Water Cooling Tower

An Attempt towards Performance Optimization

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Cooling Tower ....what is it ?

- 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 .

Typical Application

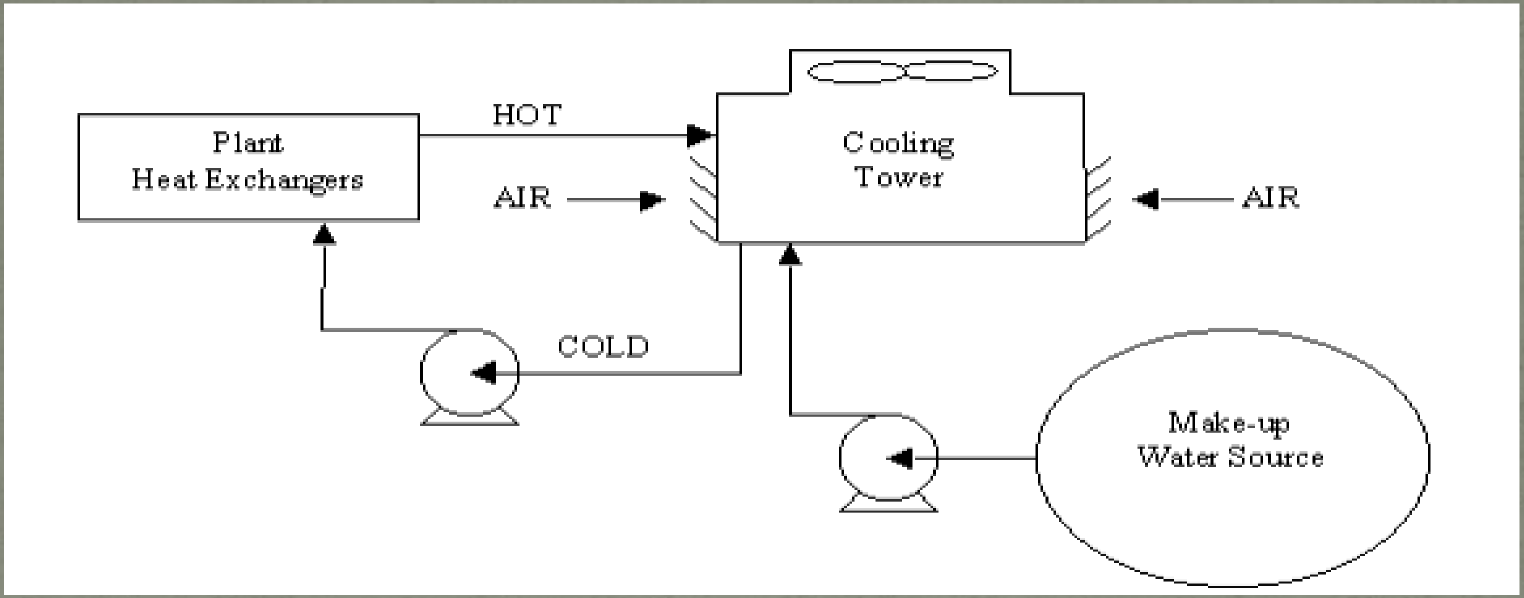
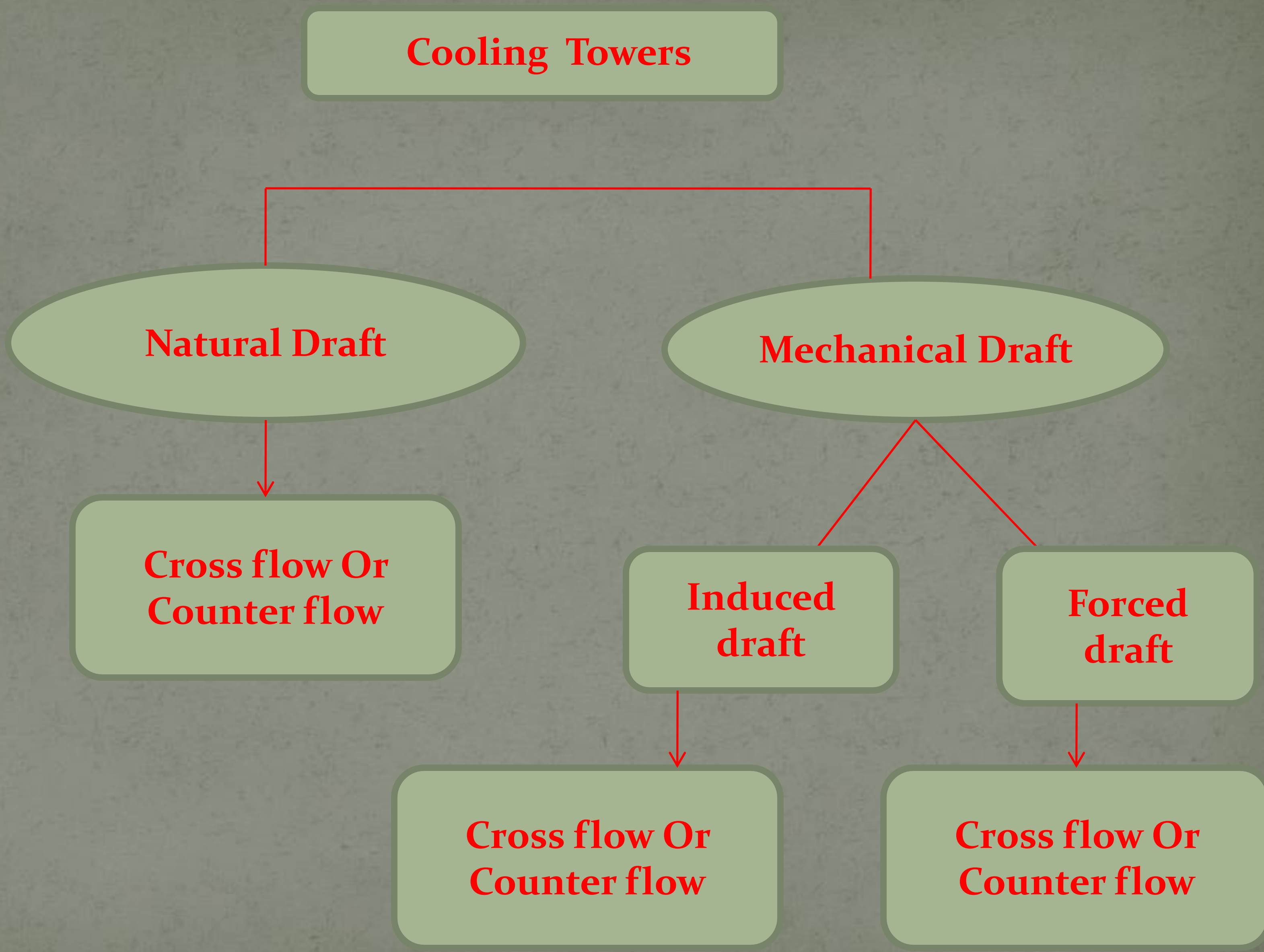


Fig 1 . Schematic illustrating the role of cooling tower in a process plant


Cooling Towers
Natural Draft
Mechanical Draft
Cross flow Or Counter flow
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].

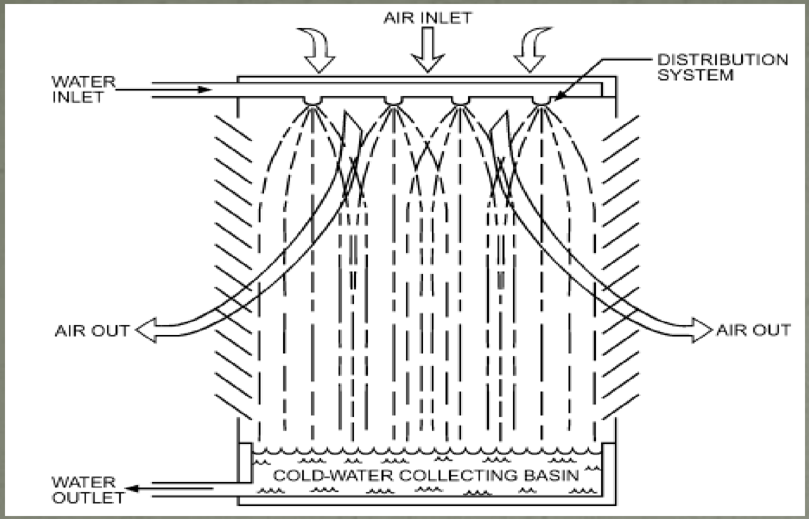


Fig.2 Vertical Atmospheric Spray tower

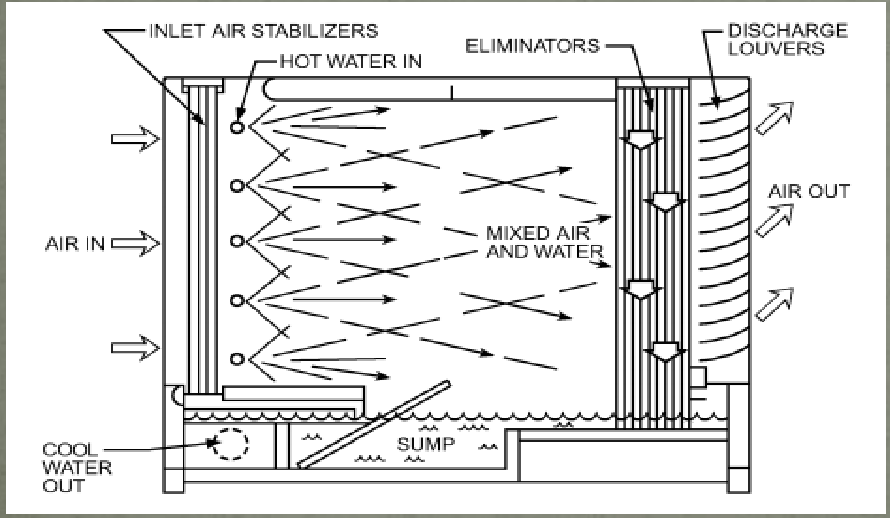


Fig. Horizontal Atmospheric Spray tower

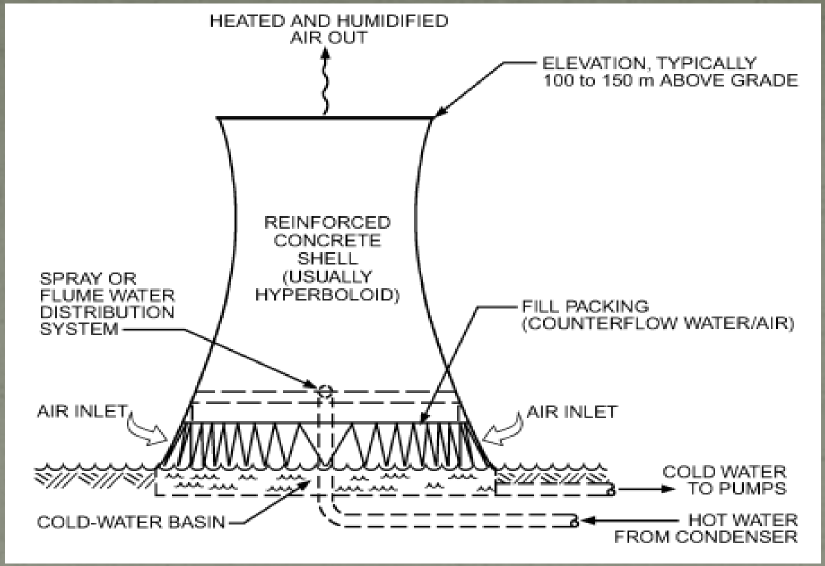


Fig. A typical Hyperbolic Cooling Tower

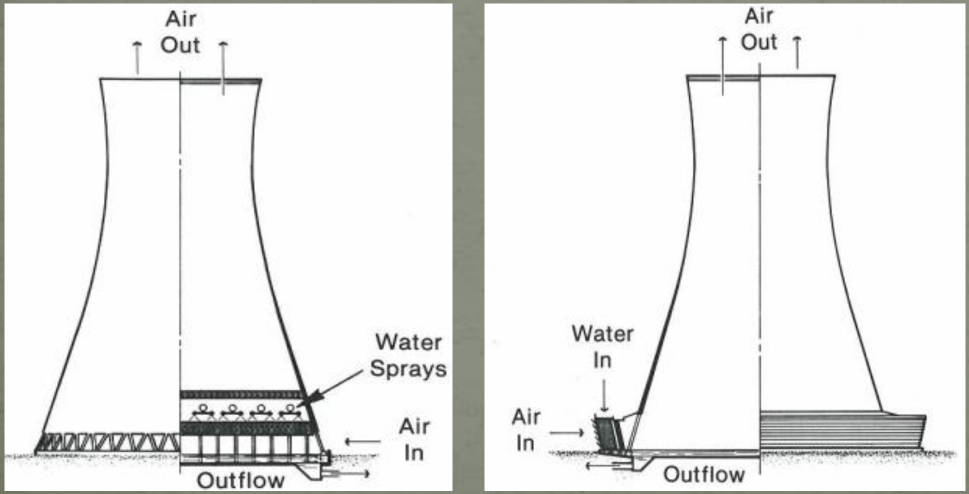


Fig. 3a & 3b . Counter and Cross flow Hyperbolic natural draft respectively

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]

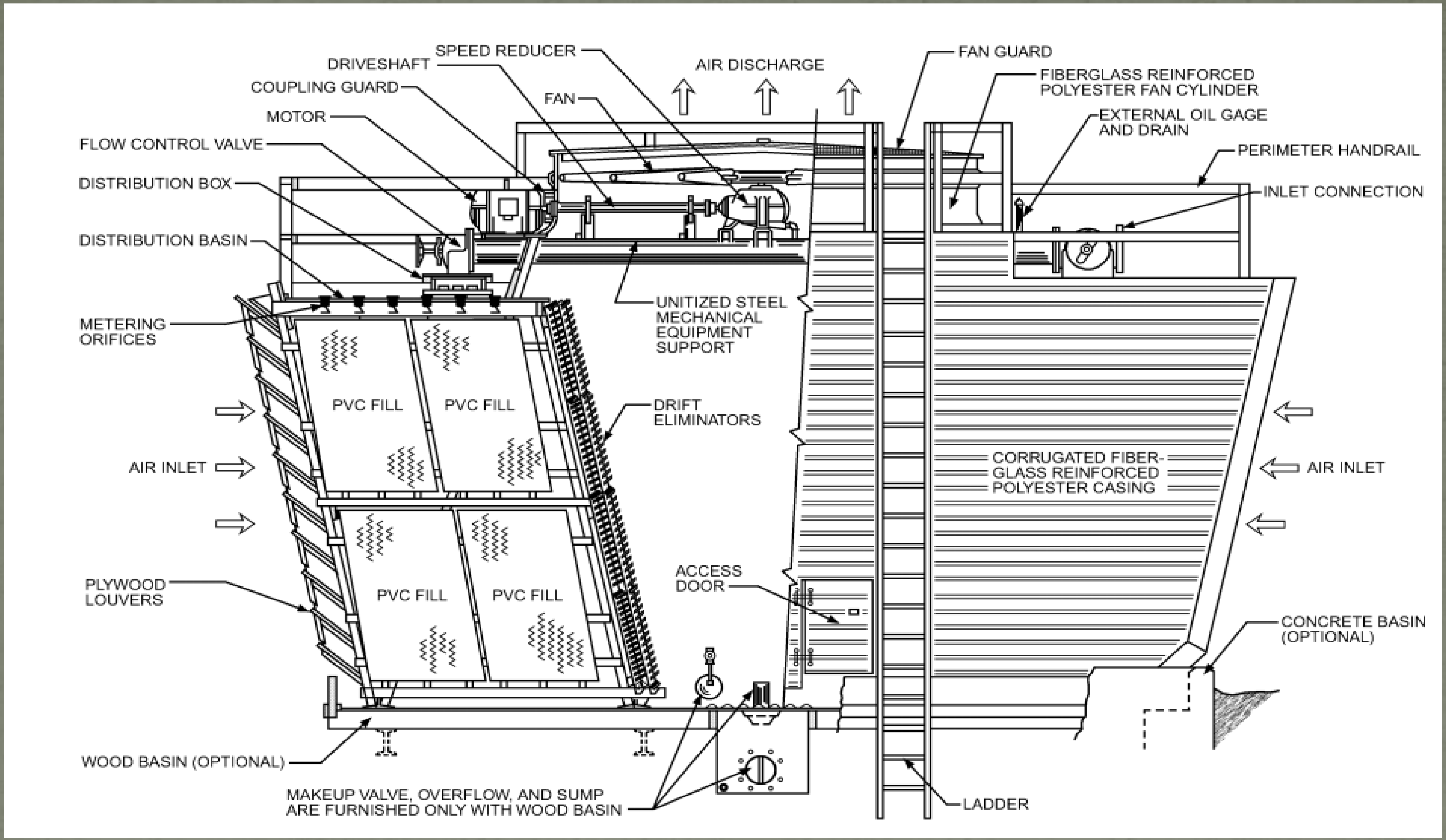


Fig. A fully labeled Induced draft double cross flow cooling tower

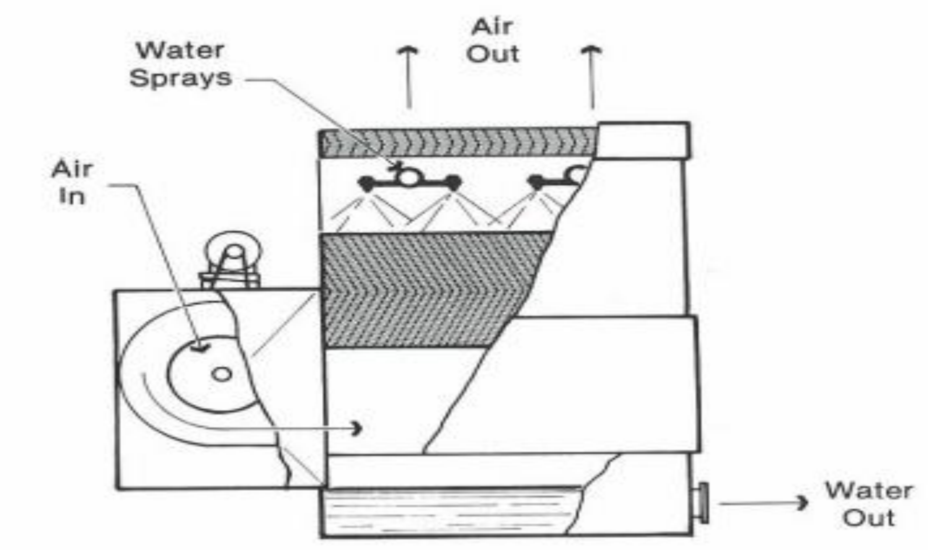


Fig.4a Forced draft counter flow tower

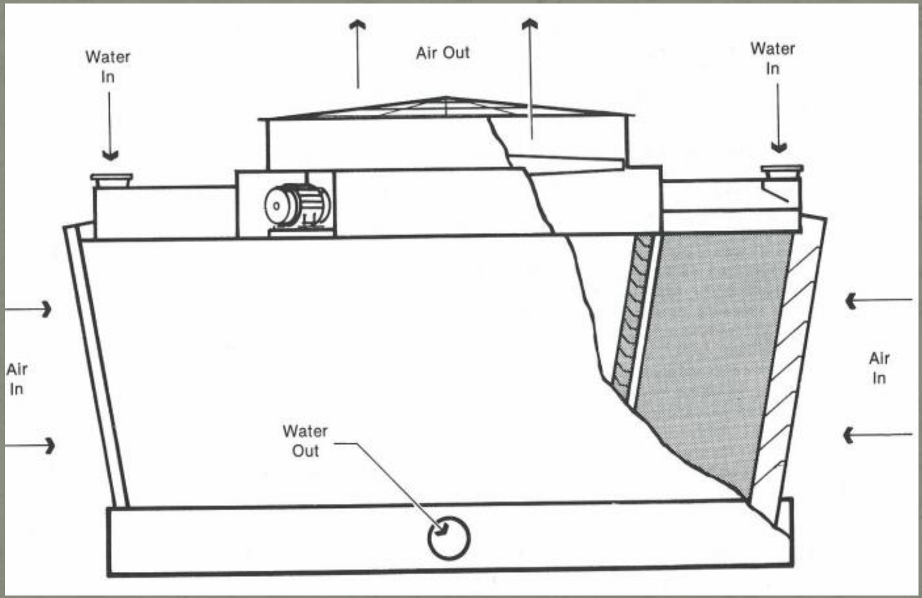


Fig.4b Induced cross double flow tower

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.

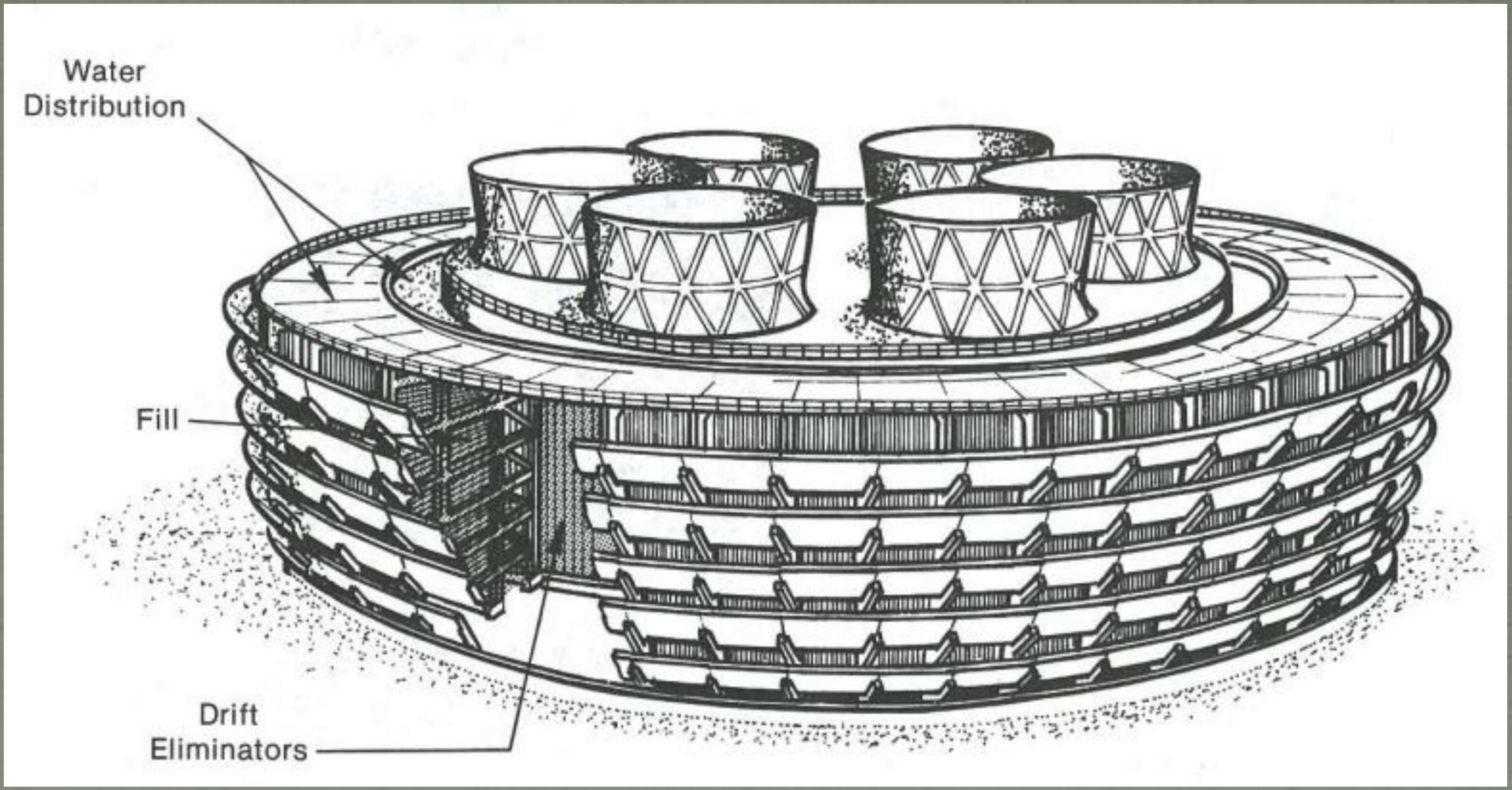


Fig. 5 A Round Mechanical Draft Cross Flow Cooling Tower

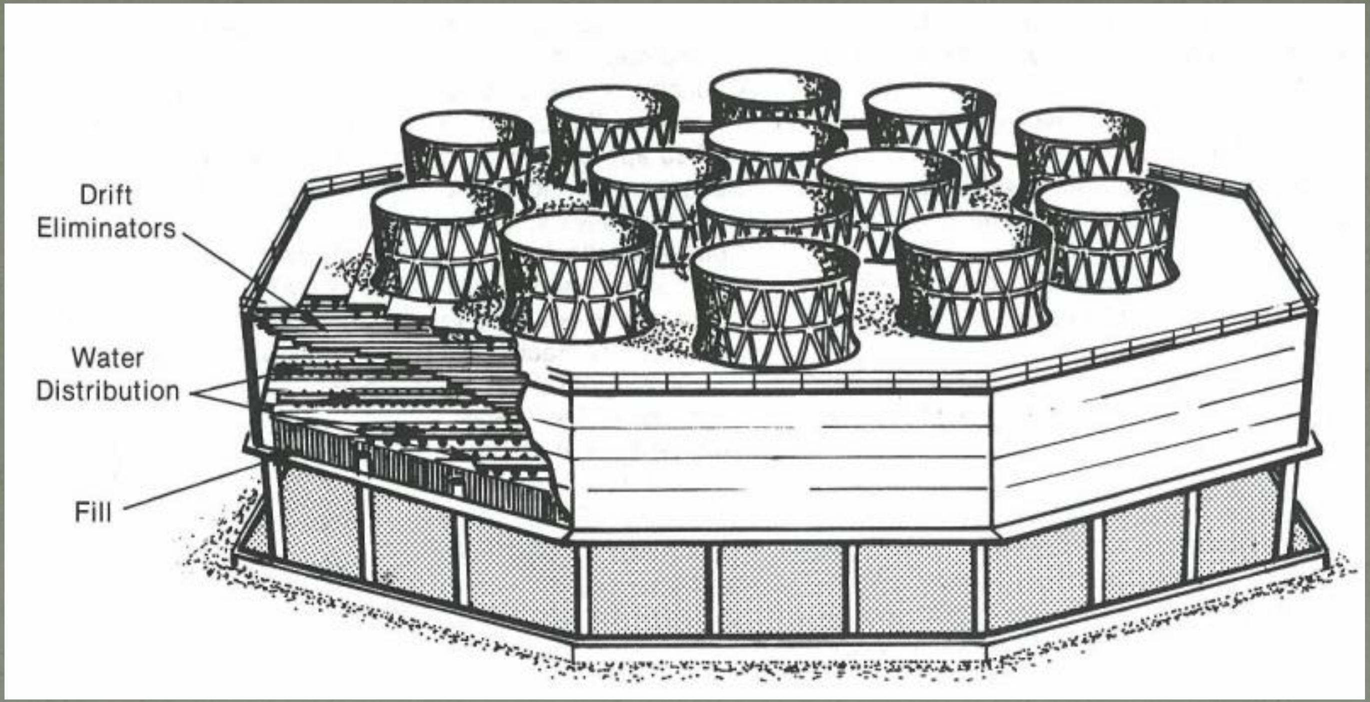


Fig.6 An Octagonal Round Mechanical Draft (RMD) Counter Flow Cooling Tower

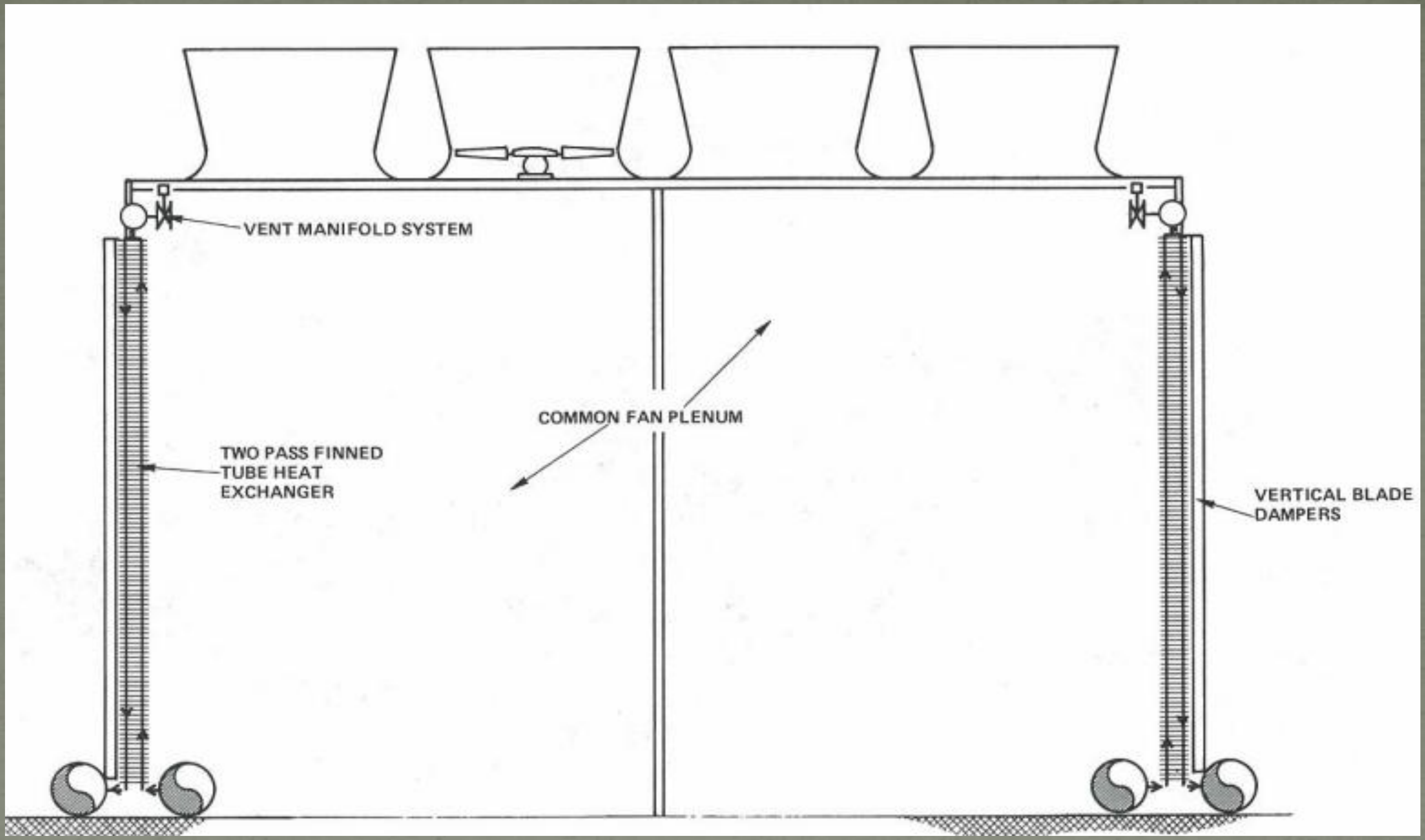


Fig.6 A Cross-Sectional View Of a Dry Tower

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

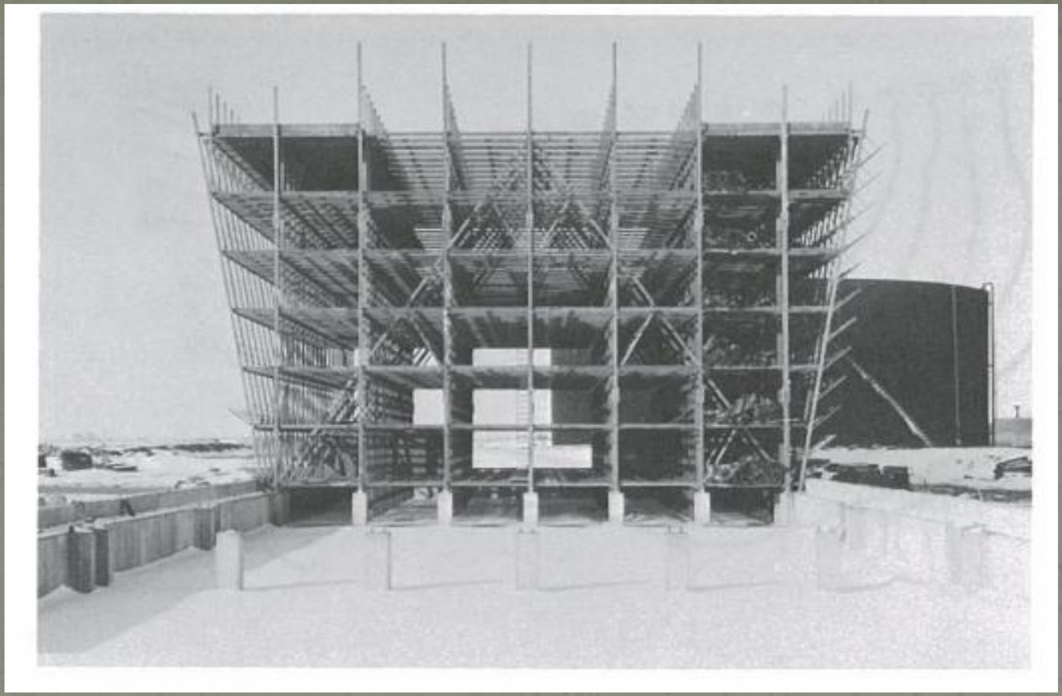


Fig. Cross Flow Tower Framework On Concrete Basin

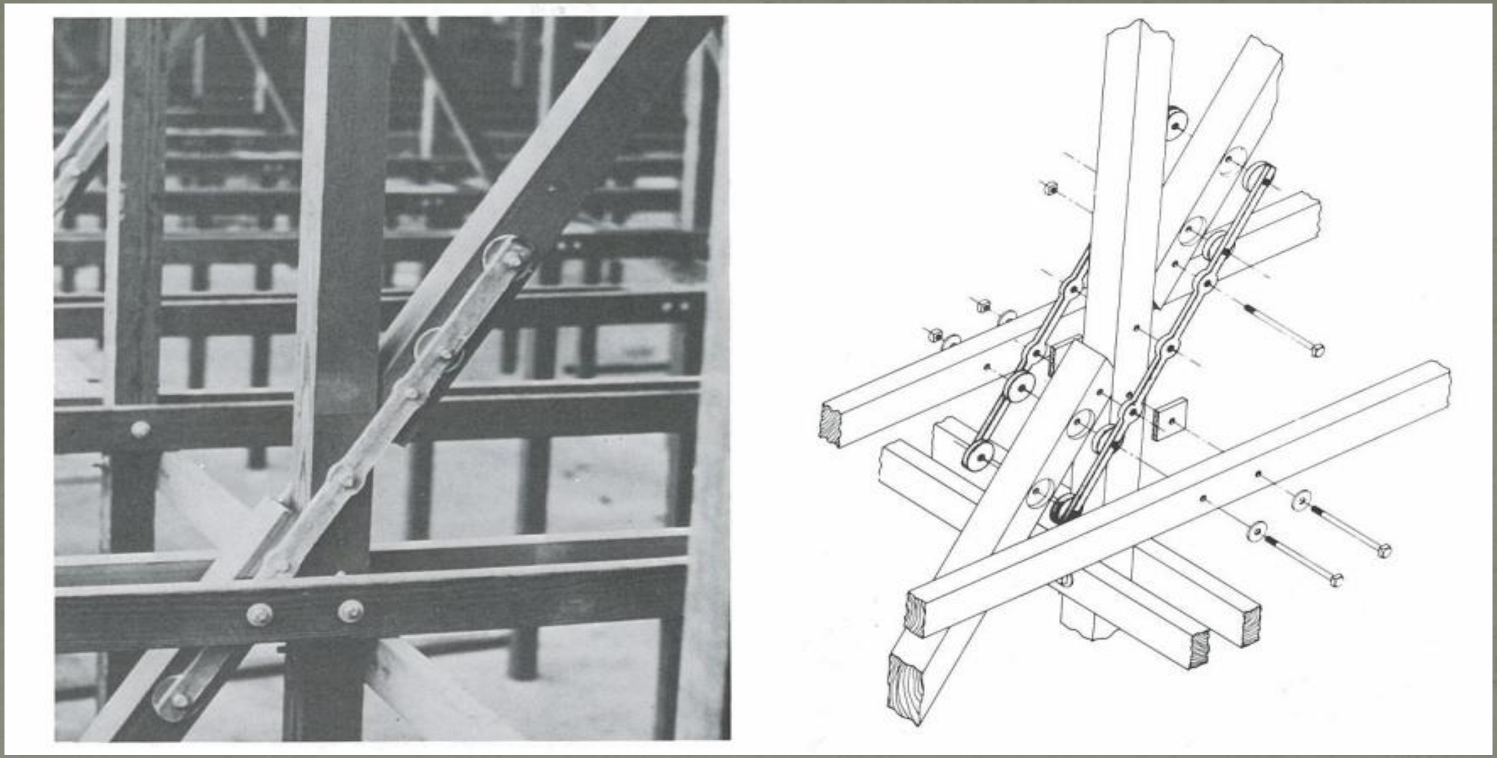


Fig. Framework and Joint Details of Cooling Tower of Wood Construction

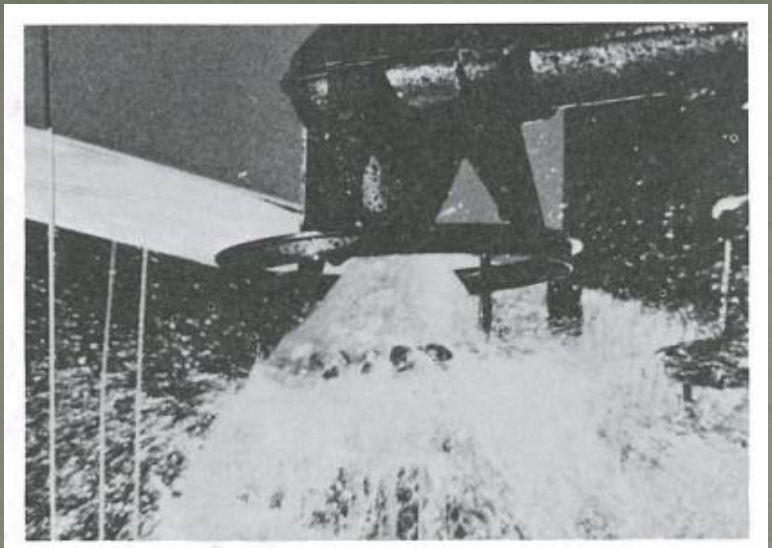


Fig. Counter Flow Water Distribution System

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)

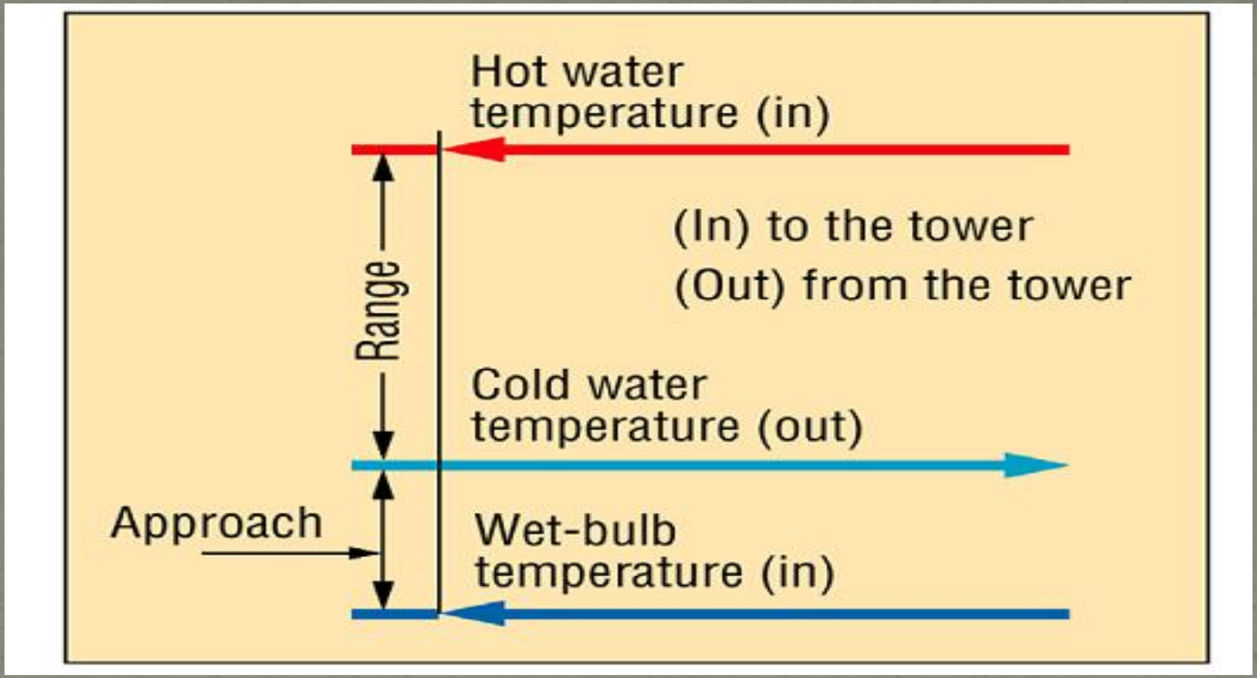


Fig. Schematic of Important Cooling Tower Parameters

Sources of Water Loss

- Evaporative loss
- Drift loss
- Blow down loss

Calculation of different types of Losses

Evaporation Loss (Cu m/hr) = (.00085 *1.8* circulation rate (Cu m/hr)*(T_1-T_2)
Where T_1 and T_2 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 :

Pressure Drop = K * (Air Velocity/4008.7)^2 * 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 calculated 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

S.No	Tower Section	K value Range
1.	Fill	Not available
2.	Drift Eliminator	1.6 – 3.0
3.	Fan Inlet	.1 - .3
4.	Water Distribution Piping	Usually included drift eliminator

	Air Inlet section (Type)	K value Range
With Louvers	Large , widely spaced louvers	2.0 - 3.0
	Small , narrow louvers	2.5 – 3.5
Without louvers	Square edge beams and square columns	1.5
	Rounded beams(R= .04*H) and Columns (R = .04 * W)	1.3
	Tapered beams and columns at 30 degree (R= .01* W)	1.2

Factors affecting Tower Performance

- Capacity
- Range
- Approach
- Wet Bulb Temperature of inlet air
- L/G ratio
- Cooling tower effectiveness

Velocity recovery at fan stack

- 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.

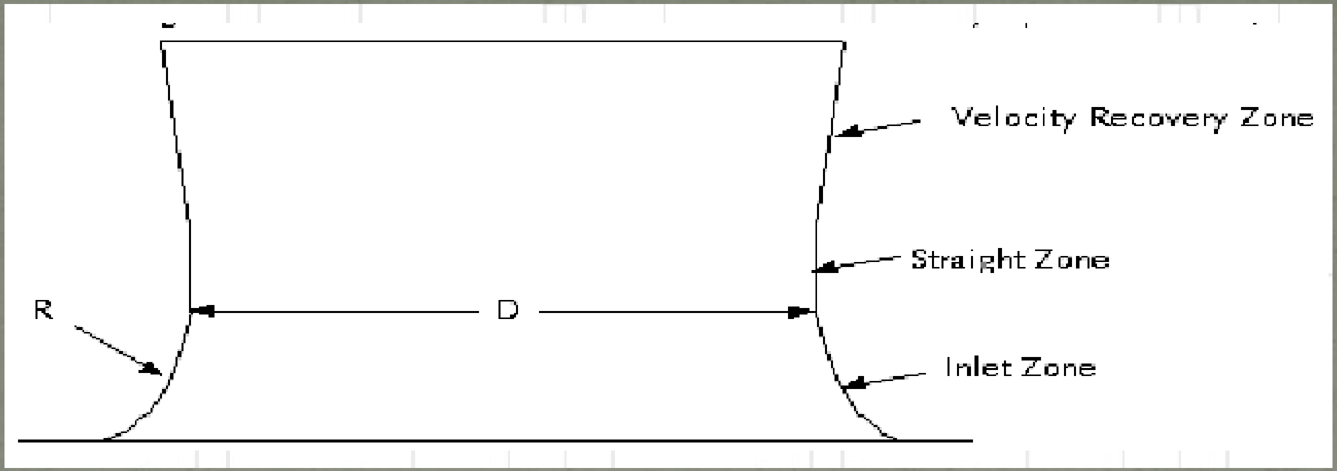
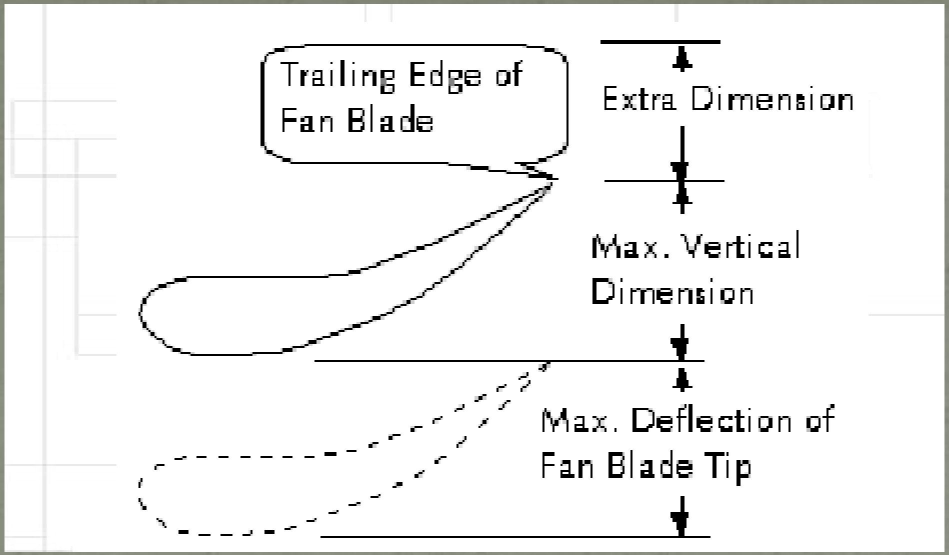


Fig. A typical Fan stack with various different zones

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

Velocity Recovery zone Height

Typically R/D = .15 or R/D = .1

1. Inlet height zone = R = (.15)* Fan diameter
   = (.1)* 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 = (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 = .8 - [.2 * (venturi height / fan diameter)* (velocity pressure @ Fan - velocity pressure @ Top of the Fan stack)]

Fan stack efficiency = .8 - [.2 * (venturi height / fan diameter)]

Both the above formulas use a taper angle of 7 degree .

Type of Fans

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.

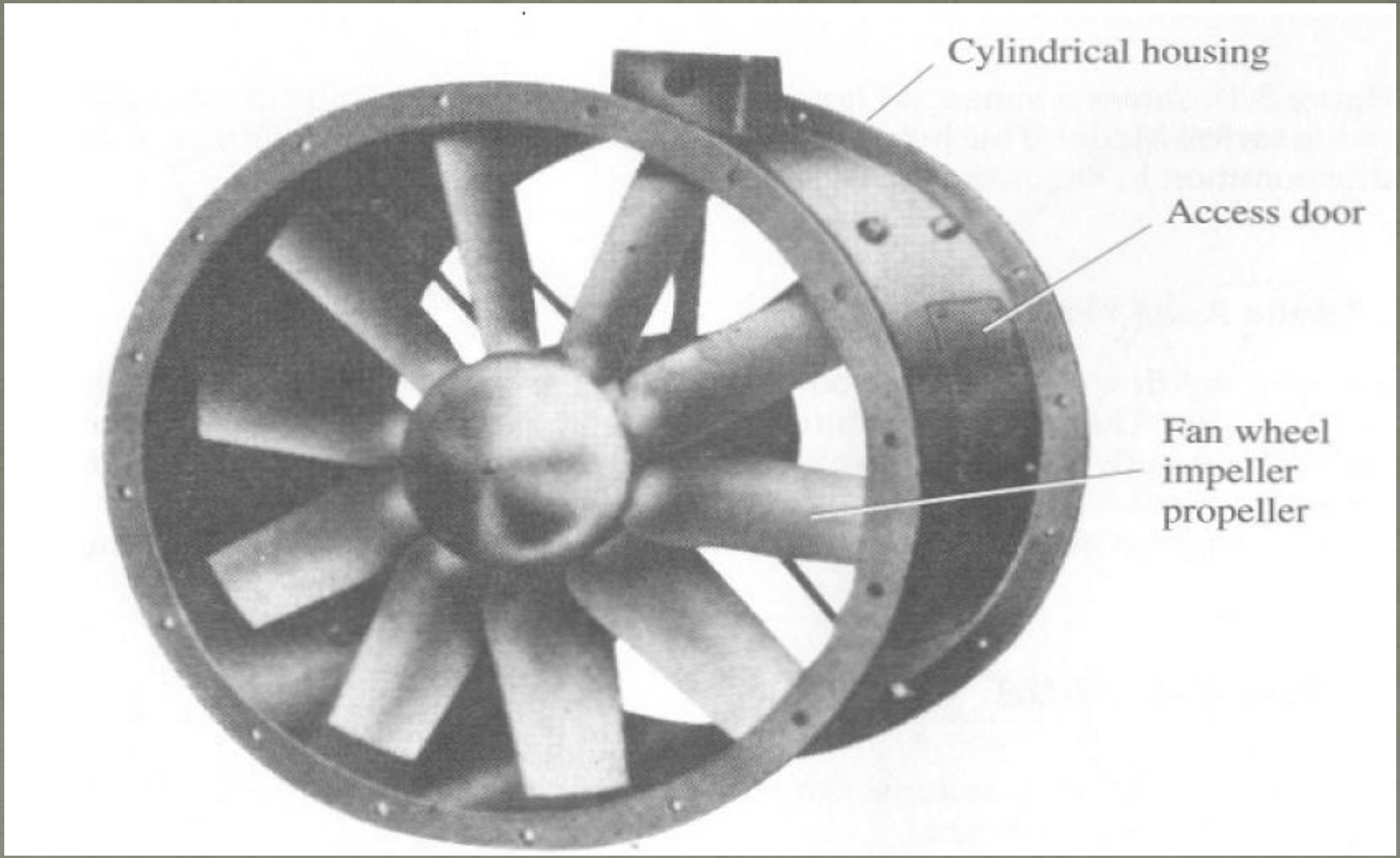


Fig. Tubeaxial Fan with direct drive from an electric motor on the inlet and with a fan wheel having a 33% hub to tip ratio and ten blades

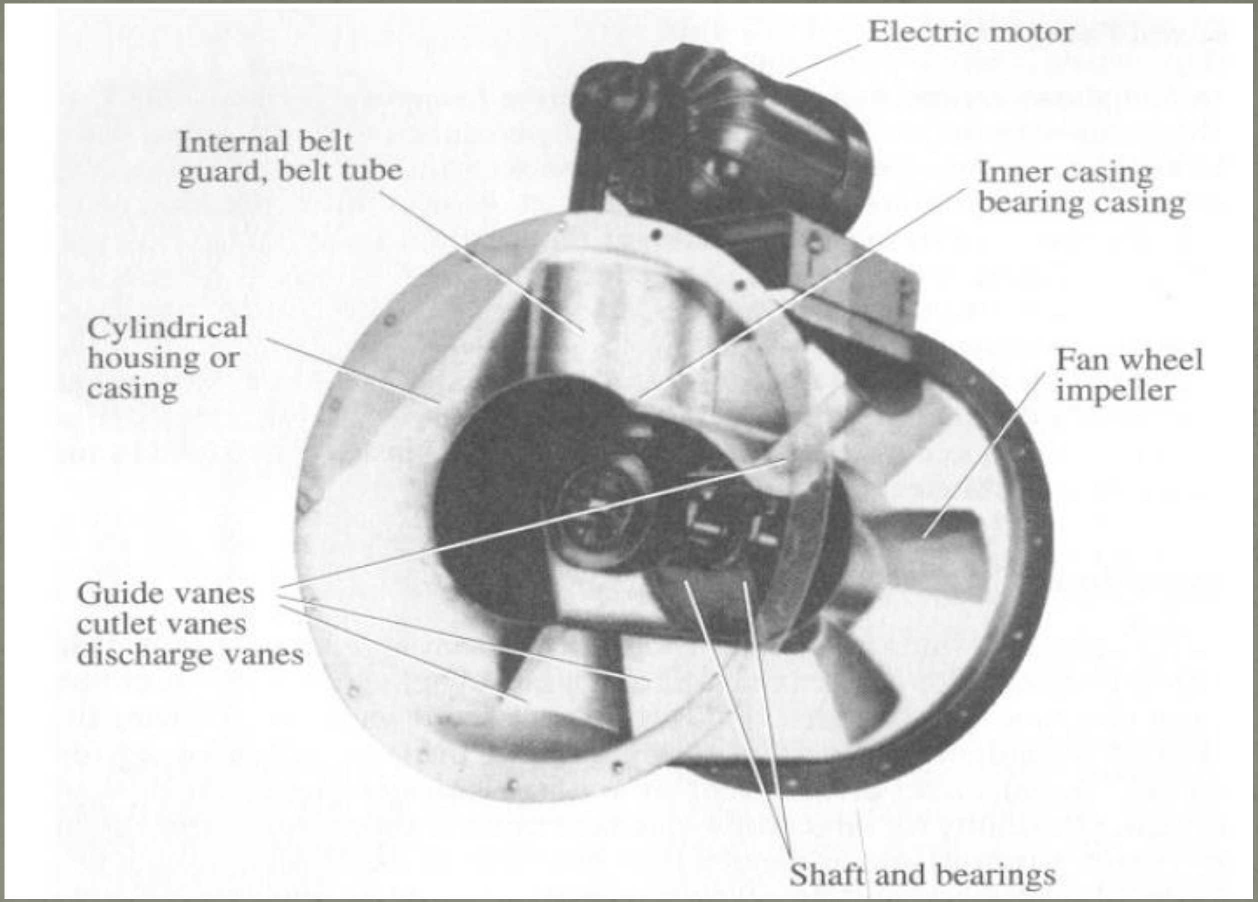


Fig. Vaneaxial fan with belt drive from an electric motor with fan wheel having 46% hub to tip ratio and nine airfoil blades

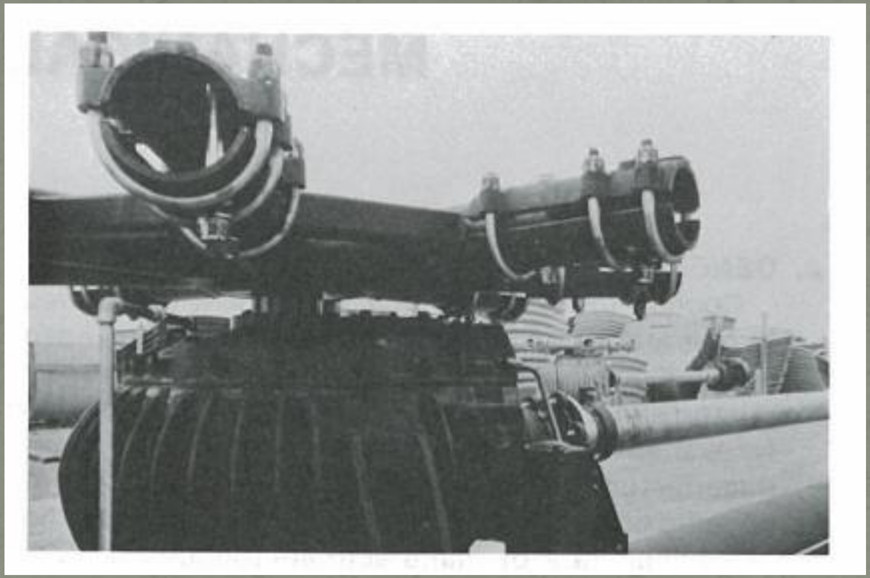


Fig. A Typical hub for large fans

Centrifugal 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 .

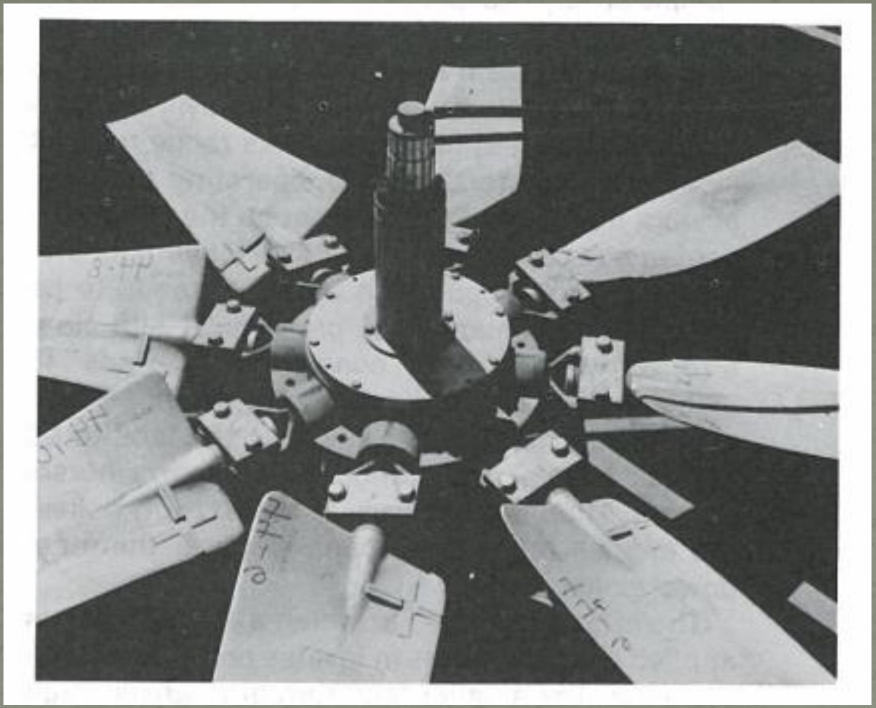


Fig. Automatic variable pitch

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 , 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 Calculation

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 Temperture (DHWT) =

Designed Cold water Temperature (DCWT) =

Designed Wet Bulb Temperature (DWBT) =

Cooling Tower Equation

$$\frac{KS}{L} = \frac{KaV}{L} = Cw\int_{tw1}^{tw2} \frac{dtw}{hw - ha}$$

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" .

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
Cw = is the specific heat of water
hw = enthalpy of air-water vapor mixture at bulk temperature of water
ha = enthalpy of air –water vapor mixture at the wet bulb temperature
tw1 = inlet water temperature
tw2 = 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.

Mechanism of Cooling

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

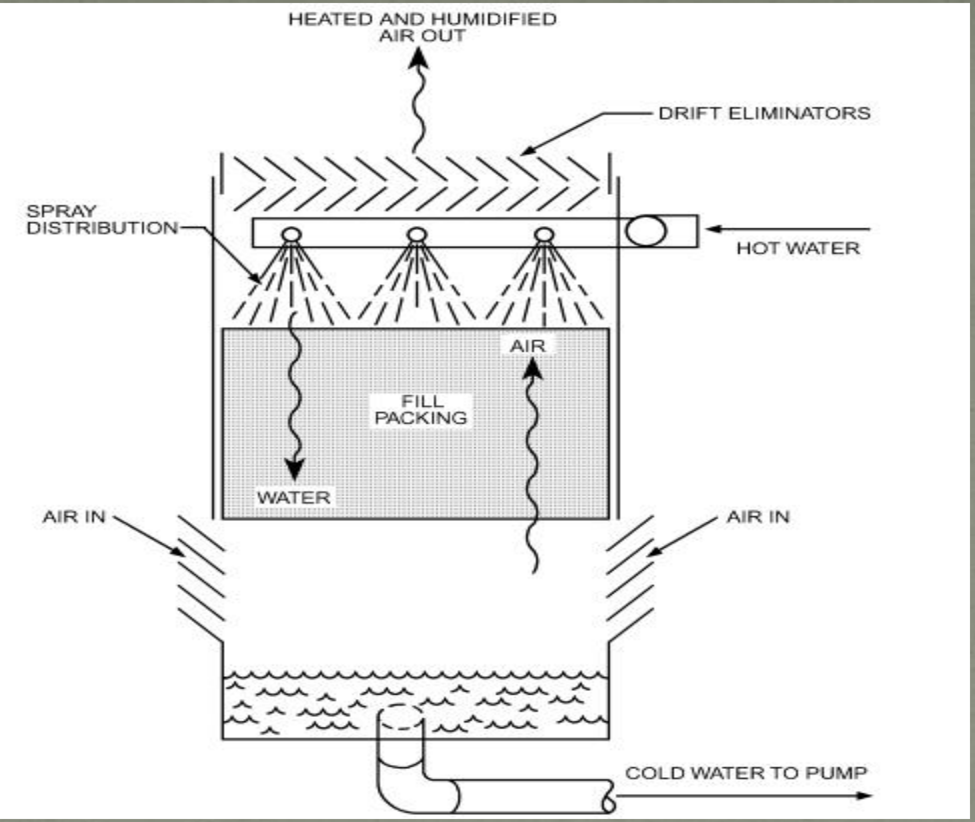


Fig. A direct contact or Open Evaporative Cooling Tower

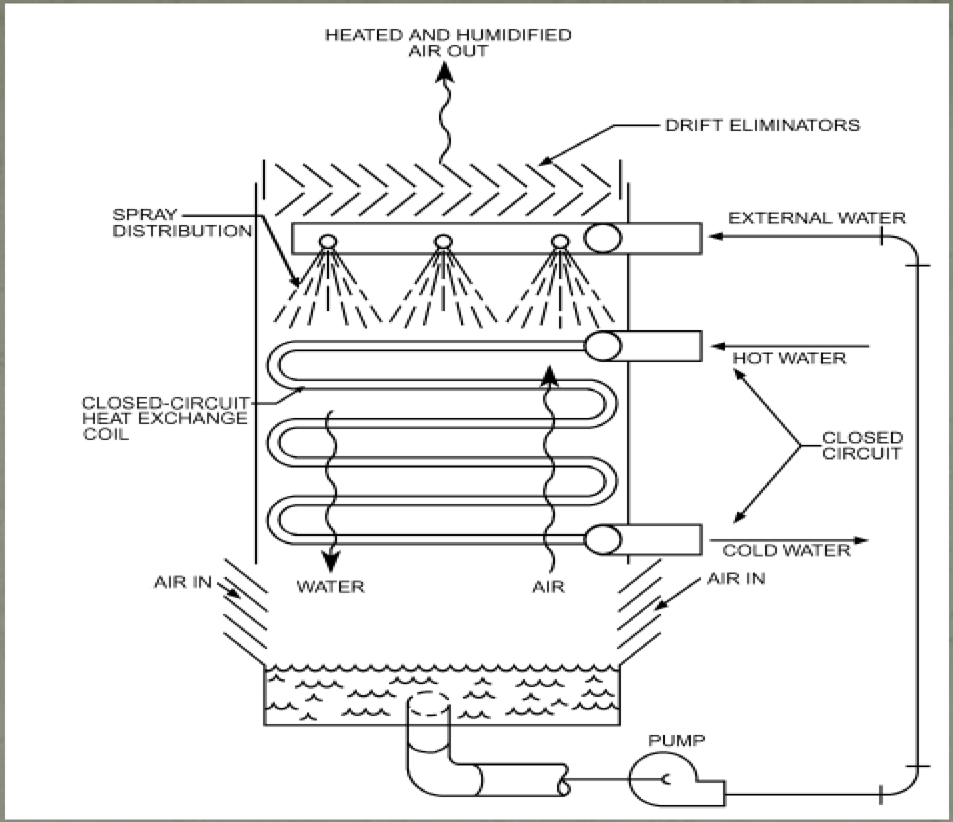


Fig . Indirect Contact or Closed Circuit Evaporative Cooling Tower

Cooling Tower Design Specifications

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