Water Cooling Tower

An Attempt towards Performance Optimization

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A cooling tower in its most generic sense, is a heat rejection device, which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature.

Constitutes an integral part of any Process Engineering Plant.

Are classified as Natural or Mechanical draft depending on whether or not they use Mechanical device such as fans.
Fig 1. Schematic illustrating the role of cooling tower in a process plant
Cooling Towers

Natural Draft
- Cross flow Or Counter flow

Mechanical Draft
- Induced draft
- Forced draft
  - Cross flow Or Counter flow
  - Cross flow Or Counter flow
Natural Draft

- Natural draft or Atmospheric draft towers utilize no mechanical device such as fan to create air flow through the tower.
- They are either Atmospheric spray type[ Fig.1] or Hyperbolic natural draft towers.
- In Hyperbolic natural draft type, air flow is produced due to the density differential between the heated air inside the stack and the cool ambient air outside the tower.
- Hyperbolic type can be cross flow or counter flow [Fig 2a &2b].
Fig. 2  Vertical Atmospheric Spray tower

Fig. Horizontal Atmospheric Spray tower
Fig. A typical Hyperbolic Cooling Tower

Fig. 3a & 3b. Counter and Cross flow Hyperbolic natural draft respectively
**Mechanical Draft**

- These differ from the natural draft type in that they make use of mechanical device such as fan to create air flow through the tower.
- They come in various different shapes and size, ranging from square to rectangular to round shaped to octagonal types.
- They are categorized as either forced draft or Induced draft.
- Forced mechanical draft towers use fans at the air inlet side and the air is forced through. [Fig. 3a]
- Induced mechanical draft towers differ from forced typed in that the fan(s) is/are located at the air exit side and induce air flow through the tower. [Fig. 3b]
Fig. A fully labeled Induced draft double cross flow cooling tower
Fig. 4a  Forced draft counter flow tower

Fig. 4b  Induced cross double flow tower
Some aspects of Forced Draft

- In a forced draft tower, entrance velocity is much higher than the exit velocity.
- These type of towers are highly vulnerable to recirculation of the exiting air.
- In terms of performance, forced draft is less stable than induced draft type.
- In cold weather, icing of fans poses a serious problem for a forced draft but not so for a induced draft.
- Mostly centrifugal type blower fans are used requiring more horsepower than propeller type fans.
- Capable of working against high static pressure.
Some aspects of an Induced draft

- In an induced draft, the exit velocity is usually 4 to 5 times higher than the entrance velocity.
- The problem of recirculation as witnessed in a forced draft is not so strong.
- Icing on the fans during cold weather is completely eliminated owing to the location of the fan within the warm air stream.
- For above reasons, designer generally prefer Induced draft to Forced draft.
Another classification of cooling towers

There are a number of different parameters on which cooling towers are classified. Some of them are

- **Type of geometrical construction** i.e., round mechanical draft, rectilinear or octagonal.
- **Type of air flow** i.e., counter current or cross current
- **Method of Heat transfer** i.e., Evaporative or dry towers.
Fig. 5 A Round Mechanical Draft Cross Flow Cooling Tower
Fig.6 An Octagonal Round Mechanical Draft (RMD) Counter Flow Cooling Tower
Fig. 6 A Cross-Sectional View Of a Dry Tower
Components of Cooling Tower

Three broad category of components :-

1. Structural Components
2. Mechanical Components
3. Electrical Components
1. **Structural Components**

- Cold water basin
- Tower framework
- Water distribution system
- Fan deck
- Fan cylinder
- Mechanical Equipment support
- Fills
- Drift Eliminator
- Casing
- Louvers
Fig. Cross Flow Tower Framework On Concrete Basin
Fig. Framework and Joint Details of Cooling Tower of Wood Construction
Fig. Counter Flow Water Distribution System

Fig. Distribution System of a Round Cross Flow Tower
2. Mechanical Components

- Fan
- Speed reducer
- Drive shafts
- Valves
- Fan guards
3. Electrical components

- Motors
- Motor controls
- Wiring systems
- Cycle of Motors
Cooling Tower Terminology

- Inlet Wet Bulb Temperature (IWBT)
- Dry Bulb Temperature (DBT)
- Hot Water Temperature (HWT)
- Cold Water Temperature (CWT)
- Approach
- Range
- Heat Load
- Tower Characteristics or Tower Demand
- Liquid to Gas Ratio
- Water loading
Cycle of Concentration (C.O.C)
Fig. Schematic of Important Cooling Tower Parameters
Sources of Water Loss

- Evaporative loss
- Drift loss
- Blow down loss
Calculation of different types of Losses

Evaporation Loss (Cu m/hr) = 0.00085 * 1.8 * circulation rate (Cu m/hr) * (T₁ - T₂)
Where T₁ and T₂ are the inlet and outlet water temperature

Cycle Of Concentration (C.O.C ) calculation :

C.O.C = dissolved solids in circulating water/(dissolved solids in make up water)

Blow down Loss = (Evaporation Loss)/(C.O.C - 1)
Pressure Losses in a Cooling Tower

Following are the areas where is a potential Pressure loss:

- Air Inlet (Entrance Losses)
- Fill
- Water Distribution piping
- Drift Eliminators
- Fan Inlets (also called Plenum losses)
Pressure Loss Calculation

Pressure drop can be calculated using the following relation:

\[
\text{Pressure Drop} = \ K \times \left( \frac{\text{Air Velocity}}{4008.7} \right)^2 \times \text{Density ratio}
\]

Here  \( K \) = Pressure drop coefficient
Density ratio = actual air density / 0.075 lb/ft^3 @ 70 Fahrenheit dry air condition.

The value of \( K \) varies in a certain range for each section, there is no fixed value of \( K \) for a section.

The above equation cannot be used to calculate the pressure drop in the fill section.

These pressures are collectively called the “Static Pressure Loss” or Just “Static Pressure” or “System Resistance”.

The performance of cooling tower fans depend on the degree of static pressures at cooling tower.
Pressure Drop Coefficient For Various Sections of Cooling Tower

<table>
<thead>
<tr>
<th>S.No</th>
<th>Tower Section</th>
<th>K value Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fill</td>
<td>Not available</td>
</tr>
<tr>
<td>2.</td>
<td>Drift Eliminator</td>
<td>1.6 – 3.0</td>
</tr>
<tr>
<td>3.</td>
<td>Fan Inlet</td>
<td>.1 - .3</td>
</tr>
<tr>
<td>4.</td>
<td>Water Distribution Piping</td>
<td>Usually included drift eliminator</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Inlet section (Type)</th>
<th>K value Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Louvers</td>
<td></td>
</tr>
<tr>
<td>Large, widely spaced louvers</td>
<td>2.0 - 3.0</td>
</tr>
<tr>
<td>Small, narrow louvers</td>
<td>2.5 – 3.5</td>
</tr>
<tr>
<td>Without louvers</td>
<td></td>
</tr>
<tr>
<td>Square edge beams and square columns</td>
<td>1.5</td>
</tr>
<tr>
<td>Rounded beams (R = 0.04*H) and Columns (R = 0.04 * W)</td>
<td>1.3</td>
</tr>
<tr>
<td>Tapered beams and columns at 30 degree (R = 0.01* W)</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Factors affecting Tower Performance

- Capacity
- Range
- Approach
- Wet Bulb Temperature of inlet air
- L/G ratio
- Cooling tower effectiveness
The performance of a cooling tower is very much influenced by the efficiency of the fan used.

Fan efficiency intern is dependent on the fan stack.

Fan stacks plays a vital role in maximizing the fan efficiency, minimizing discharge air recirculation and preventing reverse running of fan.
In most cases, $R/D = .15$ or $R/D = .1$ is recommended.
The minimum height of the straight zone of fan stack is the summation of the vertical dimension at maximum blade pitch angle, maximum deflection of fan blades tip and some extra allowance.
Typically $R/D = .15$ or $R/D = .1$

1. **Inlet height zone** = $R = (0.15) \times \text{Fan diameter}$
   
   = $(0.1) \times \text{Fan diameter}$

2. **straight zone height** = $(a) + (b) + (c)$
   
   (a) Vertical Dimension of Blade Tip @ Max. Pitch Angle
   (b) Maximum Deflection of Blade Tip
   (c) Extra Dimension from the trailing edge of blade

3. **Velocity recovery zone Height** = $(\text{Total fan stack height }) - (1) - (2)$
Velocity recovery calculation

Following formulas can be used to calculate the velocity recovery:

Formulated by Hudson Products Corporation

**Velocity Recovery** = 70% of fan stack efficiency * (velocity pressure @ Fan - velocity pressure @ Top of the Fan stack)

Formulated by MRL Corporation

**Velocity Recovery** = 0.8 - [0.2 * (venturi height / fan diameter) * (velocity pressure @ Fan - velocity pressure @ Top of the Fan stack)]

**Fan stack efficiency** = 0.8 - [0.2 * (venturi height / fan diameter)]

Both the above formulas use a taper angle of 7 degree.
Fans are categorized into following six types.

1. Axial fans
2. Centrifugal fans
3. Axial–centrifugal fans
4. Roof ventilators
5. Blower fans
6. Vortex or regenerative fans

Of the above six types of fans, only first two are commonly used in cooling towers.
Axials Fans

Axial fans are the most commonly used fans across various industries. They are also of four different types:
1. Propeller fans
2. Tube axial fans
3. Vane axial fans
4. Two stage axial flow fans.

Of the above four types of axial fans, propeller fan is mostly used in a cooling tower.
Fig. Tubeaxial Fan with direct drive from an electric motor on the inlet and with a fan wheel having a 33% hub to tip ratio and ten blades
Fig. Vaneaxial fan with belt drive from an electric motor with fan wheel having 46% hub to tip ratio and nine airfoil blades
Fig. A Typical hub for large fans
They are also of six different types based on the type of wheel used.

1. Centrifugal fans with airfoil (AF) blades
2. Centrifugal fans with backward curved (BC) blades
3. Centrifugal fans with backward inclined (BI) blades
4. Centrifugal fans with radial tip (RT) blades
5. Centrifugal fans with forward curved (FC) blades
6. Centrifugal fans with radial blades (RBs).

The above fans are listed in the order of decreasing efficiency
Types of fans used in Cooling Tower

- Propeller type axial fans are predominantly used in cooling towers.

- Centrifugal fans are preferred for cooling towers designed for indoor installation.

- In recent times, another kind of propeller fans called the “Automatic Variable Pitch” fans are in much demand.
Fig. Automatic variable pitch
Some aspects of a Propeller Fans

- They can move large quantities of air at relatively low static pressure.
- They are relatively inexpensive to operate and hence may be used on any size tower and fill design for high overall efficiency.
- The rotational speed varies inversely with diameter. This speed–diameter relationship is not a constant.
- Commonly cast Aluminum is used as the fan blade material, however these now a days light weight, highly corrosion Fiber Glass –Reinforced Plastic (FRP) is used.
Some aspects of Centrifugal Fans

- They cannot handle large volumes of air and hence are suitable only for smaller installation.
- It has characteristically high input horse power requirement, in fact twice as much as for a propeller fan.
- Centrifugal fans are usually of high sheet metal construction, with protective coating being hot-dip galvanization.
Fan laws

All Propeller fans are bounded by a set of laws commonly called the Fan Laws. For a given Fan and a Cooling tower, the following holds:

- The capacity (cfm) varies directly as the speed (rpm) 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 horse power varies as the cube of the capacity ratio.
At constant capacity (cfm), fan horsepower and static pressure vary directly with air density.
Motors and associated parts
Heat Load of a cooling tower is the amount of heat that needs to be removed from the process water to achieve the desired cooling water temperature.

It can be calculated using the following relation:

Heat Load (BTU/min) = GPM * R * 8.33

Where R = Range of the Cooling Tower (HWT-CWT)
GPM = water circulation in gallons per minute
Actual Heat Load

Heat Load as on the morning of 29.06.09

Total water circulation rate = 2600 m³/hr (approxima)

Hot water temperature = 42.43 degree centigrade
Cold water temperature = 34 degree centigrade

Heat load (BTU/Min) = GPM * R * 8.33 = 11447.46 * 8.33 *
47.174 = 4498387.242 BTU/min = 79100.84 kilowatt
approximately
Designed Heat Load

Designed Hot Water Temperature (DHWT) = 42 deg C
Designed Cold Water Temperature (DCWT) = 32 deg C
Designed Range = DHWT - DCWT = 10 deg C = 50 deg

Designed Water circulation rate =

Designed Heat Load = GPM * R * 8.33

= 11887.74 * 50 * 8.33 = 4951243.71

BTU/min = 86986.54 kilowatt
The heat load calculated in the previous slide is 79100.84 kilowatt.

Wet bulb temperature measured = 28.9 degree centigrade
Dry bulb temperature measured = 33.3 degree centigrade
Hot water temperature = 42.43 degree centigrade
Cold water temperature = 34 degree centigrade
Approach = 34 - 28.9 = 5.1 degree centigrade
Range = 42.34 - 34 = 8.34 degree centigrade

Cooling tower thermal efficiency can be calculated as
Efficiency = (HWT-CWT)/(HWT-WBT) = .623
Or
Efficiency = 62.3 %
Designed Thermal Efficiency

Designed Hot water Temperature (DHWT) =
Designed Cold water Temperature (DCWT) =
Designed Wet Bulb Temperature (DWBT) =
The above equation is the characteristic heat transfer equation of a cooling tower. This is called the Merkel’s equation. The term on the left hand side signifies “degree of difficulty to cool”.

\[
\frac{KS}{L} = \frac{K_a V}{L} = C_{wv} \int_{\text{tw1}}^{\text{tw2}} \frac{dbw}{h_w - h_a}
\]

- **K** is the overall enthalpy transfer coefficient
- **a** is the area of transfer surface per unit volume of the tower
- **V** is the effective tower volume
- **L** is the water flow rate
- **C_w** is the specific heat of water
- **h_w** is enthalpy of air-water vapor mixture at bulk temperature of water
- **h_a** is enthalpy of air-water vapor mixture at the wet bulb temperature
- **tw_1** is inlet water temperature
- **tw_2** is outlet water temperature
The left hand side of the Merkel’s equation represents “Number of Transfer Units” NTU.

A plot of NTU against L/G ratio gives what is called as the demand curve.
Cooling towers are classified based on the mode of heat transfer. They are evaporative type and dry type.

- Evaporative type cooling towers involves actual physical contact between air and water and involves both latent as well as sensible heat transfer.
- Evaporative cooling towers are also of two types called direct contact or open cooling tower and close circuit cooling tower.
A direct contact evaporative type tower exposes water directly to the cooling atmosphere, thereby transferring the source heat load into air.

A close circuit cooling tower on the other hand involves indirect contact between heated fluid and atmosphere through heat exchanger.

Dry type cooling tower make use of dry surface coil sections and there is no direct contact between air and water. Cooling is achieved purely by sensible heat transfer.
Fig. A direct contact or Open Evaporative Cooling Tower
Fig. Indirect Contact or Closed Circuit Evaporative Cooling Tower
## Cooling Tower Design Specifications

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Induced Double Cross flow</td>
</tr>
<tr>
<td># Cells</td>
<td>4</td>
</tr>
<tr>
<td>Fills</td>
<td>PVC - “V” bar supported on GRP grids</td>
</tr>
<tr>
<td>Fill height</td>
<td>NA</td>
</tr>
<tr>
<td>Blade angle</td>
<td>A(20), B, C and D have 10 degree each</td>
</tr>
<tr>
<td>Tip Clearance</td>
<td>20 - 30 mm</td>
</tr>
<tr>
<td>Water circulation</td>
<td>2600 m³/hr</td>
</tr>
<tr>
<td>Fan Diameter</td>
<td>18 ft or 216 inch for all four fans</td>
</tr>
<tr>
<td>Drift eliminator</td>
<td>Single wave PVC eliminator</td>
</tr>
<tr>
<td>Nozzle spacing</td>
<td>4-6 inch</td>
</tr>
<tr>
<td>Design HWT</td>
<td>42 degree centigrade</td>
</tr>
<tr>
<td>Design</td>
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