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Study and Design of Cooling Tower

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Abstract:
Cooling tower is used by industries, power plants to lower the temperature of water (usually in large quantity) efficiently and economically. There are different factors affecting the performance of the cooling tower which should be considered while designing. This paper focuses on construction, working principle, classification, factors affecting performance of cooling tower and design of counter flow cooling tower.

Keywords: Cooling Tower, Evaporative cooling, Counter flow, Induced draft

I.INTRODUCTION

Cooling tower is heat and mass transfer device that rejects heat to the atmosphere through the cooling water stream to lower the temperature of water coming out from process e.g hot water at condenser outlet. The type of cooling is generally termed as 'Evaporative Cooling' as majority of heat transfer occurs by evaporation. Cooling towers either use evaporation of water to remove process heat from hot water coming from process and cool working fluid near wet bulb temperature (WBT) or use only air to cool working fluid near dry bulb temperature (DBT). The heat lost by water is heat gained by air and cooled water is then recirculated in process. The performance depends on cooling range, approach, ambient air wet bulb temperature, flow of water to be cooled, rate at which air is passed over the water, temperature level, performance coefficients of the packing to be used and the volume of packing. Cooling towers are used in various applications like manufacturing processes, power generation, air conditioning, oil refining, chemical processing, etc. Cooling towers are able to lower the water temperatures more than devices that use only air to reject heat, like the radiator in a car therefore more cost-effective and energy efficient. The main advantages of the cooling tower over other conventional heat exchangers are a) they can achieve temperature below temperature of air used to cool it and b) they are smaller and cheaper for same cooling load.

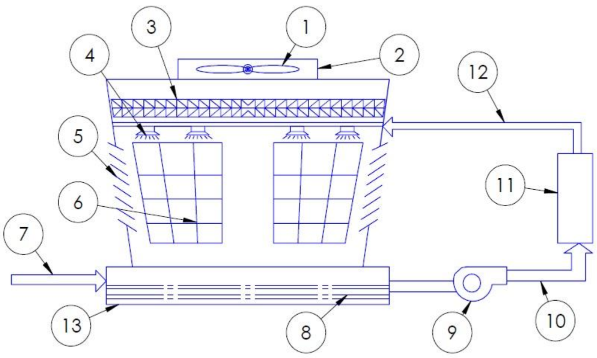


Figure.1. Cooling Tower Schematic

Nomenclature: 1.Fan , 2. Fan Deck, 3. Drift Eliminators, 4. Nozzles, 5. Louvers, 6. Fill or Packing Material, 7. Makeup Water source, 8. Water with concentrated dissolved salts, 9. Pump, 10. Cooled water to process, 11. Process, 12. Warm water, 13. Cold water basin

II. PRINCIPLE OF OPERATION

Cooling tower is essentially a mass and heat transfer device which works on principle of evaporative cooling. It removes heat from water which is then gained by air coming in contact with it and as a result of evaporation, it loses a fraction of water. When blown concurrently or counter currently, air comes in contact with water, the enthalpy of which is higher and at the time of contact, this air causes evaporation of water droplet. It is known that during evaporation process latent heat exchange takes place which in turn results into conversion of water droplet into vapor form. Due to removal of sensible heat remaining water droplet loses temperature and cools down. The water distribution system atomizes water into small droplets and spreads it over larger area. The packing material is provided to increase the area on which water to be spread. Due to higher surface area in packing heat transfer rate increases and water is further cooled to required temperature. Air passed water droplets takes away certain amount of water content in vapor form with it which is not desirable. Therefore, to recover lost water, drift eliminates are provided below the fan deck arrangement. The makeup water source is used to replenish water lost due to evaporation. The cooled water falls downward and is collected in the basin and supplied to the process as and when needed.

III. COMPONENTS OF COOLING TOWER

1) Casing or Shell: The outer structure which encloses the heat transfer process and supports all the other components is called as Casing of cooling tower.
2) Drift eliminator: Drift eliminators reduce water loss through cooling tower, thereby preventing carriage of water droplets outside by outlet air stream.
3) Water distribution system: It includes piping, valves and nozzles to distribute water over the fill material. It is located in between drift eliminators and fill material.
4) Packing or Fill material: In cooling towers, factor which influences the 'heat transfer rate' most, is area of contact between air and water. Fill material is the material which is used to increase the heat transfer rate by allowing increased contact area between air and water.

5) Cold water basin: It is situated at bottom of the cooling tower structure wherein cooled water is collected and sent for reuse. It requires a number of connections for the followings

- For make-up water from supply mains along with means of control for maintaining water level.
- water treatment
- Provision for immersion of electric heater, to avoid freezing of pump suction outlet.
- Connection for cooled water return

6) Louvers: Primarily used in cross flow cooling tower to equalize the inlet air flow and to confine the water inside cooling tower.

7) Fans: Air is used as cooling medium in cooling towers. Thus, fans are used in mechanical draft cooling towers to force the air through fill material to increase heat transfer rate by increasing air flow rate.

IV. IMPORTANT PARAMETERS TO DETERMINE COOLING TOWER PERFORMANCE

- Dry Bulb Temperature (D.B.T.): It is the temperature indicated by thermometer when it is directly exposed to air, when thermometers bulb is not affected by moisture.
- Wet Bulb Temperature (W.B.T.): It is temperature recorded by thermometer when bulb of thermometer is covered with wet cloth.
- Range: It is the difference between the cooling tower water inlet and outlet temperature.
- Approach: It is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature.
- Cooling Tower Effectiveness: It is ratio of range to the ideal range, i.e. difference between cooling water inlet temperature and ambient wet bulb temperature.

ε = Range / (Range + Approach)

- Cooling capacity: Amount of water that a cooling tower will cool through a specified range, at specified approach and WBT. It is the product of mass flow rate of water, specific heat and temperature difference (Range).
- Evaporation loss: It is the water quantity evaporated for cooling duty and, theoretically, for every 10,00,000 kCal heat rejected, evaporation quantity works out to 1.8 m3. An empirical relation used often is:

Evaporation Loss (m^3/hr) = 0.00085 x 1.8 x circulation rate (m^3/hr) x (T_1-T_2)

(T_1-T_2) = Temperature difference between inlet and outlet water.

- Cycles of concentration (C.O.C): It is the ratio of dissolved solids in circulating water to the dissolved solids in make-up water.
- Liquid/Gas (L/G) ratio: It is the ratio of mass flow rate of water t0o the mass flow rate of air.

It can be calculated using following equation

$L(T_1 - T_2) = G(h_2 - h_1)$

$$\frac{L}{G} = (h_2 - h_1)/(T_1 - T_2)$$

Where:

L/G = liquid to gas mass flow ratio (kg/kg)
T_1 = hot water temperature (°C)
T_2 = cold water temperature (°C)
h_2 = enthalpy of air-water vapor mixture at exhaust wet-bulb temperature
h_1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature

- Heat Load- It is the amount of heat required to remove from the water, which is to be cooled.

V. COOLING TOWER DESIGN

Design of Cooling Tower for following Technical Specifications is explained below:

Inlet temperature of water (T_1) =45°c
Outlet temperature of water (T_2) =35°c
Dry bulb temperature of water (DBT) =29°c
Wet bulb temperature of water (WBT) =25°c
Relative humidity =72%
Water flow rate (L) =9000 m^3 /hr
Ka varies between 64 to 140, i.e. 95±35 (From 16 CT, built by research cotrel)
And 100±30 (from 39 Cooling Towers, Marley Co.)
It is trial and error procedure, to determine the optimum value.

DATA FROM PSYCHOMETRIC CHART AND STEAM TABLE:

1. Enthalpy of air at inlet temperature (H_{a1}) =76.39 KJ/kg
2. Enthalpy of air at outlet temperature (H_{a2}) =154.52 KJ/kg
3. Enthalpy of water at inlet temperature (H_{w1}) =188.10 KJ/kg
4. Enthalpy of water at outlet temperature (H_{w2}) =146.545 KJ/kg
5. Specific humidity of air at inlet temperature (W_1) =0.0201kg/kg of air
6. Specific humidity of air at outlet temperature (W_2) =0.0451 kg/kg of air
7. Specific volume of air at inlet temperature (V_{s1}) =0.8722m^3/kg
8. Specific volume of air at outlet temperature (V_{s2}) =0.9473 m^3/kg

DESIGN PROCEDURE:

Range=T_1-T_2=45-35°c=10°c
Approach=T_2-WBT=35-25=10°c
(For economic Design, approach should be greater than 3°c.)
It is assumed that , for well designed cooling tower , outlet air temperature is average of inlet and outlet water temperatures. Hence,

outlet air temperature (t_2) = $\frac{T1+T2}{2}$ =40°c

Also, outlet air is assumed to be saturated for optimum performance.
Therefore, enthalpy of air at outlet (h_2)=166.65KJ/Kg
(Air flow rate may vary±10% of optimum air flow.
During cooling process, for every 10°f drop in temperature of water 1% water evaporates. Evaporation being very small, is commonly neglected.)

DETERMINATION OF L/G RATIO:

Heat lost by water is equal to heat gained by air, Hence

$$\frac{L}{G} = \frac{h2 - h1}{Cp(T1 - T2)}$$

Where,
h_1= enthalpy of air at inlet =76.39 KJ/Kg.

$$\frac{\frac{9000*1000}{3600}}{G} = \frac{166.65-76.39}{4.187(45-35)}$$

G=1159.71Kg/s

Heat transfer in cooling towers occurs by two major mechanisms: Sensible heat transfer from water to air (convection) and transfer of latent heat by the evaporation of water, at air water boundary layer. The total heat transfer is sum of these two boundary layer mechanisms. The total heat transfer can also be expressed in terms of change in enthalpy of each bulk phase. Fundamental equation of heat transfer in cooling tower is given by F. Merkel which is known as Merkel's equation.

$$(\frac{Ka\bar{V}}{Lcp})=\int_{T2}^{T1}(\frac{dT}{hsa-ha})$$

The right hand side of Merkel's equation is difficult to calculate as terms (h_{sa}-h_a) can't be expressed in terms of temperatures. Hence, alternate method i.e. Simpson's rule is used to evaluate the integral.

CALCULATED TOWER CHARACTERISTICS BY SIMPSON RULE:

Dividing range into Five equal sections of 2.0°c

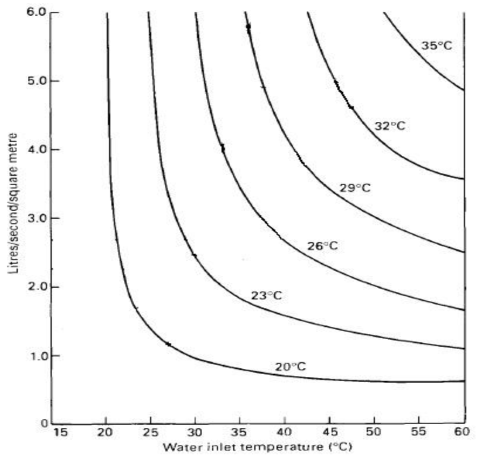
T(°c)	h_{sa}	h_a	$(h_{sa} - h_a)^{-1}$
35	129.38	101.88	0.03636
37	143.23	112.12	0.03214
39	158.46	123.3	0.02844
41	176.24	135.49	0.02515
43	193.75	148.82	0.02225
45	214.2	163.4	0.01968
			AVG=0.02736

TOWER CHARACTERISTICS:

$$(\frac{Ka\bar{V}}{\bar{L}}) = C_{pw} \times \text{Range} \times (\frac{1}{hsa-ha})_{AVG}$$

=1.1455

DETERMINATION OF LOADING FACTOR ($\bar{L}$):



Curved lines on graph indicate outlet water temperature

From graph, ($\bar{L}$)= 3.5 L/ s/ m^2

DETERMINATION OF AREA OF PACKING/FILL:

$$B=\frac{L}{\bar{L}} = \frac{9000*1000}{3600}/3.5 = 714.28\ m^2$$

DETERMINATION OF TOWER DIMENSIONS:

$$Z=(\frac{Ka\bar{V}}{\bar{L}}) * \frac{L}{Ka}$$

Ka=100 lbs of air/(hr.Ft^3)

Ka=0.4449 kg of air/sec m^3

EFFECTIVE TOWER HEIGHT:

Z=9.01 m

HEAT LOSS BY WATER (HL):

HL = Lx C_p (T1– T2)

=376.74 x10^6 KJ/hr

VOLUME OF AIR REQUIRED (V):

V= (HL x Vs1) / [(Ha2– Ha1) - (W2– W1) x Lx T2]

=4.4125 x10^6 m^3/hr

HEAT GAIN BY AIR (HG):

HG= V x [(Ha2– Ha1) - (W2– W1) x Lx T2] / Vs1

=376.74x10^6 KJ/hr

MASS OF AIR REQUIRED (Ma):

Ma=Volume of air required / Specific volume of air at inlet temperature

= V / V_{s1}

=5.0591x10^6 kg/hr

THE QUANTITY OF MAKE-UP WATER (Mmak):

Mmak= V x (W_2– W_1) / Vs2

=502.74x10^6 kg/hr

Now, taking Evaporating loss in calculation

(Mmak)= 502.7432x10^6x [1 + (1.44/100)]

=509.98x10^6 kg/hr

EFFECTIVENESS OF COOLING TOWER

$\varepsilon = (T_1 - T_2) / (T_1 - T_{a1})$

=50%

DIFFERENT TYPES OF LOSSES:

1. DRIFT LOSSES (DL):

Drift losses are generally taken as 0.10 to 0.20% of circulating water

(DL) = 0.20 x L/ 100

=18x10^3 kg/hr

2. WINDAGE LOSSES (WL):

Windage losses are generally taken as 0.005 of circulating water.

WL = 0.005 x L

=45x10^3 kg/hr.

3. EVAPORATION LOSSES (EL):

Evaporation losses are generally taken as 0.00085 of circulating water.

EL = 0.00085 x Lx (T1– T2)

=76.5x10^3 kg/hr

4. BLOW DOWN LOSSES (BL):

Number of cycles required for cooling tower is given by

Cycles = XC / XM

Where,

XC = Concentration of solids in circulating water

XM = Concentration of solids in Make-up water

Water balance equation for cooling tower is

M = WL + EL + DL

=139.5x10^3 kg/hr

XC / XM = M / (M - EL)
=2.2142 cycles
So, Blow down loss
BL = EL / (Cycles - 1)
=92.8863x10^3 kg/hr

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