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No 19, Jalan Bilal Mahmood
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Malaysia</td><td>COOLING TOWER SELECTION, SIZING AND TROUBLESHOOTING

LEVEL TWO
TRAINING MODULE</td><td></td></tr>
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INTRODUCTION

Scope

This design guideline assists engineers in understanding the basic principles, selection and design of cooling towers.

Cooling towers are commonly used to remove the heat from industrial cooling waters used in heat exchanger 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 can be classified into several types based on the air draft and flow pattern. Each type of cooling tower has its own advantages and disadvantages; thus the proper selection is needed based on the system operation. Beside type selection, 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 needed to keep the cooling tower in good working condition.

Some theories are needed to be understood before an engineer start 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.

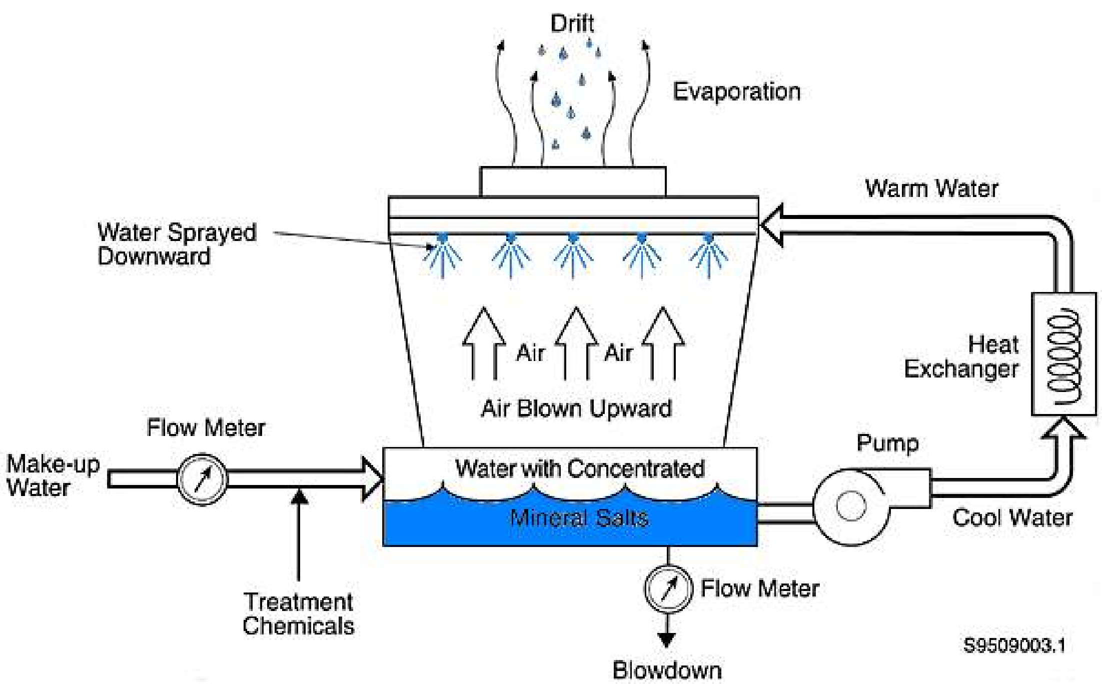

Fig 1. Schematic diagram of a cooling water system

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:

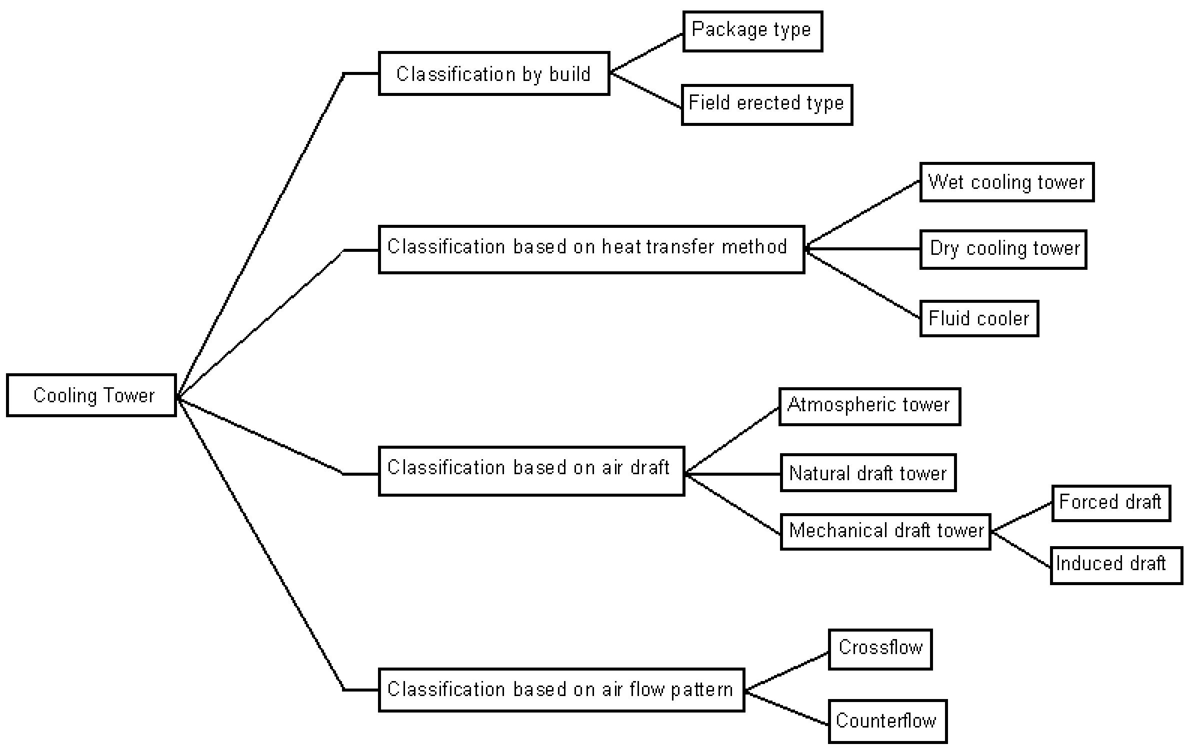

Fig 2. Classifications of cooling towers

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.
<u>Classification based on air draft</u>

Atmospheric Tower

An atmospheric tower consists 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.

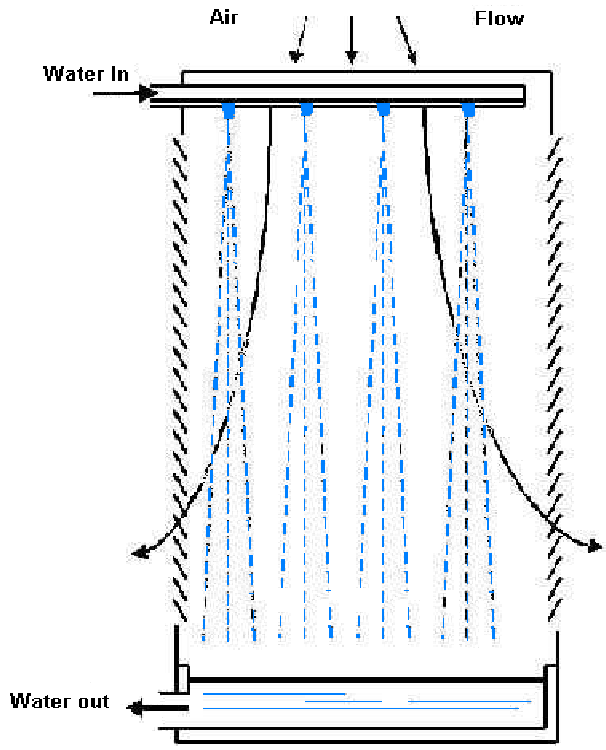

Fig 3. Atmospheric cooling tower

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.

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. They are generally used for water flow rates above 45,000 m^3/hr.

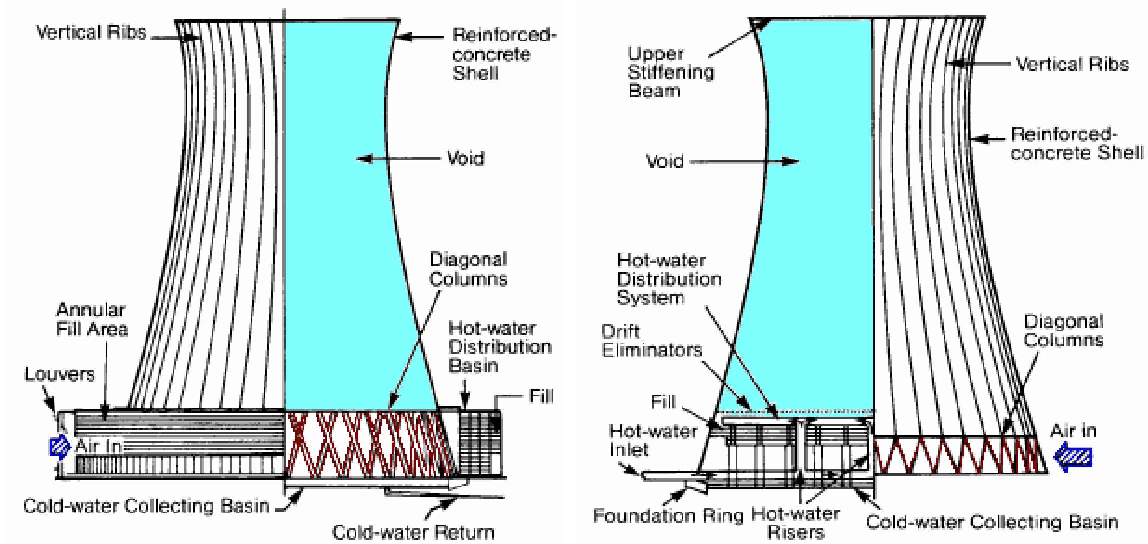

Fig 4 (a) Cross flow and (b) counter flow natural draft cooling tower

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.

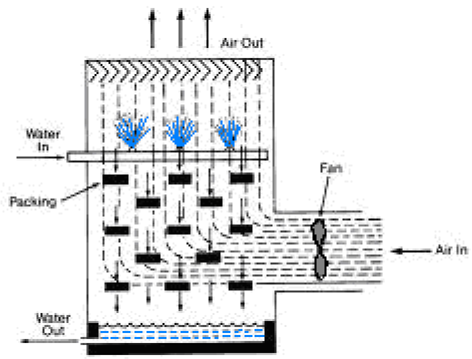

Fig 5. Forced draft cooling tower

b. Induced draft

Induced draft towers are mechanical draft towers with a fan at the discharge which pulls air through the 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.

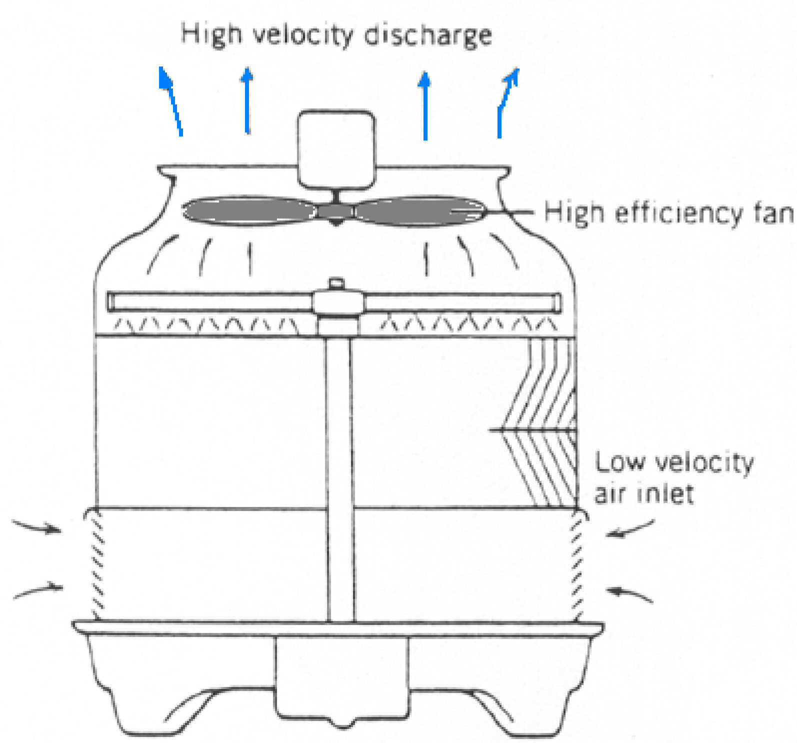

Fig 6. Induced draft cooling tower

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.

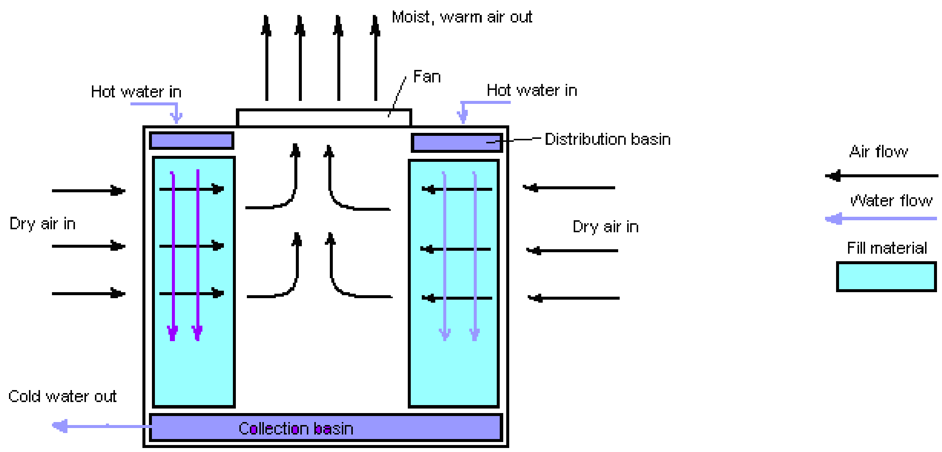

Fig 7. Crossflow type design

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.

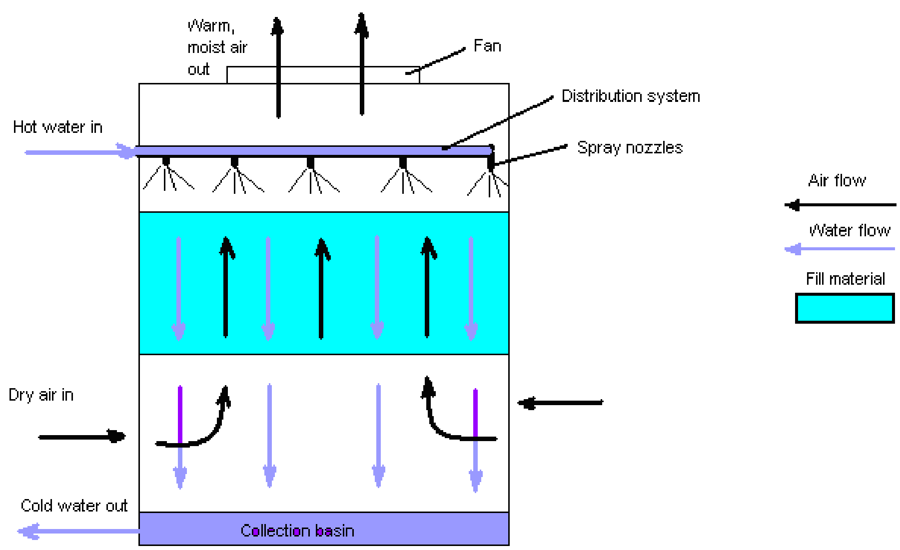

Fig 8. Counterflow type design

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.

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.

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.

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.

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, °F
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