Chapter 5
Cooling Tower Design

The place where acquisition of land is very expensive, we may use cooling tower for cooling purposes. A cooling tower requires smaller area than a spray pond. It is an artificial device used to cool the hot cooling water coming out of condenser effectively. The cooling tower is a semi – enclosed device made of steel or concrete structure and corrugated surfaces or trough or baffles are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenser falls down in radial sprays from height and the atmospheric air enters from the base of the tower. The partial evaporation of water takes place which reduces the temperature of circulating water.

This cooled water is collected in the pond at the base of the tower and pumped into the condenser. Draft eliminators are provided at the top of the tower to prevent the escaping of water particles with air.

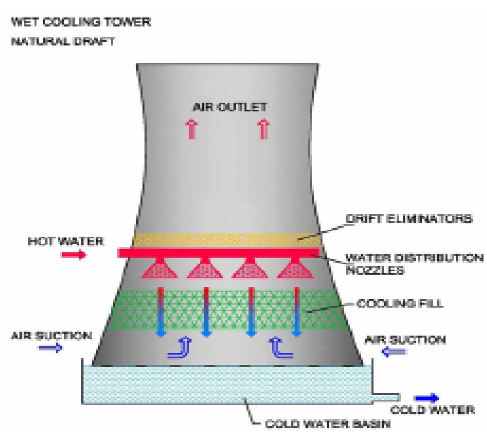
According to the method of air circulation, cooling towers are classified as:

1. Natural draught type cooling tower
2. Mechanical draught type cooling tower
   a. Forced draught type
   b. Induced draught type
3. Hyperbolic draught cooling tower

Natural draught type cooling tower

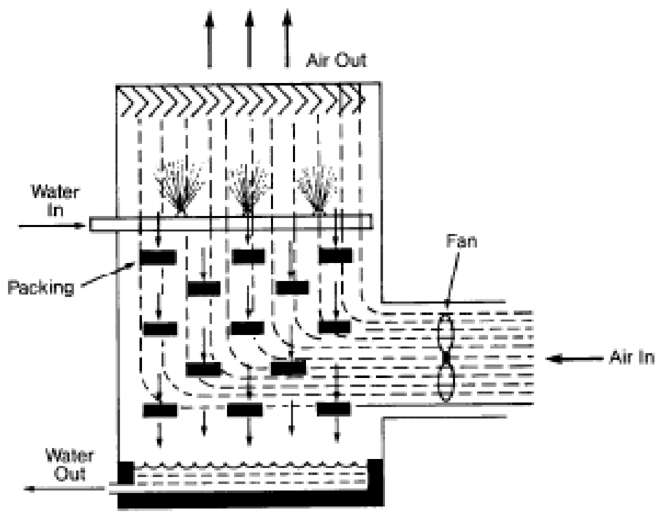
In this hot water from condenser is pumped at the top where water sprays through a series of spray nozzles. Then waterfalls over decks, the decks also increase the amount of wetted surface in the tower and breaks up the water into droplets.

The air flowing across in transverse direction cools the falling water. These towers are used for small capacity power plants such as diesel power plants.



Forced draught cooling tower

In this tower draught air fan is installed at the bottom of tower. The hot water from the condenser enters the nozzles. The water is sprayed over the tower filling slats and the rising air cools the water. The entrained water is removed by eliminators located at the top.



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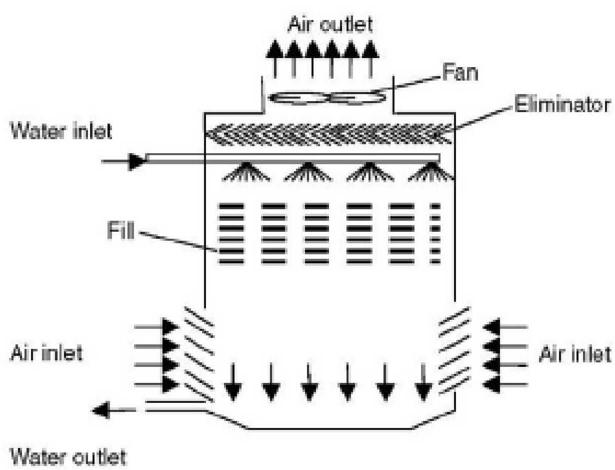
Induced draught cooling tower

The difference here is in the supply of air. The drought fans installed at the top of tower draw air thought the tower. The hot water is allowed to pass thought the tower bellow the eliminators. The air moving in the upward direction cools the down coming hot water particles issued from spray nozzles some percentage (1%) of total water goes into air in the form of water vapour.



Hyperbolic cooling tower

It is usually made of steel reinforced cement concrete to withstand high wind pressure. First type of this type was installed in US at big sandy station of kenvcky power Co. It is capable of handling $120x10^3$ gpm and cools the water from 43oc to 30^oC. It has minimum diameter of 39.5 m and maximum diameter of 74.5 m and 400 meters high.

The hot water from the condenser is supplied to the ring troughs. Which are placed at 8-10 m above the ground level? The nozzles are provided on the bottom side of troughs to break up water into sprays. The air enters the cooling tower just above the pond located at the bottom, from the air openings provided, rises upward and absorbs heat from the falling water spray. The cooled water is collected into the pond. Some makeup water is supplied to overcome the losses into the atmosphere along with air due to evaporation. It needs about 35% of makeup water for compensating. This type of cooling tower is generally used since it is very efficient.

Advantages:

(1) No air fans are required so power cost and auxiliary equipments are totally eliminated.

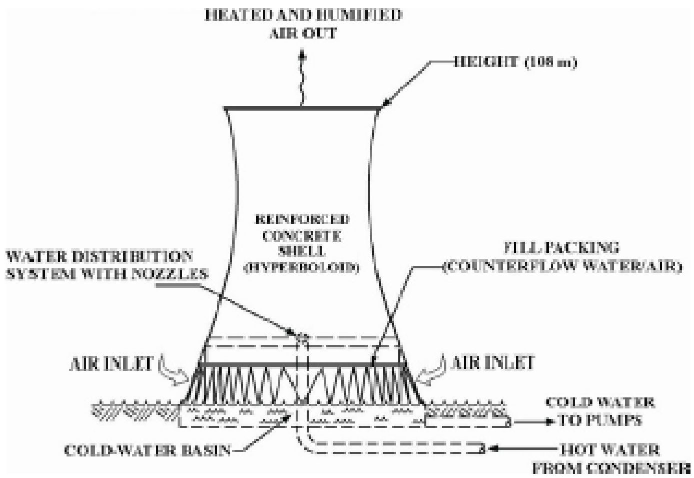
(2) Hyperbolic structure creates its own draught assuring efficient operation even when there is no wind.

(3) Operation and maintenance cost are reduced.

(4) Ground fogging is avoided in hyperbolic towers.

Major drawbacks

(1) Its initial cost inconsiderably very high.
(2) Its performance varies with the personal changes in DBT and RH of air.



Cooling water supply

For the condensation of steam into condensate to be used as feed water to the boiler, cooling water has to be supplied to the condenser. If there is abundant source of cooling water like river or pond, there is no problem. But if the supply of water is limited with high cons, it is necessary to use cooling tower for water cooled condensers. The method commonly used to overcome a condition of limited cooling water supply is to repeatedly cool and circulate it through as shown in Figure 9.

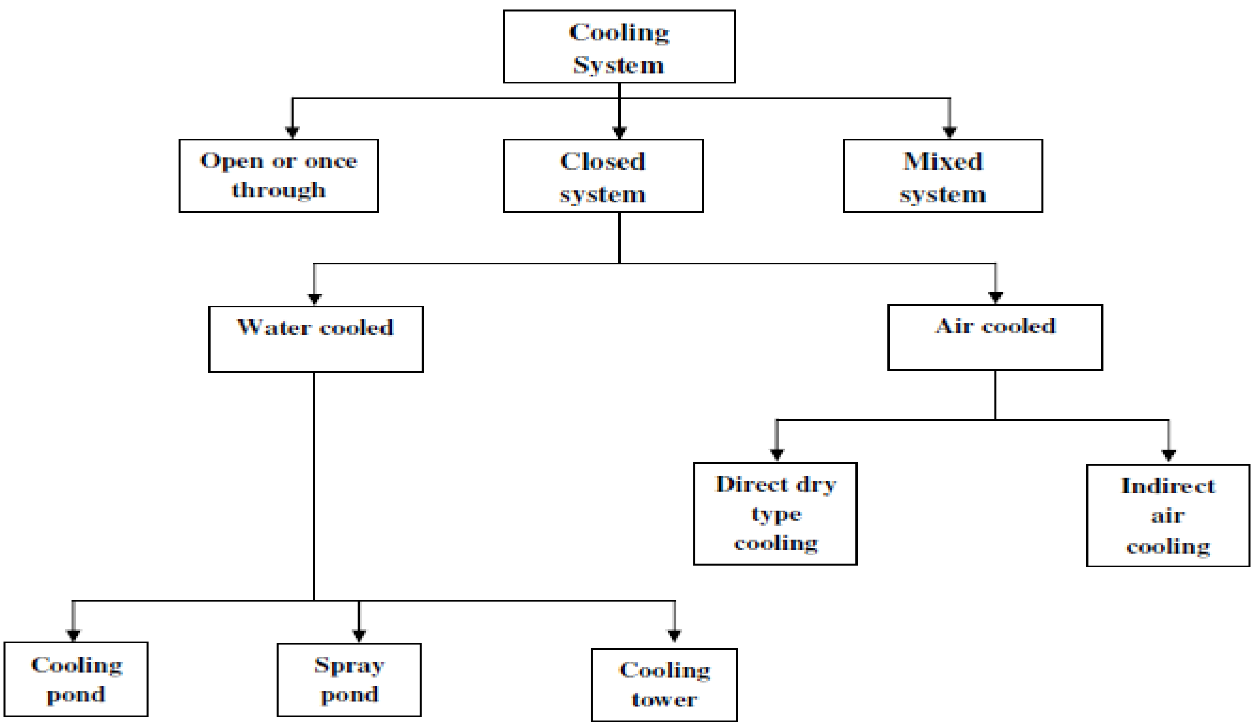


Figure 9

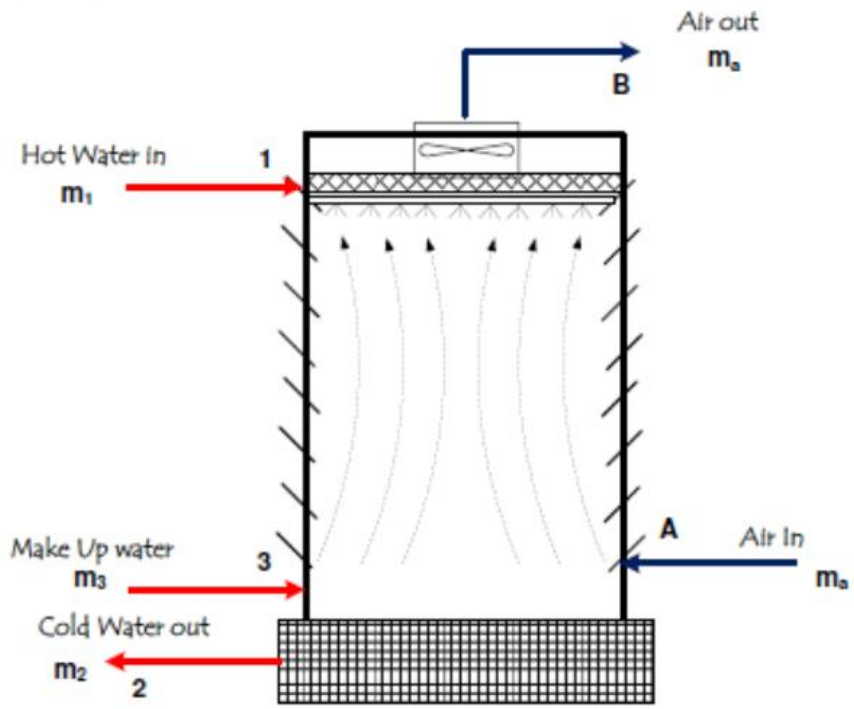
Cooling pond

The simplest system of removing heat from the cooling water consists of cooling it in an open pond. The effectiveness of this method depends upon a very long surface area of the pond and hence it is used mostly for small condenser only. In this system sufficient amount of water is lost by evaporation and windage. The factors which affect the rate of heat dissipation from cooling pond are area and depth of pond, temperature of water entering the pond and wind velocity, atmospheric temperature, shape and size of water spray nozzle and relative humidity. Cooling ponds are of two types namely:

1. Non directed flow type
2. Direct flow type

COOLING TOWER

A Cooling tower is a wind braced enclosure or shell usually made of wood, concrete or metal with fillings on the inside to aid water exposure. The water to be cooled is pumped into a distributing header at the top of the tower from which it drops in sprays to the filling. The water spreads out in the filling thus exposing new water surfaces to the air circulating through the tower. The cooled water drops to the bottom of the tower called the catch basin. The air circulating through the tower becomes partially saturated with moisture by evaporating some amount of water. This evaporation is mostly what cools the water.



1. Actual Cooling Range

$$ACR = t_1 - t_2$$

Where:

ACR – Actual Cooling Range
t_1 – hot water temperature, °C
t_2 – cold water temperature, °C

2. Cooling Tower Approach

$$CTA = t_2 - t_{wA}$$

Where:

twA – entering wet bulb temperature of air, °C

3. Theoretical Cooling Range

$$TCR = t_1 - t_{wA}$$

$$e = \frac{ACR}{TCR} \times 100\%$$

$$e = \frac{t_1 - t_2}{t_1 - t_{wA}} \times 100\%$$

4. Total Pressure

$$P = Pa + Pv \quad KPa$$

5. Vapor Pressure

$$Pv = Pw - PA(t_d - t_w) \quad KPa$$

Where:

$$A = \frac{6.66 \times 10^{-4}}{°C} \times 100\% \rightarrow \text{if } tw \geq 0°C$$

$$A = \frac{5.94 \times 10^{-4}}{°C} \times 100\% \rightarrow \text{if } tw < 0°C$$

6. Specific Humidity or Humidity Ratio

$$W = \frac{0.622Pv}{P - Pv} \ \frac{km}{kgda}$$

7. Relative Humidity

$$RH = \frac{Pv}{Pd} \times 100\%$$

8. Enthalpy

$$h = 1.0045t_d + W(2501.3 + 1.86t_d) \ \frac{KJ}{kgda}$$

9. Specific Volume

$$\upsilon = \frac{0.287(t_d + 273)}{P - Pv} \ \frac{m^3}{kgda}$$

10. Degree of Saturation

$$\mu = RH\left(\frac{P - Pd}{P - Pv}\right)$$

11. By moisture balance in the tower:

a) With make up water, $m_1 = m_2$

$$m_3 = m_a(W_B - W_A) \quad kg/sec$$

b) Without make up water available, $m_1 \neq m_2$:

$$m_1 - m_2 = m_a(W_B - W_A) \quad kg/sec$$

$$m_2 = m_1 - m_a(W_B - W_A) \quad kg/sec$$

12. By energy balance in the tower:

a) With make up water

$$m_a = \frac{m_1(h_1 - h_2)}{(h_B - h_A) - (W_B - W_A)h_3} \quad kg/sec$$

$$h_2 = \frac{m_1 h_1 - m_a\left[(h_B - h_A) - (W_B - W_A)h_3\right]}{m_1} \quad KJ/kg$$

$$t_2 = \frac{h_2}{4.187} \ °C$$

b) Without make up water

$$m_a = \frac{m_1(h_1 - h_2)}{(h_B - h_A) - (W_B - W_A)h_2} \quad kg/sec$$

$$h_2 = \frac{m_1 h_1 - m_a(h_B - h_A)}{m_1 - m_a(W_B - W_A)} \quad KJ/kg$$

$$t_2 = \frac{h_2}{4.187} \ °C$$

13. Driving Pressure

$$\Delta P_d = \frac{gH(\rho_o - \rho_i)}{1000} \quad KPa$$

14. Mass Flow rate of air and vapor mixture

$$m = m_a(1 + W)\frac{kg}{sec}$$

$$m = m_a + m_v$$

15. Cooling water flow rate related to Brake Power of an Engine

$$m = 904.3\left[\frac{\text{Brake Power}}{t_1 - t_2}\right]$$

where:

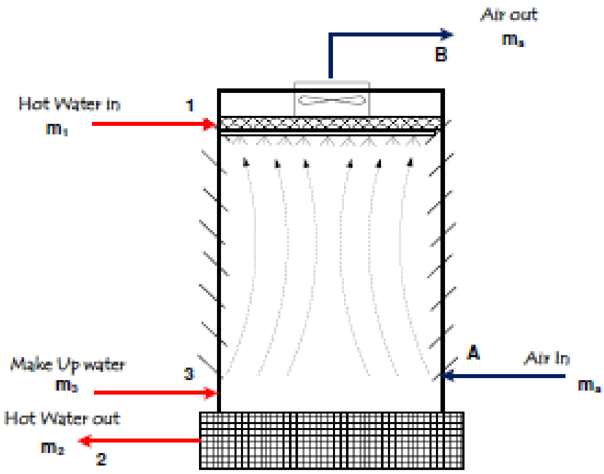
m_1 - mass flow rate of water entering tower in kg/sec
m_2 - mass flow rate of cooled water in kg/sec
m_3 - make up water in kg/sec
h_1 - enthalpy of hot water in KJ/kg
h_2 - enthalpy of cooled water in KJ/kg
h_3 - enthalpy of make up water in KJ/kg
h_A - enthalpy of air entering tower in KJ/kgda
h_B - enthalpy of air leaving tower in KJ/kgda
W_A - humidity ratio of air entering tower in kgm/kgda
W_B - humidity ratio of air leaving tower in kgm/kgda
m_a - mass flow rate of dry air in kg/sec
t_d - dry bulb temperature in °C
t_w - wet bulb temperature in °C
t_1 - temperature of hot water, °C
t_2 - temperature of cooled water, °C
t_3 - temperature of make up water, °C
H - tower height, meters
ρ_o - density of outside air and vapor mixture, kg/m^3
ρ_i - density of inside air and vapor mixture, taken at exit of the fill, kg/m^3

Example No. 1

A cooling tower receives 3.2 L/sec of water at 46°C. Atmospheric air at 16°C DB and 55% RH enters the tower at 3 m^3/sec and leaves at 32°C saturated. Determine:

a) the volume of water leaving the tower in L/sec (3.08 L/sec)

b) exit temperature of water in °C. (25.15°C)



Using Fundamental formulas or Psychrometric chart

At 16°C and 55% RH

$$W_A = 0.00621 \frac{kgm}{kgda}$$

$$h_A = 31.792 \frac{KJ}{kgda}$$

$$\upsilon_A = 0.8278 \frac{m3}{kgda}$$

At 32°C and 100% RH

$$W_B = 0.030712 \frac{kgm}{kgda}$$

$$h_B = 110.803 \frac{KJ}{kgda}$$

$$\upsilon_B = 0.9077 \frac{m3}{kgda}$$

$$m_a = \frac{m_1(h_1 - h_2)}{(h_B - h_A) - (W_B - W_A)h_2} \quad kg/sec$$

$$h_2 = \frac{m_1 h_1 - m_a(h_B - h_A)}{m_1 - m_a(W_B - W_A)} \quad KJ/kg$$

For water @ 46°C

$$\rho = 990 \frac{kg}{m^3}$$

$$m_1 = 3.2 \frac{L}{sec} x \frac{1m^3}{1000L} x 990 \frac{kg}{m^3} = 3.168 \frac{kg}{sec}$$

$$ma = 3 \frac{m^3}{sec} x \frac{1}{0.8278 \frac{m^3}{kg}} = 3.62 \frac{kg}{sec}$$

Without considering makeup water