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Experimental Study of the Performance of Cooling Tower

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Abstract: ***Cooling tower is an essential component of air conditioning plant, chemical plant etc. It is used to reduce the temperature of hot water stream by using outside air and thus heat is rejected to atmosphere .This paper includes the working principle of cooling tower and a set up is fabricated and various parameters related to cooling tower is calculated i.e. range, approach, effectiveness and evaporation loss. Validation of practical model is done using empirical relation. Various equations i.e. Modified Apjohn equation, Modified Ferrel equation and Carrier equation are provided. Carrier equation is used for determining vapour pressure and thus humidity ratio and finally which can be used to determine evaporation loss.***

Keywords: Cooling tower, DBT (Dry Bulb temperature), WBT (Wet Bulb temperature), Evaporation loss, Effectiveness

1. Introduction

Water is a scare resource on earth and it is effectively used for cooling. In refrigeration system heat is rejected at condenser. Generally for high capacity system water is used as a cooling medium for condenser. Thus water temperature raises and it should be cooled for reusing. So for cooling, a devise is used, known as cooling tower. Cooling tower is an evaporative heat exchanger in which heat is transferred by direct contact. The hot water is made to flow from one side and outside air flows from other side. Heat is transferred from hot water to air and water gets cooled. Thus cooled water can be used again for condenser cooling. In this process some water is evaporated and it is called as evaporation loss.

In figure 1, hot water is coming from top of the cooling tower and outside air is entering from bottom side. Hot water is sprayed with the help of nozzles for effective cooling. Heat is exchanged between them. To increase the heat transfer a fill or wire mesh packing is used in cooling tower. Some chemicals (ions, acids) are originally present in water and some are intentionally added to stop the increase in microbe's population. Due to evaporation loss, some water is evaporated in each cycle so concentration of chemical increases. It may be possible that ions will form a cluster and it will deteriorate the efficiency of cooling tower so water is blow down when concentration of these solids reaches to a particular level, this constituted blow down losses in cooling tower. Generally, evaporation loss constitutes 83% and blow down constitutes 17% of water losses in a cooling tower [3]. This paper contains experimental study of cooling tower i.e. various parameters related to cooling tower performance are calculated and validation of practical values is done using empirical relations. Carrier equation is used for validation purpose.

Practical evaporation loss is 9.25 kg/hr and evaporation loss that is calculated through empirical relations (theoretical evaporation loss) is 5.45 kg/hr.

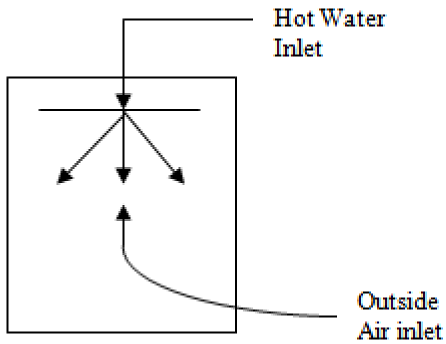

Figure 1: Cooling Tower

2. Working Principle and Terminologies used in Cooling Tower

Cooling tower is a device which takes heat from the high temperature source and rejects it to atmosphere. It is a direct contact evaporative type heat exchanger. Both fluids come into direct contact and evaporation of water takes place. Air becomes hot and water gets cooled down.

2.1 Range

It is the difference between inlet water and outlet water temperature to cooling tower.

$$\text{Range} = t_{wi} - t_{wo} \quad (1)$$

2.2 Approach

It is the difference between outlet water temperature and inlet air's wet bulb temperature (WBT).

$$\text{Approach} = t_{wo} - t_1' \quad (2)$$

2.3 Effectiveness-

It is the ratio of range and ideal range (Range + Approach) [4]

$$\varepsilon = (t_{wi} - t_{wo}) / (t_{wi} - t_1') \quad (3)$$

where, t_{wi} = Inlet water temperature,

t_{wo} = Outlet water temperature,
$t_{1,}$ = DBT of air at inlet,
t_1 = WBT of air at inlet,
$t_{2,}$ = DBT of air at outlet,
t_2 = WBT of air at outlet,
Ɛ = Effectiveness of cooling tower

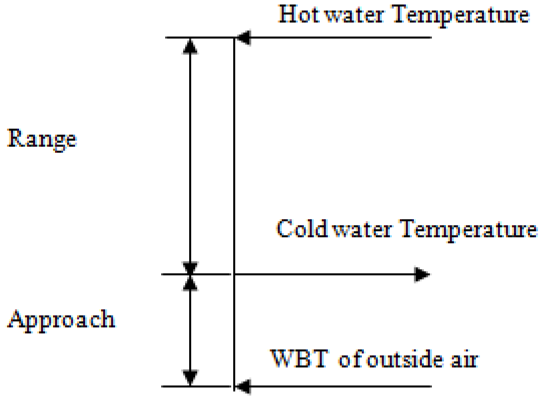

Figure 2: Range and Approach for cooling tower

3. Experimental Set-up

3.1 Cooling Tower

The body of cooling tower model is fabricated of M. S. sheet. Its front side is provided with a Perspex sheet for visualization of cooling tower operation. Hot water is injected from the top of tower so that it can distribute water over the zigzag shaped wire mesh packing. A wind box is fitted at the bottom of tower so that outside air can enter.

3.2 Wire mesh packing

Expanded wire mesh is used as tower packing material. It is considered as unique for film packing. The forming of wire mesh is made such that each little aperture acts as a directing vane for air, moving bulk of air alternatively from one side to other. This action results in air traveling a distance of about 1.5 times of the total depth of packing.

3.3 Blower

A blower is used to supply outside air to the cooling tower. An orifice meter is provided for air flow measurement. U-tube manometer is used which is filled with mercury.

3.4 Measuring Tank

At the bottom a cylindrical measuring tank is provided so that water flow rate at the outlet can be calculated. Hence evaporation loss can also be calculated by just subtracting the outlet water flow rate from inlet water flow rate.

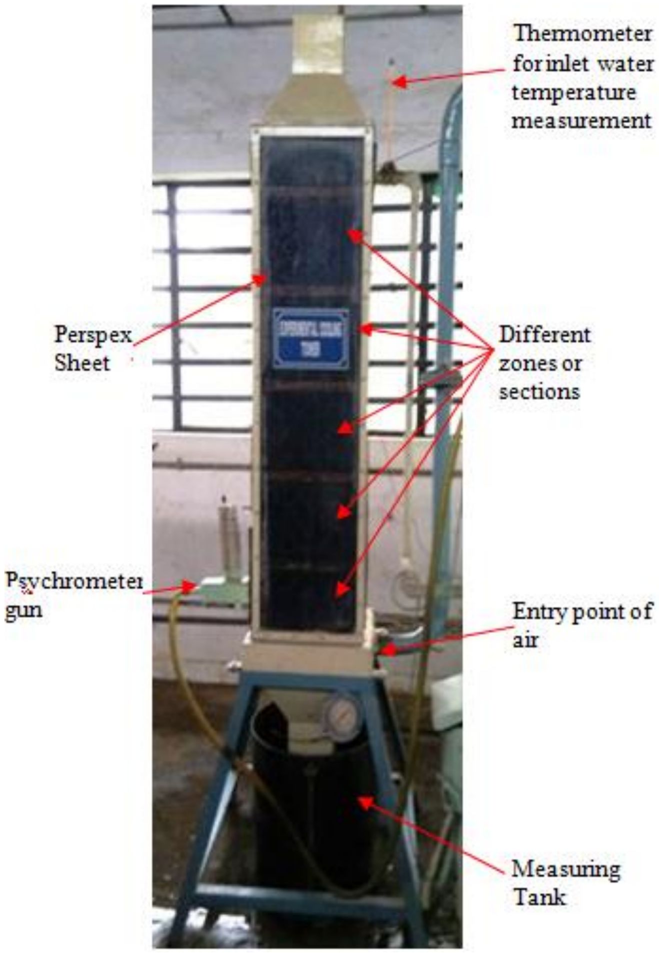

Figure 3: Cooling Tower

3.5 Other Instruments

a) At the top of tower and in the wind box, psychrometers are fitted to measure DBT and WBT of exit and entry air respectively. The tower is vertically divided into 5 zones. WBT and DBT of each zone is calculated using psychrometer gun. Various zones temperature will help us to understand the condition of air in different-different zones.

b) Inlet water flow to the cooling tower is provided with a rotameter for flow measurement. It is also passed through electric geyser for heating of water.

3.6 Control Panel

The control panel is consisted of
a) A rotameter for water flow measurement,
b) Switches for putting on / off geyser,
c) U tube manometer for air flow measurement

Figure 4: Control Panel

Table 1: Parameters related to various equipments

Sr. No.	*Name of Component*	*Specification*
1.	Cooling Tower	cross section 0.3m x0.3m; height 1.25m
2.	Wire mesh packing	2 sets of expanded wire mesh
3.	Blower	Centrifugal Blower, Power- 3 H.P.
4.	Measuring Tank diameter	45 cm
5.	Diameter of orifice	2.4 cm
6.	Coefficient of discharge	0.8

4. Experiment Results and Analysis

In this experiment, temperature of water at the inlet and outlet, air's WBT and DBT at inlet and outlet, air's DBT and WBT at each section or zones, Inlet water flow rate, outlet water flow rate is measured. Initially inlet water flow rate is fixed to 200 litre/hr or 200 kg/hr.

Various values as measured below-

Table 2: Measured values

Air Inlet Temperature (^oC)		*Air Outlet Temperature (^oC)*		*Water Temperature (^oC)*		*Mano-meter Reading*
DBT	WBT	DBT	WBT	Inlet	Outlet	
37	30	46	45	47	38	35 mm

Table 3: Measured values for five zones

Zone 1 (^oC)		Zone 2 (^oC)		Zone 3 (^oC)		Zone 4 (^oC)		Zone 5 (^oC)	
DBT	WBT	DBT	WBT	DBT	WBT	DBT	WBT	DBT	WBT
40	32	42	35	43	37	44	40	45	43

4.1 Calculation

a) Density of air (ϱ_{air})
P= 1.013 bar (atmospheric pressure),
R = 0.287 KJ/Kg-K (Gas constant),
T= 300 K (outside Temperature)

ϱ_{air}= P/RT= 1.013/0.287*300 = 1.176 kg/m^3

b) Volume flow rate of air (Q) = C_d *A* √2gh,

h= height of equivalent air column to 35 mm of Hg (mercury)
$(h\varrho g)_{mercury} = (h\varrho g)_{air}$; $\varrho_{mercury}$ = 13600 kg/m^3

35*13600 = h*1.176
h= 404.761 m of air column

Q = C_d *A* √2gh
= 0.8*(π/4)*2.4*2.4*√2*9.81*404.761
= 3.617*√2*9.81*404.761 = 3.617*89.11= 0.0322 m^3/s

c) Mass flow rate of air = ϱ_{air} Q = 1.176*0.0322
= 0.0379 kg/s = 136.46 kg/hr

d) Water flow rate at inlet = 200 kg/hr

e) Mass flow rate of water at outlet
Measuring tank diameter = 45 cm
Measuring tank Area = (π/4)*45*45 =1589.625 cm^2

It takes 30 seconds to raise its level by 1 cm
So volume flow rate of water at outlet = 1589.625*1/30
=52.99 cm^3/sec
= 0.19075 m^3/hr

Mass flow rate of water at outlet = 1000*0.19075
= 190.75 kg/hr

f) Practical evaporation loss = 200-190.75 =9.25 kg/hr

g) Effectiveness = (47-38)/(47-30)
= 0.5294 = 52.94%

Table 4: Results

Sr. No.	*Parameters*	*Values*
1.	Mass flow rate of air	136.46 kg/hr
2.	Mass flow rate of water at outlet	190.75 kg/hr
3.	Effectiveness	52.94%
4.	Evaporation loss	9.25 kg/hr

5. Analytical Method

By knowing three independent properties, state of moist air can be fixed. So if barometric pressure, DBT and WBT are known, other properties of air can be found using psychrometric equations [5]. Vapour pressure of water can be estimated using following empirical relations.

a) Modified Apjohn equation

$$P_v = P_v' - \frac{1.8P(t-t')}{2700}$$

b) Modified Ferrel equation

$$P_v = P_v' - 0.00066P(t-t')\left[1 + \frac{1.8t}{1571}\right]$$

c) Carrier equation

$$P_v = P_v' - \frac{1.8\,(P - P_v')\,(t-t')}{2800-1.3(1.8t+32)}$$

Where, t = dry bulb temperature, ^{o}C
t' = wet bulb temperature, ^{o}C
P = barometric pressure
P_v = vapor pressure
P_v' = saturation vapor pressure at wet-bulb temperature

5.1 Entry point of air

$$P_v = P_v' - \frac{1.8\,(P - P_v')\,(t-t')}{2800-1.3(1.8t+32)}$$

WBT at inlet = $30^{o}C$,
P = 1.013 bar
P_v' = 0.0425 bar (From steam table)

$$P_v = 0.0425 - \frac{1.8\,(1.013-0.0425)\,(37-30)}{2800 - 1.3(1.8*37+32)}$$

P_v = 0.038 bar

Humidity ratio (w) = $(0.622* P_v)/(P- P_v)$

W_1= 0.622*0.038/ (1.013-0.038)
W_1= 0.024 kg of water vapor/kg of dry air

5.2 Exit of air

$$P_v = P_v' - \frac{1.8\,(P - P_v')\,(t-t')}{2800-1.3(1.8t+32)}$$

WBT at outlet = $45^{o}C$,
P = 1.013 bar
P_v' = 0.096 bar (From steam table)

$$P_v = 0.096 - \frac{1.8\,(1.013-0.096)\,(46-45)}{2800 - 1.3(1.8*46+32)}$$

P_v = 0.095 bar

Humidity ratio (w) = $(0.622* P_v)/(P- P_v)$

W_2= 0.622*0.095/ (1.013-0.095)
W_2= 0.064 kg of water vapor/kg of dry air

Air flow rate is assumed to be constant i.e. 136.46 kg/hr. As for measuring different zones of temperature a small part of air is used by pychrometric gun but it constitutes very small part so air flow rate is assumed to be constant.

Evaporation loss = mass flow rate of air* $(W_2 - W_1)$
= 136.46 (0.064-0.024)
= 5.45 kg/hr

6. Conclusion

Cooling tower is used to reduce the temperature of hot water stream. It is mainly used in air conditioning plants, chemical plants etc. Evaporation loss and effectiveness are two important performance parameters of cooling tower. Effectiveness of the cooling tower model comes out to be 52.94%. Practical evaporation loss is calculated i.e. 9.25 kg/hr.

Validation of practical values is done using empirical relations. For calculating theoretical evaporation loss various empirical relations i.e. Modified Apjohn equation, Modified Ferrel equation and Carrier equation are provided. By reviewing literature it is came to know that results provided by carrier equation is most satisfactory. So analytical calculation is done using carrier equation and thus theoretical evaporation loss is calculated as 5.45 kg/hr which comes nearer to practical value.

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Bhupesh Kumar Yadav received the B.Tech degree in Mechanical Engineering from Malaviya National Institute of Technology (MNIT), Jaipur in 2014. He is the GOlD Medalist of the batch. Presently he is pursuing M.Tech in Thermal Engineering from Malaviya National Institute of Technology (MNIT), Jaipur.