Design of mechanical draftcooling tower and determination of thermal efficiency

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***ABSTRACT*: The present paper is a detailed methodology for thermal design of cooling tower. The technical data is taken for Mechanical draft cooling tower. A cooling tower is a heat rejection device which rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature or, in the case of closed circuit dry cooling towers, rely solely on air to cool the working fluid to near the dry-bulb air temperature. Common applications include cooling the circulating water used in oil refineries petrochemicalchemical plants, thermalpower stations and HVAC systems for cooling buildings. The classification is based on the type of air induction into the tower: the main types of cooling towers are natural draft and induced draft cooling towers.Industrial cooling towers can be used to remove heat from various sources such as machinery or heated process material. The primary use of large, industrial cooling towers is to remove the heat absorbed in the circulating cooling water systems used in power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food processing plants, semi-conductor plants, and for other industrial facilities such as in condensers of distillation columns, for cooling liquid in crystallization, etc. The principle of operation of cooling towers is very similar to that of the evaporative type of condensers, in which the warm water gets cooled by means of evaporation. Water evaporates as a result of the hot water droplet coming in contact with the air (which is being pumped out by means of a fan). This evaporating water also absorbs the latent heat from the water surrounding it. By losing latent heat, the water is cooled. Cooling towers offer an excellent alternative particularly in locations where sufficient cooling water cannot be easily obtained from natural sources or where concern for the environment imposes some limits on the temperature at which cooling water can be returned to the surrounding.**

***Keywords:* cooling tower, condenser, evaporation, natural draft, induced draft**

I. INTRODUCTION

Cooling tower is used to fulfil the purpose of cooling with minimum usage of fresh water. It circulates fresh water for cooling to the machine and uses least make up water that is lost due to evaporation. Apart from industry cooled water is needed for, for example, air conditioners, or power generation. A cooling tower is the equipment used to reduce the temperature of a water stream by extracting heat from water and emitting it to the atmosphere. Cooling towers make use of evaporation whereby some of the water is evaporated into a moving air stream and subsequently discharged into the atmosphere. As a result, the remainder of the water is cooled down significantly as shown in the figure. 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, and are therefore more cost-effective and energy efficient. The energy input must be rejected as on available in the steam turbine exhaust, at the main steam condenser performs the dual function of removing this rejected energy from the plant cycle and keeping the turbine back pressure at the lowest possible level. The rejected heat energy inevitable must be returned to the atmosphere. The main condenser does this by transferring the latent heat of exhaust steam to water exposed to at the atmosphere. This water recall circulating or cooling water. Common applications include cooling the circulating water used in oil refineries, petrochemical and other chemical plants, thermal power stations and HVAC systems for cooling buildings. The classification is based on the type of air induction into the tower: the main types of cooling towers are natural draft and induced draft cooling towers. Cooling towers vary in size from small roof-top units to very large hyperboloid structures (as in the adjacent image) that can be up to 200 metres (660 ft) tall and 100 metres (330 ft) in diameter, or rectangular structures that can be over 40 metres (130 ft) tall and 80 metres (260 ft) long. The hyperboloid cooling towers are often associated with nuclear power plants, although they are also used to some extent in some large chemical and other industrial plants. Although these large towers are very prominent, the vast majority of cooling towers are much smaller, including many units installed on or near buildings to discharge heat from air conditioning.

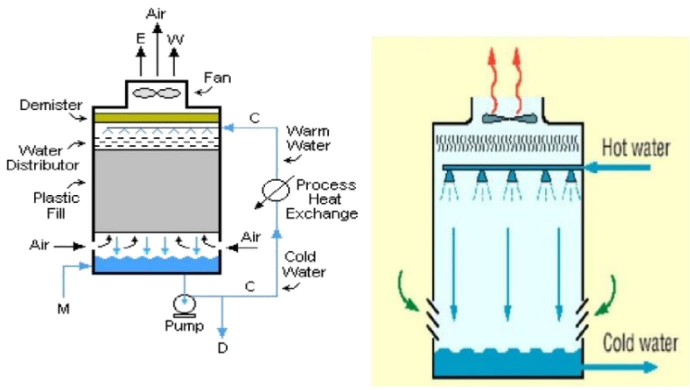

Fig. 1: working of induced draft cooling tower

II. EXPERIMENTAL SETUP

EXPERIMENTAL INSTRUMENTATION:

All measurements for this test were carried out using calibrated instruments. Digital thermostat are used for temperature measurements. Manometers, for measurement of water flow velocity, indicated as head in the manometers. Ultrasonic flow meter was also used to measure the flow.

2.1 EXPERIMENT PROCEDURE

a. Hot Water Temperature: Two locations Hot water duct inside the tower were chosen for HWT measurement, and the average of the readings for each one hour duration, is taken for each location. The average from the two locations is considered for calculations.

b. Cold Water Measurement: Two locations were chosen for CWT measurements and from the average one hour duration for each location, the final average is obtained

c. DBT/WBT: At properly chosen three locations in the vicinity of the tower, both DBT and WBT were noted, taking care to wet the wick around the mercury bulb of the Wet Bulb Thermometer, and whirling the psychomotor every time a reading is taken, the average of the readings from three locations, for each hour is taken for evaluation purposes

d. Flow measurement: Flow is measured by using ultrasonic flow meter. Readings obtained from ultrasonic flow meter are considered for further evaluation. The total flow into the tower is obtained as the sum of the two main flow risers and the two auxiliary flow risers. Using the Performance curves evaluation is done from the average values for stable one hour for HWT and CWT, Range R is obtained, and likewise RH from DBT and WBT average values. Temperature readings of hot water and cold water between time periods 12.00 to 13.00 hr are more consistent. Load was constant besides fairly good values of range, WBT which are closer to design values.

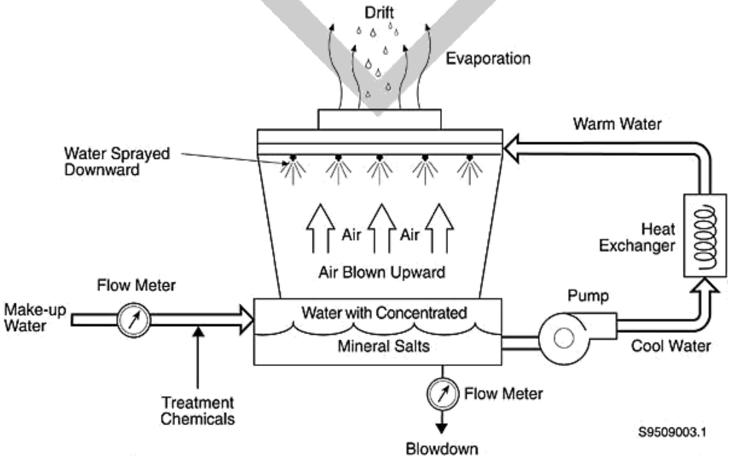

Fig. 2: layout of cooling tower

2.2 CALCULATION
COOLING TOWER SYSTEM

Where,
C = Circulating cooling water
E = Evaporated water
W = Windage or Drift loss
M = Make-up water
D = Draw-off or Blow down water

To prevent the salt in the above sketch, water pumped from the tower basin is the cooling water routed through the process coolers and condensers in an industrial facility. The cool water absorbs heat from the hot process streamswhich need to be cooled or condensed and the absorbed heat warms the circulating water (C). The warm water returns to the top of the cooling towerand trickles downward over the fill material inside the tower. As it trickles down, it comes in contact with ambient air rising up through the tower either bynatural draft or by forced draft using large fans in the tower. That contact causes a small amount of the water to be lost as wind age (W) and some of thewater (E) to evaporate. The heat required to evaporate the water is derived from the water itself, which cools the water back to the original basin watertemperature and the water is then ready to recirculate. The evaporated water leaves its dissolved salts behind in the bulk of the water which has not beenevaporated, thus raising the salt concentration in the circulating cooling concentration of the water from becoming too high, a portion of the water is drawn off (D) for disposal. Fresh make-up water (M) is supplied to the towerbasin to compensate for the loss of evaporated water,the wind age loss water and the draw-off water.

ASSESSMENT OF COOLING TOWER

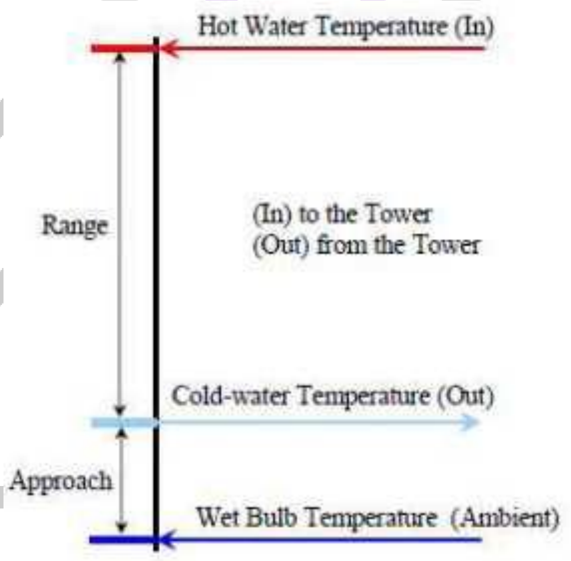

Fig. 3: Range and Approach of cooling tower

RANGE:
This is the difference between the cooling tower water inlet and outlet temperature. A high CT Rangen means that the cooling tower has been able to reduce the water temperature effectively, and is thus performing well.

APPROACH:
This is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. Although, both range and approachshould be monitored, the `Approach' is a better indicator of cooling tower performance.

EFFECTIVENESS:
This is the ratio between the range and the ideal range (in percentage), i.e. difference between cooling water inlet temperature and ambient wet bulb
temperature, or in other words it is = Range / (Range + Approach).

TECHNICAL SPECIFICATION:

Volume of circulating water (V)	30 m^3 / hr
Inlet temperature of water (T_1)	38^0 C
Outlet temperature of water (T_2)	32^0 C
Wet bulb temperature (WBT)	29^0 C
Height of cooling tower (H)	2.3 m
Material of pipe used for water flow	S.S.
Inside diameter of pipe (d_i)	0.10 m
Outside diameter of pipe (d_o)	0.12 m
Inlet temperature of air (T_{a1})	20^0 C
Outlet temperature of air (T_{a2})	27^0 C
Design relative humidity (Φ)	0.80 %
Allowable Evaporating losses	1.44 %

DATA FROM PSYCHOMETRIC CHART AND STEAM TABLE

Enthalpy of air at inlet temperature (H_{a1})	50 KJ / Kg
Enthalpy of air at outlet temperature (H_{a2})	73 KJ / Kg
Specific Humidity of air at inlet temperature (W_1)	0.0118 Kg / Kg of air
Specific Humidity of air at outlet temperature (W_2)	0.018 Kg / Kg of air
Specific Volume of air at inlet temperature (V_{s1})	0.842 m^3 / Kg
Specific Volume of air at outlet temperature (V_{s2})	0.875 m^3 / Kg
Enthalpy of water at inlet temperature (H_{w1})	159.10 KJ / Kg
Enthalpy of water at outlet temperature (H_{w2})	134.00 KJ / Kg

DESIGN CALCULATION:

COOLING TOWER APPROACH (CTA)

CTA = T2 – WBT = 32 – 29 = 30 C

COOLING TOWER RANGE (CTR)

CTR = T1 – T2 = 38 – 32 = 60 C

Now, Mass of water circulated in cooling tower

Mw1 = Volume of circulating water x Mass density of water
Mw1 = 30 x 1000
Mw1 = 30000 Kg / hr

VOLUME OF AIR REQUIRED (V)

V = (HL x Vs1) / [(Ha2 – Ha1) - (W2 – W1) xCpw x T2]
V = (753480 x 0.842) / [(73 - 50) (0.018 – 0.0118) x 4.186 x 32]
V = 28617.25 m3 / hr

HEAT GAIN BY AIR (HG)

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

HG = 28617.25 x [(73 - 50) – (0.018 – 0.0118) x 4.186 x 32] /0.842
HG = 634430.05 /0.842
HG = 753480 KJ / hr

MASS OF AIR REQUIRED (Ma)

Ma = Volume of air required / Specific volume of air at inlet tempt.
Ma = V / Vs1
Ma = 33987.23 Kg / hr

THE QUANTITY OF MAKE-UP WATER (Mmw)

Mmw = V x (W2 – W1) / Vs2
Mmw = 28617.25 x (0.018 – 0.0118) / 0.875
Mmw = 202.7736 Kg / hr
Now, taking Evaporating loss in calculation
Mmw = 202.7736 x [1 + (1.44 / 100)]
Mmw = 205.70 Kg / hr
Mmw = 205.70 / 60
Mmw = 3.43 Kg / min

VELOCITY OF WATER INSIDE THE WATER PIPE (V_w)

Volume of water transfer through cooling tower per hour is 30 m3 /hr So the velocity of water through pipe is
Vw = 30 / Area of pipe
Now, Area of pipe is given by a = (I / 4) x di 2
a = (I / 4) x (0.1) 2
a = 0.00785 m2
So, Vw = 30 / 0.00785
Vw = 3821.65 m / hr
Vw = 1.06 m / s

LENGTH OF WATER PIPE REQUIRED (L)

HL = 2IKL (T1 – T2) / log (ro /ri) (1.1)
Material of the pipe used in cooling tower is S.S, So the thermal conductivity for the steel material is 40W / m-deg. So,
K = 40 W / m-deg
Put value of K in equation (1.1)
753480 = 2I x 40 x L x (38 - 32) / log (0.06 /0.05)
753480 = 19045 x L
L = 39.60 m

NUMBER OF TURNS REQUIRED (N)

Height of cooling tower = 2.3 m.
Water pipes are used in circular shape due to shape of the cooling tower is circular and circular shape is also beneficial for smooth flow.
Consider the space between adjacent two water pipe is 0.2 m.
Pitch of the water pipe = 2 x 0.2 = 0.4 m
From top of the cooling tower, leave 0.3 m space for maintenance and Other work
Available height for water pipes = 2.3 -0.3= 2 m
So, Number of turns required (N) N = 2 / 0.4
N = 5

COOLING TOWER CHARACTERISTIC

Merkel gives the cooling tower characteristic equation as

(KaV / mw1) = [(T1 – T2) / 4] x {(1 /K h1) +(1 / Kh2) + (1 / Kh3) + (1 / Kh4)} (1.2)

Where,

K = Mass transfer co-efficient (Kg / hr m2)
a = Constant area (m2)
V = Active cooling volume (m3)
mw1 = Mass of water (Kg / hr)
T1 = Hot water temperature (0 C)
T2 = Cold water temperature (0 C)

Now,

Mh1 = Value of Hw - Ha at T2 + 0.1 (T1 – T2)
Mh2 = Value of Hw - Ha at T2 + 0.4 (T1 – T2)
Mh3 = Value of Hw - Ha at T1 - 0.4 (T1 – T2)
Mh4 = Value of Hw - Ha at T1 - 0.1 (T1 – T2)

CALCULATION FOR 3

H1= T2 + 0.1 (T1 – T2)
= 32 + 0.1 (38 - 32)
= 32.600 C
Value of Hw at 32.600 C is 136.11 KJ / Kg
Value of Ha at 32.600 C is 89 KJ / Kg
Mh1 = Hw - Ha
Mh1 = 136.11 – 89
Mh1 = 47.11 KJ / Kg

CALCULATION FOR 3

H2= T2 + 0.4 (T1 – T2)
= 32 + 0.4 (38 - 32)
= 34.400 C
Value of Hw at 34.400 C is 144.47 KJ / Kg
Value of Ha at 34.400 C is 105 KJ / Kg
Mh2 = Hw - Ha
Mh2 = 144.47 – 105
Mh2 = 39.47 KJ / Kg

CALCULATION FOR 3

H3= T1 - 0.4 (T1 – T2)
= 38 – 0.4 (38 - 32)
= 35.600 C
Value of Hw at 35.600 C is 148.65 KJ / Kg
Value of Ha at 35.600 C is 111.80 KJ / Kg
Mh3 = Hw - Ha
Mh3 = 148.65 – 111.80
Mh3 = 36.85 KJ / Kg

CALCULATION FOR 3

H4= T1 - 0.1 (T1 – T2)
= 38 – 0.1 (38 - 32)
= 37.400 C
Value of Hw at 37.400 C is 157 KJ / Kg
Value of Ha at 37.400 C is 122.50 KJ / Kg
Mh4 = Hw - Ha
Mh4 = 157 – 122.50
Mh4 = 34.50 KJ / Kg
Now put all above value in equation (1.2)
(KaV / mw1) = 0.1540

EFFICIENCY OF COOLING TOWER

N = (T1 – T2) / (T1 – WBT)
N = (38 - 32) / (38 - 29)
N = 66.67 %

EFFECTIVENESS OF COOLING TOWER

P = (T1 – T2) / (T1 – Ta1)
P = (38 - 32) / (38 - 20)
P = 0.33

III. CONCLUSION:

In this study, we have analyzed the water distribution across the plane area of the cooling tower. We have adjusted the amount of water to suit the air flow conditions, which cannot be influenced with natural draft cooling towers. In this way, the optimal moistening of the cooling tower packing is ensured, which results in a more effective heat transfer. With a optimal water distribution, a constant local water outlet temperature is obtained, which decreases the entropy generation and the exergy lost from the cooling tower. The result is lower outlet water temperature from the cooling tower and, thus, from the condenser, which results in greater efficiency of the power plant.

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