basins of towers operating in parallel
Lack of cooling and hence increase in temperatures owing to increased temperature range	1. Water flow below the design valve	Regulated the flow by means of the valves
	2. Irregular airflow or lack of air	Check the direction of rotation of the fans and/or belt tension (broken belt possible)
	3a. Recycling of humid discharge air	Check the air descent velocity
	3b. Intake of hot air from other sources	Install deflectors
	4a. Blocked spray nozzles (or even blocked spray tubes)	Clean the nozzles and/or the tubes
	4b. Scaling of joints	Wash or replace the item
	5. Scaling of the fill pack	Clean or replace the material (washing with inhibited aqueous sulphuric acid is possible but long, complex and expensive)

DEFINITIONS

ACFM – The actual volumetric flow rate of air-vapor mixture.

Air Horsepower – The power output developed by a fan in moving a given air rate against a given resistance.

Air inlet – Opening in a cooling tower through which air enters. Sometimes referred to as the louvered face on induced draft towers.

Air rate – Mass flow of dry air per square foot of cross-sectional area in the tower's heat transfer region per hour.

Air travel – Distance which air travels in its passage through the fill. Measured vertically on counterflow towers and horizontally on crossflow towers.

Air velocity – Velocity of air-vapor mixture through a specific region of the tower (i.e. the fan).

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.

Approach – Difference between the cold water temperature and either the ambient or entering wet-bulb temperature.

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

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.

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.

Bay – The area between adjacent transverse and longitudinal framing bents.

Bent – A transverse or longitudinal line of structural framework composed of columns, grid, ties, and diagonal bracing members.

Blowdown – Water discharged from the system to control concentrations of salts and other impurities in the circulating water.

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

Brake Horsepower – The actual power output of a motor, turbine, or engine.

Btu (British thermal unit) – The amount of heat gain (or loss) required to raise (or lower) the temperature of one pound of water 1^{o}F.

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

Casing – Exterior enclosing wall of a tower, exclusive of the louvers.

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 distribution systems.

Circulating water rate – Quantity of hot water entering the cooling tower.

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 blowdown.

Collection basin – Vessel below and integral with the tower where water is transiently collected and directed to the sump or pump suction line.

Counterflow – Air flow direction through the fill is counter-current to that of the falling water.

Crossflow – Air flow direction through the fill is essentially perpendicular to that of the falling water.

Cycles of concentration (C.O.C) – The ratio of dissolved solids in circulating water to the dissolved solids in make up water.

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.

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.

Double flow - A crossflow cooling tower where two opposed fill banks are served by a common air plenum.

Drift – Circulating water lost from the tower as liquid droplets entrained in the exhausted air stream.

Drift eliminator – An assembly of baffles or labyrinth passage through which the air passes prior to its exit from the tower, for the purpose of removing entrained water droplets from the exhaust air.

Driver – Primary device for the fan drive assembly. Although electric motors predominate, it may also be a gas engine, steam turbine, hydraulic motor or other power source.

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

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 wert-bulb temperature.

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, cost of financing, etc., all normalized to a specific point in time.

Evaporation loss – Water evaporated from the circulating water into the air stream in the cooling process.

Fan cylinder – Cylindrical or venturi-shaped structure in which a propeller fan operates.

Fan deck – Surface enclosing the top structure of an induced draft cooling tower, exclusive of the distribution basins on a crossflow tower.

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.

Fan scroll – Convolute housing in which a centrifugal (blower) fan operates.

Fill – That portion of a cooling tower which constitutes its primary heat transfer surface.

Fill cube – (1) Counterflow: the amount of fill required in a volume one bay long by one bay wide by an air travel high. (2) Crossflow: The amount of fill required in a volume one bay long by an air travel wide by one story high.

Fill deck – One of a succession of horizontal layers of splash bars utilized in a splash-fill 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.

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-fill 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.

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

Flow-control valves – Manually controlled valves which are used to balance flow of incoming water to all sections of the tower.

Flume – A through 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. Flumes are also used to conduct water from the cold water basins of multiple towers to a common pumping area or pump pit.

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”.

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.

Heat load – Total heat to be removed from the circulating water by cooling tower per unit time.

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.

Hot water temperature – Temperature of circulating water entering the 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.

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

Leaving wet-bulb temperature – Wet-bulb temperature of the air discharge from a cooling tower.

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.

Liquid-to-gas ratio – A ratio of total mass flows of water and dry air in a cooling tower.

Longitudinal – Pertaining to occurrences in the direction of tower length.

Louvers – Blade or passage type assemblies nstalled 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 integrally molded to the fill sheets.

Make-up – Water added to the circulating water system to replace water lost by evaporation, drift, windage, blowdown, and leakage.

Mechanical draft – Refers to the movement of air through cooling tower by means of a fan or other mechanical devices.

Module – A preassembled portion or section of a cooling tower cell. On larger factory-assembled towers, two or more shipping modules may require joining to make a cell.

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.

Net effective volume – That portion of total structural volume within which the circulating water is in intimate contact with the flowing air.

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

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.

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 7.0 indicates neutral water.

Pitot tube – An instrument that operates on the principle of differential pressures. Its primary use on a cooling tower is in measurement of circulating water flow.

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.

Plume – The effluent mixture of heated air and water vapor (usually visible) discharge from a cooling tower.

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.

Range – Difference between the hot water temperature and the cold water temperature (HW-CW).

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.

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 induced air flow through a natural draft tower.

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 of the fan.

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 bar may be flat, or may be formed into shaped cross-section for improved structural rigidity and/or improved heat transfer capability.

Splash fill – Descriptive of a cooling tower in which splash type fill is used for the primary heat transfer surface.

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

Stack – An extended fan cylinder whose primary purpose is to achieve elevation of the discharge plume.

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.

Standard air – Air having a density of 0.075 lb/cuft. Essentially equivalent to 70^{o}F dry air at 29.92 in Hg barometric pressure.

Story – The vertical dimension between successive levels of horizontal framework ties, girts, joists, or beams. Story dimensions vary depending upon the size and strength characteristic of the framework material used.

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

Total air rate – Total mass flow of dry air per hour through the tower.

Total water rate – Total mass flow of water per hour through the tower.

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.

Transverse – Pertaining to occurrences in the direction of tower width.

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.

Water loading – Circulating water rate per horizontal square foot of fill plan area of the cooling tower.

Water rate – Mass flow of water per square foot of fill plan area of the cooling tower per hour.

Wet-bulb temperature – The temperature of entering or ambient air adjacent to the cooling tower as measured with a wet-bulb thermometer.

Wet-bulb thermometer – A thermometer whose bulb is encased within a wetted wick.

Windage – Water lost from the tower because of the effects of wind.

Wind load – The load imposed upon a structure by a wind blowing against its surface.

NOMENCLATURE

a	contact area, ft^2/ft^3 tower volume
B	base area, ft^2
c_p	heat capacity of water, Btu/lb^oF
F	air flow rate, ft^3/min
G	air flow rate, lb/h
h	enthalpy of air stream, Btu/lb
h_a	enthalpy of air-water vapor mixture at wet-bulb temperature, Btu/lb dry air
h_a^a	specific enthalpy of dry air, kJ/kg
h_s	specific enthalpy of saturated mixture, kJ/kg dry air
h_w	enthalpy of air-water vapor mixture at bulk water temperature, Btu/lb dry air
h’	enthalpy of saturated air at water temperature, Btu/lb
H	humidity of an air-water vapor mixture, kg of H_2O/kg of dry air or lb of H_2O/lb of dry air
Hp	head of pump, ft
H_P	percentage humidity, %
H_R	percentage relative humidity, %
H_S	saturation humidity
K	air mass-transfer coefficient, lb water/(h.ft^2)
Ka	volumetric air mass transfer constant, lb water/(h.ft^3)
$\frac{Ka\overline{V}}{\overline{L}}$	tower characteristic, lb air/lb H_2O
L	water flow rate, lb/(h.ft^2)
$\overline{L}$	Loading factor, lb H_2O/h
P	power, hp
P_T	total pressure (101.325 kPa, 760 mmHg, or 1.0 atm)
R	range ($T_1 - T_2$), ^oF
p_A	partial pressure of water vapor in the air
p_{AS}	partial pressure of the pure water at the given temperature
P_s	pressure of water vapor at saturation, N/m^2
s_s	specific entropy of saturated mixture, J/K·kg dry air

T_1	inlet-water temperature, °F
T_2	outlet-water temperature, °F
t_2	outler-air temperature, ^oF
V	total fill volume, ft^3
V_a	specific volume of dry air, m^3/kg
V_s	specific volume of saturated mixture, m^3/kg dry air
$\overline{V}$	specific fill volume, ft^3/ft^2
W_d	drift loss
W_b	blowdown [consistent units, m^3/(h.gal.min)]
W_m	makeup water
W_s	humidity ratio at saturation, mass of water vapor associated with unit mass of dry air
Z	fill height, ft
$\Delta h1$	value of $(h_w - h_a)$ at $T_2 + 0.1(T_1 - T_2)$
$\Delta h2$	value of $(h_w - h_a)$ at $T_2 + 0.4(T_1 - T_2)$
$\Delta h3$	value of $(h_w - h_a)$ at $T_1 - 0.4(T_1 - T_2)$
$\Delta h4$	value of $(h_w - h_a)$ at $T_1 - 0.1(T_1 - T_2)$
L/G	water-air flow rate ratio, lb H_2O/lb air
η	fan efficiency, dimensionless (~0.80)
ρ	density, lb/ft^3