Conventional Analysis of Performance of Cooling Tower Used for Industrial Purpose

Rahul Patel, Ramji Tripathi, Sukhdev Gangwar

Abstract— ***Several types of machines and equipment's that transfer heat from one fluid to other. Cooling tower is one of them that transfer heat of high temperature water of heat exchanger to low temperature water and then cooled water circulates to heat exchanger again. Cooling tower generate cooled water in large amount and store in a water reservoir. If cooling tower is not design properly it can affect the cooling performance. These cooling towers are enormous and have various unique specifications depending on the environment that they will operate under and the extent to which the owners want to remain efficient and environment friendly. Cooling towers may either use the evaporation of water by removing heat from rest water and cool them near the wet-bulb temperature of air or, in the case of closed circuit as dry cooling tower in which working fluid cool near to the dry-bulb temperature of air. Several parameters as Cooling range, Wet bulb temperature, Mass flow rate of water, Tower height, Air velocity through tower and many other things that affect the performance of cooling tower. For a good designer all this parameter would want to mind for proper designing and functioning of cooling tower.***

Index Terms* — *Cooling tower, Effectiveness, Water flow rate, Tower demand and Wet bulb temperature.

I. INTRODUCTION

A cooling tower extracts heat from hot water greater then atmospheric temperature and cools it near to atmospheric temperature by emitting it to the atmosphere. Conduction, convection and radiation are basic mode of heat transfer but most of heat release from water by means of evaporation. In evaporation some amount of water is evaporate by taking latent heat of evaporation from remaining water and discharged into the atmosphere. Through this process temperature of remaining water droop down. Cooling towers are generally able to droops the temperatures of water than devices, like the radiator in a car.

Cooling towers are used several places as Oil refineries, Chemical plants, Power stations, Building cooling, Natural gas processing plant, Food processing plant etc. it also vary in size according to its use and size of the plant. It can be as small as roof-top units to very large cooling tower of hyperboloid structures of up to 200 metres high and 100 metres in diameter. The hyperboloid cooling towers are generally for nuclear power plants, although they are used in some large chemical and other industrial plants also.

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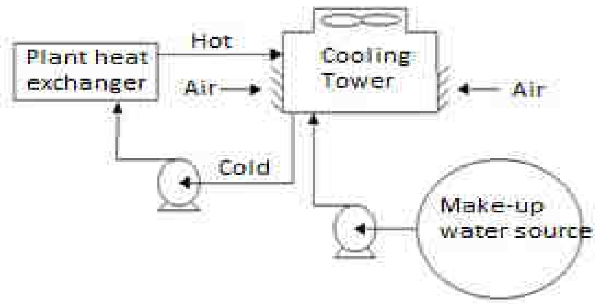

Fig. 1: Cooling tower block diagram

Cooling towers are a very important part of any plant. Although there are several type of cooling tower as Wet Cooling Tower, Dry Cooling Tower, Direct dry cooling tower, Indirect dry cooling tower, Fluid cooler and Atmospheric tower but all these cooling towers perform a single task that is to reject heat into the thermal energy resiviour. An alternative storage of water that is make-up water is used to replenish water lost by evaporation. Out let of heat exchangers that is hot water, is sent to the cooling tower and cooled water exits from cooling tower are sent back to the heat exchangers for further cooling.

II. PERFORMANCE PARAMETER OF COOLING TOWER

Against design values, seasonal variations require adjustment and tuning of water and air flow rates to get the best cooling tower effectiveness through measures like water box loading changes, blade angle adjustments.

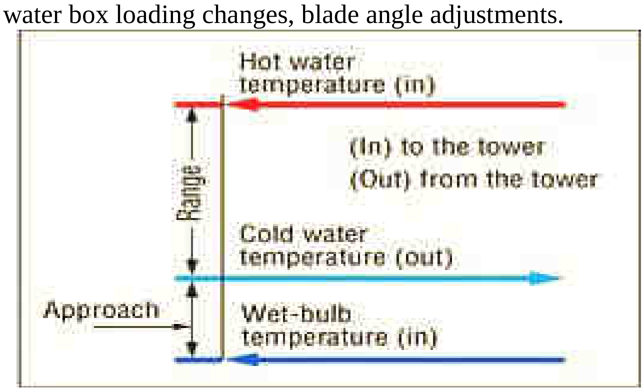

Fig. 2: Range and Approach

Some performance parameter of cooling tower is listed as:

(i) Range is the difference of inlet and outlet water temperature of cooling towers.

(ii) The difference between the cooling tower outlet water temperature and ambient wet bulb temperature is known as **Approach**.

(iii) Effectiveness of cooling tower is the ratio of range to the ideal range, i.e. difference between wet bulb temperature and cooling water inlet temperature.

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(iv) Cooling capacity is heat rejection rate that is given as product of mass flow rate of water to specific heat and temperature difference.

(v) Cycles of concentration is the ratio of dissolved solids in circulating water to the dissolved solids in makeup water.

(vi) Ratio of Liquid to Gas (L/G) of a cooling tower is the ratio of mass flow rates of water and air.

III. FABRICATION OF COOLING TOWER

After deciding tower characteristic of the plant engineer must design a tower that matches the required value. The required tower size decided after following consideration:

(i) Cooling range.

(ii) Approach to wet bulb temperature.

(iii) Water mass flow rate.

(iv) Air velocity through tower.

(v) Tower height.

After designing, cooling tower is fabricated by using many components made of PERSPEX acrylic sheet after designing each of components. It consists of several parts as:

A. Air distribution chamber- Air distribution chamber is made of Perspex material. Apart from this air distribution chamber consist of Trough which collects falling water droplets from water column. In this air is provided by a centrifugal blower so that air can help in force convection to hot water. A digital thermometer is also fitted to know exit water temperature.

Fig. 3: Water collecting basin, Anemometer, Water column, Hot water tank

B. Hot water tank - A cubical hot water tank made of Perspex material of 12″x12″x12″ in dimension. It is filled with running water and a water heater is fixed for heating water. Hot water is pumped from this tank to water column through pump fitted with the help of GI pipes.

C. Make up water tank- This tank is mostly similar to hot water tank that is made of same material. Its function is to supply water to hot water tank when water level falls below desired level. Water level is checked by floating valve fitted in it.

D. Water column- This is placed over air distribution chamber. On top of it there is a spray nozzle, through which hot water is sprayed on the series of fills. An anemometer is placed near to the nozzle to measure wind speed. It is vertical in construction and is nearly 30cm in height.

Fig. 4: Model of fabricated cooling tower

E. Fills- Fills are placed inside water column in zigzag manner. Total 16 numbers of rectangular fills of 12cm x10.5cm size are used. They are arranged in such a way that they form matrix of 4 rows and 4 columns. Hot water is sprayed on these through nozzles, which flows from one duct to another and they look like series of baffles plates.

F. Water pump- Water pump is used to pump hot water from hot water tank to water column through pipes**.**

G. Blower- Blower is used for providing forced air inside air distribution chamber. Water is cool by forced convection so that blower is required for enough air inside this chamber.

H. GI pipes- A Galvanised Iron pipe of 1/2″ in diameter is fitted to carry hot water from hot water tanks to water column.

I. Manometer- Inclined tube manometer is used to measure orifice differential pressure or packing resistance.

J. Digital thermometer- Digital thermometer is a device used to measure temperature of water. In cooling tower three temperature gauges are fixed on three main positions, one is hot water tank second cold water exit and third is near nozzle for measuring hot water temperature.

K. Water heater- Water heater is an electric device that is used to heat water. It is connected to one side of hot water tank. It is of 1 kW capacity.

L. Water collecting basin- A water collecting basin is placed in air distribution chamber some degree inclined from horizontal. In this, hot water falls after passing through duct. Water collected here is made to flow back in hot water tank.

M. Regulating valve- Stop and regulating valves are manually operated valves use in any instance of a pipe section needs to be shut-off during service and maintenance.

N. Spray nozzle- A **spray nozzle** is a precision device that facilitates dispersion of liquid into a spray. It is used in

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cooling tower to make hot water dispersion into water column.

O. Anemometer- An Anemometer is a device used for measuring wind speed, and is a common weather station instrument. It is being used in cooling tower at top water column to measure speed of air.

IV. Result & Analysis

A. RESULTS

With certain assumption keeping environmental consideration i.e. average t_{surr}, average humidity φ, constant air flow etc fixed. Following results have found after measurement of fabricated model.

a) Air flow rate: By using anemometer calculated air flow rate is 1.8 m/s.

b) Cooling tower approach:

CTA = Outlet temp of water - Wet bulb temp

$= (42 - 28.5)^0C = 13.5^0C$

c) Cooling tower range:

= Inlet water temp. (T_1) - Outlet water temp (T_2)

$= (54 - 42)^0C = 12^0C$

Table1: Observation table for characteristic of cooling tower

1. Sr. No	2. CT in (°C)	3. CT out (°C)	4. WBT (°C)	5. Range (°C)	6. Approach (°C)	7. Effectiveness (%)	8. Heat Loss kj/hr	9. h_{Outlet} Air kj/kg	10. KaV/L	11. L/g	12. Dry air ω kg/kg	13. Eva. Loss kg/hr
1.	38	35.8	31.0	02.2	04.8	31.40	3.0884	103.0	0.656	6.363	0.0265	0.689
2.	39	36.8	27.0	02.7	09.8	21.60	04.158	101.0	1.026	4.070	0.0221	0.846
3.	40	37.4	28.0	02.6	09.4	21.67	04.004	097.0	1.550	2.690	0.0231	0.815
4.	41	37.0	27.5	04.5	09.5	32.14	06.930	094.0	4.070	0.888	0.0205	1.410
5.	42	38.0	29.0	04.2	08.8	32.23	06.468	095.6	3.135	1.333	0.0115	1.316
6.	43	38.2	27.0	04.8	11.2	30.00	07.392	098.0	2.572	0.375	0.0198	1.504
7.	44	38.3	28.0	05.6	10.3	35.00	08.624	096.0	4.256	0.982	0.0218	1.755
8.	45	38.9	28.5	06.1	10.4	36.96	09.394	100.2	2.650	1.573	0.0187	1.912
9.	46	39.3	29.0	06.7	10.3	39.41	10.318	101.3	2.523	1.650	0.0238	2.100
10.	47	39.9	27.0	07.1	12.9	35.55	10.934	104.5	2.673	1.901	0.0198	2.225
11.	48	40.6	27.5	07.4	13.1	36.09	11.396	103.2	2.338	1.787	0.0199	2.319
12.	49	41.0	28.0	08.0	13.0	38.09	12.320	103.8	2.624	1.592	0.0185	2.508
13.	50	41.3	28.0	08.1	13.3	36.81	12.474	105.0	2.267	1.840	0.0218	2.539
14.	51	41.8	28.5	09.2	13.3	40.88	14.168	105.2	2.526	1.654	0.0227	2.884
15.	52	42.4	28.0	09.6	14.4	40.00	14.784	106.2	2.475	1.688	0.0218	3.009
16.	53	42.8	28.0	10.2	14.8	40.80	15.708	107.5	2.615	1.598	0.0208	3.197
17.	54	42.0	28.5	12.0	13.5	47.05	18.480	108.2	2.919	1.431	0.0231	3.762

d) Mass flow rate of water:

$m_w = A\, V_w\, \rho_w$

Where $V_w = C_d \sqrt{2gh}$

$C_d = 0.6$ (coefficient of discharge)

$A = \pi r^2 = 3.14*(0.64)^2\ cm^2 = 1.2861*10^{-4}\ m^2$

And $h = 90cm$, $V_w = C_d \sqrt{2gh} = 0.7968$ m/s

Then, $m_w = 1.2861*10^{-4}*0.7968$

$= 0.10248*10^{-3}\ m^3/s$

$= 0.368\ m^3/hr.$

e) Mass of water:

M_W=Mass flow rate * density of water

= 0.10248kg/s = 368.91kg/ hr.

f) Heat loss by water:

$Q_L = M_W * C_{Pw} * (T_1 - T_2)$

= 368.91*4.186*(12) = 18.531kJ/ hr.

g) Heat gain by air:

$Q_a = m_a (h_2 - h_1) = m_a (108.23-90)$

By energy balance equation

Heat gain = Heat loss

$18.531 = m_a \times 10$ OR $m_a = 1.0786$ kg/ hr.

Where, h_1 and h_2 are the enthalpy of air at inlet and outlet of the column, respectively (to be obtained from the psychometric corresponding to the mean WBT & DBT).

h) Cooling tower characteristics:

$NTU = (K_a V/L) = C_w \int_{T2}^{T1} dT/(h2 - h1)$

Where by chart, $h_2 = 108.23$ kJ/kg, $h_1 = 90.05$ kJ/kg

$T_1 = 54^0C$, $T_2 = 42^0C$, KaV/L = 2.9196

i) L/G Ratio:

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

= 1.431

j) Efficiency of cooling tower:

$\eta = [(T_1 - T_2) / (T_1 - WBT)]$

= 100×12 / 25.5 = 47.05%

k) Cooling Capacity:

Cooling Capacity is heat rejection rate of water which is18.531 kJ/ hr.

l) Different losses:

DRIFT LOSS (DL) = $(0.20 M_w)/100$

= 0.20×368.91/100 = 0.737 kg/hr.

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EVAPORATIVE LOSS $=0.00085\ M_w\ (T_1 - T_2)$

$= 0.00085 \times 368.91(12) = 3.762$kg/hr.

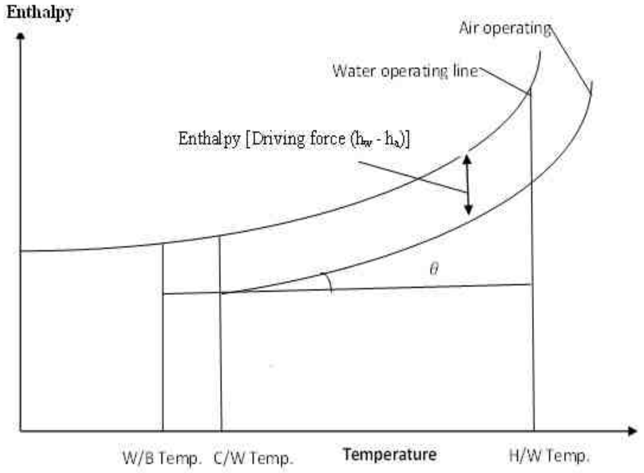

Fig. 5: Enthalpy v/s Temperature

The cooling process can best be explained on a psychometric chart which plots graph between enthalpy vs temperature. The process is illustrated in the graph; is called driving force diagram.

B. ANALYSIS

Different designing parameters are studied and analysis them given as:

a) Variation of Range and Approach with cooling tower inlet temperature.

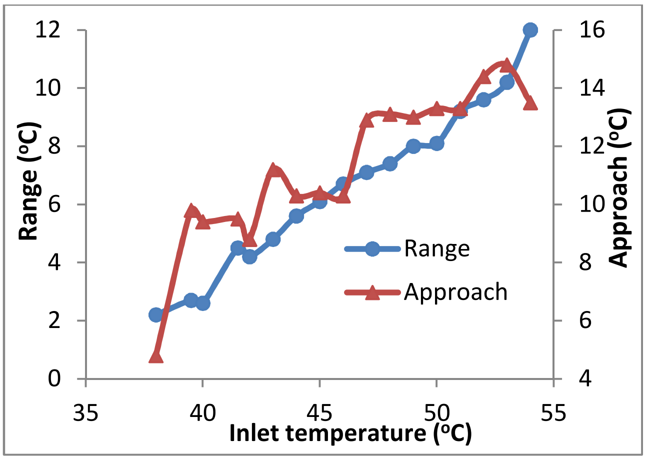

Fig. 6: Variation of Range and Approach with cooling tower inlet temperature

The fig. 6 shows variation of Range and Approach with cooling tower inlet temperature. Range is the difference of cooling tower inlet temperature and outlet temperature. When the inlet temperature of water is increasing, driving force between the inlet temperature and wet bulb temperature increases so that range will increase and also a constant load required as water flow rate is decreasing. On the other hand approach of cooling tower also increases and that is the difference between inlet temperature and the WBT. An increase in the inlet temperature the wet bulb temperature moves the air operating line towards the right and upward to establish equilibrium between both cold water temperature and hot water temperature.

b) Variation of Effectiveness and WBT with cooling tower inlet temperature.

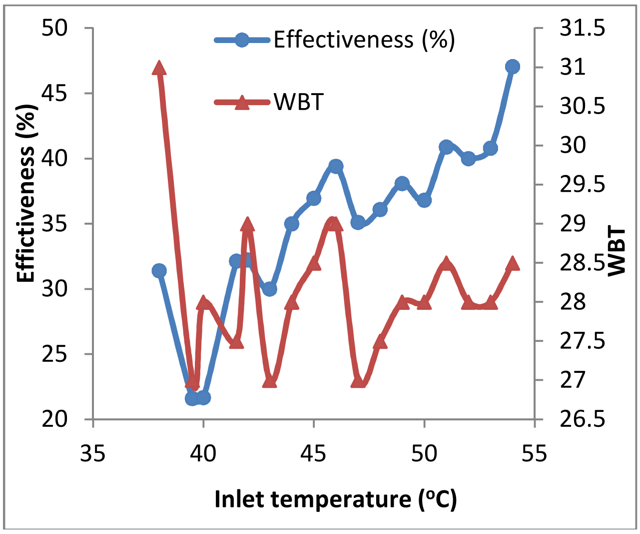

Fig. 7: Variation of Effectiveness and WBT with cooling tower inlet temperature

The fig. 7 shows variation of Effectiveness and WBT with cooling tower inlet temperature. First effectiveness increases but at higher temperature it becomes almost constant because at these temperature air becomes saturated and no more heat transfer takes place. Since approach decreases and range increases the effectiveness increases and also difference between the temperature of water leaving a cooling tower and wet bulb temperature is an indication of increase in effectiveness. The WBT increases in zig-zag way because of the outside temperature vary with time to time of experimental observation.

c) Variation of Effectiveness and Heat loss with cooling tower inlet temperature.

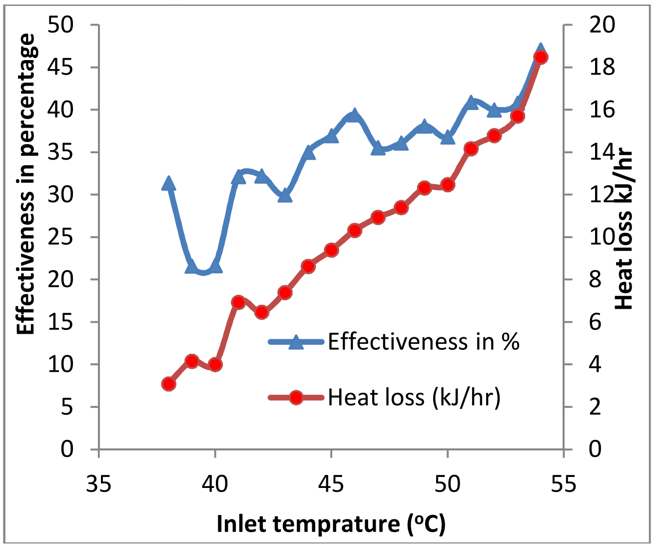

Fig. 8: Variation of Range and Approach with cooling tower inlet temperature

The fig. 8 shows the variation of Effectiveness in % and heat loss kJ/hr from water with cooling tower inlet temperature. With increasing in temperature rate of heat loss increases and because of this effectiveness also increases that is approximately from 20% to 50%.

d) Variation of specific humidity and enthalpy of air at outlet with cooling tower inlet temperature.

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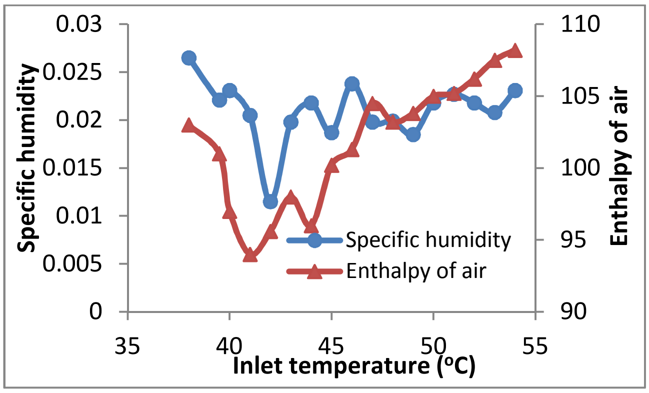

Fig. 9: Variation of specific humidity and enthalpy of air at outlet with cooling tower inlet temperature.

The fig. 5.03 shows relation of Specific humidity and Enthalpy of air with cooling tower inlet temperature. Firstly specific humidity decreases, and after some time it increases slowly. As humidity is the water vapour present in the dry air initially water vapour is removed from the air by the heat transfer takes place between the water and air. But after some extent humidity increases due to evaporation process and when air leaving the cooling tower becomes saturated humidity becomes almost constant. Enthalpy of air at outlet suddenly decreases then increases and at higher inlet temperature it becomes almost constant. At the entry of cooling tower it is related to the specific humidity as it decreases and increases due to evaporation loss of water in air and approaches to a constant value because air becomes saturated.

e) Variation of Range v/s approach

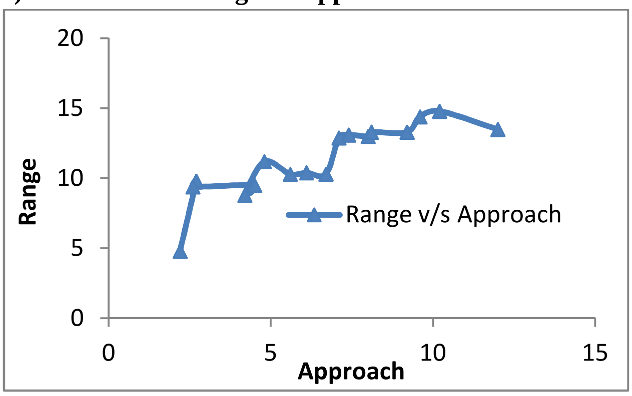

Fig. 12: Variation of Range v/s approach

The fig. 12 shows the variation of Range and approach. Both range and approach is the function of temperature. As hot water temperature increases, difference of the hot water temperature also increases but at 100% saturation wet bulb temperature becomes the dry bulb temperature.

f) Variation of KaV/L and L/G ratio of air at outlet with cooling tower inlet temperature.

The fig. 10 shows the variation of KaV/L and L/G with cooling tower inlet temperature. KaV/L is also called number of transfer units or Tower demand. From graphical representation it is clear that first it increases rapidly than decreases and after some time it becomes almost constant since it is the function of temperature and enthalpy. In this way L/G ratio also decreases rapidly and after some time at higher temperature it becomes almost constant.

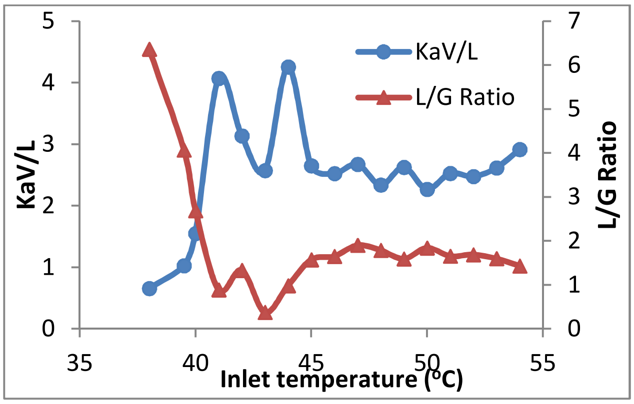

Fig. 10: Variation of KaV/L and L/G ratio of air at outlet with cooling tower inlet temperature.

g) Variation of Range v/s effectiveness

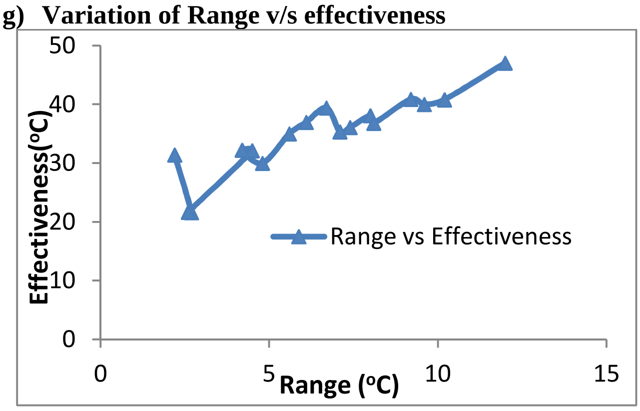

Fig. 11: Variation of Range v/s effectiveness

The fig. 11 shows the variation of effectiveness with range. Range is the function of temperature. At higher temperature effectiveness becomes constant due to evaporation loss and enthalpy difference between the air and hot water of water tank.

h) Variation of Range v/s specific humidity of dry air

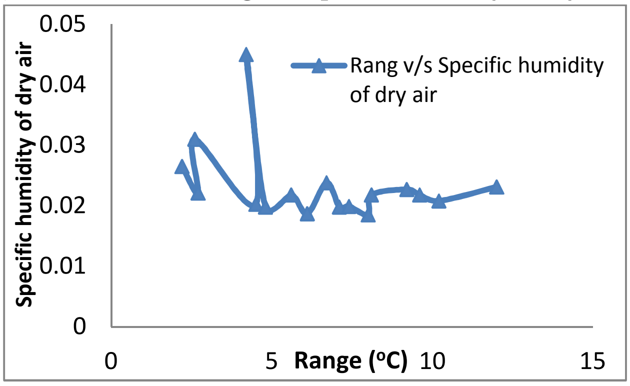

Fig. 13: Variation of Range v/s specific humidity of dry air

The fig. 13 shows the variation of specific humidity with Range. As range is the function of inlet temperature and outlet temperature and specific humidity is the function of WBT and DBT. That's why specific humidity first increases reaches to peak point than decreases to 0.02 and becomes constant.

i) Tower demand curve

The curves contain a set of 821 curves, giving the values of KaV/L for 40 wet bulb temperature, 21 cooling ranges and

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35 approaches. By the above calculation we plot the point of performance on given reference curve whether it is efficient or not.

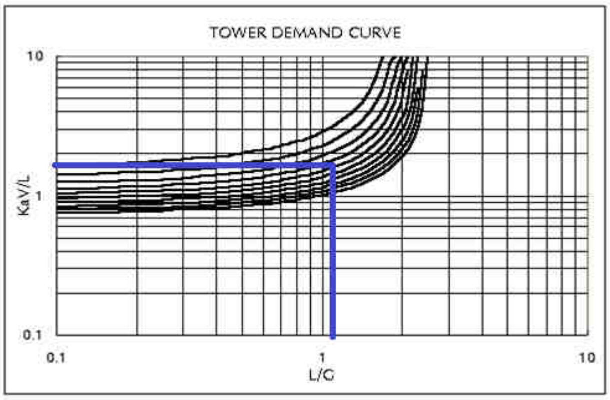

Fig. 14: Tower demand at 54OC inlet temperature

This blue line indicates the performance of cooling tower. Where L/G is 1.431 and KaV/L is 2.9196.

j) Tower Characteristics curve

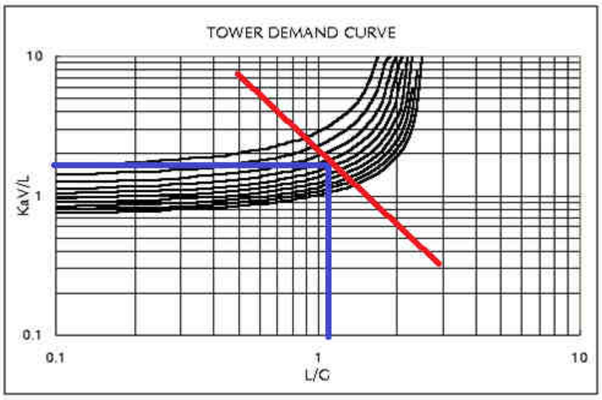

Fig. 15: Tower Characteristics curve at 54OC inlet temperature

These blue lines are passing through the tower characteristics curve (red line).

V. CONCLUSION

On the basis of Result and Analysis of collected data from observation of prototype of cooling tower the following points have been concluded:

1. Through this experiment it is demonstrates that operation and performance of cooling towers are not straightforward as it want to be.
2. These misconceptions and incomplete knowledge during cooling tower design can harmful to you and can losses your money.
3. Idea to purchase a new tower will cost more in the long run if plant operations do not run efficiently due to an ill-designed cooling tower.
4. Best way of Utilization of fan power affect's the energy cost of Tower operation.
5. As tower performance was viewed in terms of range so upgrading of an existing tower may turrn out to be futile.
6. Without any misconception, full working knowledge of the performance of cooling towers helps in order to purchase and operate to the best advantage for maximum production and minimum cost.

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