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Research Article

THERMAL DESIGN OF COOLING TOWER

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ABSTRACT

Cooling towers are equipment devices commonly used to dissipate heat from power generation units, water-cooled refrigeration, air conditioning and industrial processes. 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. Some techniques refer to different methods used to increase the thermal performance of cooling tower. The present paper is a detailed methodology for thermal design of cooling tower. The technical data is taken for Mechanical draft cooling tower.

KEYWORDS Cooling tower, Thermal Design, Different types of losses

INTRODUCTION

A cooling tower is a semi-enclosed device for evaporative cooling of water by contact with air. It is a wooden, steel or concrete structure and corrugated surfaces or baffles or perforated trays are provided inside the tower for uniform distribution and better atomization of water in the tower. The hot water coming out from the condenser is fed to the tower on the top and allowed to tickle in form of thin drops. The air flows from bottom of the tower or perpendicular to the direction of water flow and then exhausts to the atmosphere after effective cooling. To prevent the escape of water particles with air, draft eliminators are provided at the top of the tower.

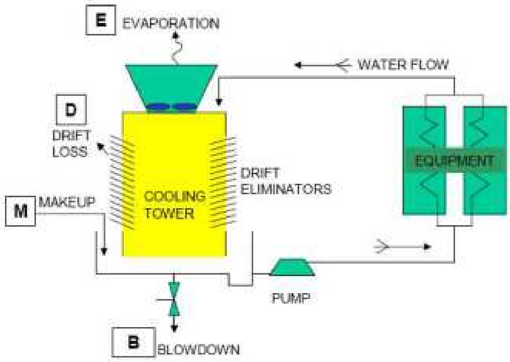

Figure 1 Schematic diagram of a cooling water system

COOLING TOWER SYSTEM

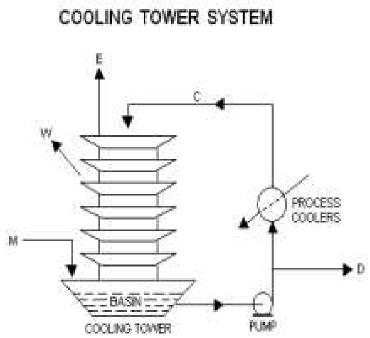

Figure 2 Cooling tower system

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

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 streams which 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 tower and 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 by natural 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 the water (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 water temperature 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 been evaporated, thus raising the salt concentration in the circulating cooling water. To prevent the salt 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 tower basin to compensate for the loss of evaporated water, the wind age loss water and the draw-off water.

ASSESSMENT OF COOLING TOWER

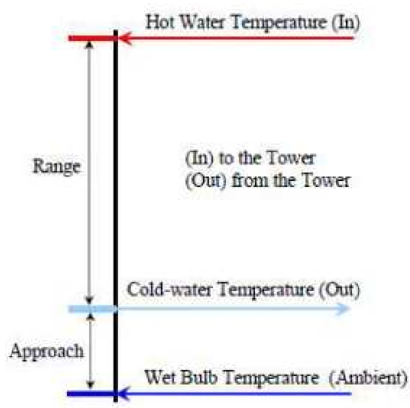

Figure 3 Range and Approach of cooling tower

RANGE

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

APPROACH

This is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. Although, both range and approach should 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)

$CTA = T_2 – WBT = 32 – 29 = 3^0 C$

COOLING TOWER RANGE (CTR)

$CTR = T_1 – T_2 = 38 – 32 = 6^0 C$

Now, Mass of water circulated in cooling tower

M_{w1} = Volume of circulating water x Mass density of water

$M_{w1} = 30 \times 1000$

$M_{w1} = 30000$ Kg / hr

HEAT LOSS BY WATER (HL)

$HL = M_{w1} \times C_{pw} \times (T_1 – T_2)$

$HL = 30000 \times 4.186 \times (38 - 32)$

HL = 753480 KJ / hr

VOLUME OF AIR REQUIRED (V)

$V = (HL \times V_{s1}) / [(H_{a2} – H_{a1}) - (W_2 – W_1) \times C_{pw} \times T_2]$

$V = (753480 \times 0.842) / [(73 - 50) – (0.018 – 0.0118) \times 4.186 \times 32]$

$V = 28617.25\ m^3$ / hr

HEAT GAIN BY AIR (HG)

$HG = V \times [(H_{a2} – H_{a1}) - (W_2 – W_1) \times C_{pw} \times T_2] / V_{s1}$

$HG = 28617.25 \times [(73 - 50) – (0.018 – 0.0118) \times 4.186 \times 32] / 0.842$

HG = 634430.05 /0.842

HG = 753480 KJ / hr

MASS OF AIR REQUIRED (M_a)

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

$M_a = V / V_{s1}$

$M_a = 33987.23$ Kg / hr

THE QUANTITY OF MAKE-UP WATER (M_{mak})

$M_{mak} = V \times (W_2 – W_1) / V_{s2}$

$M_{mak} = 28617.25 \times (0.018 – 0.0118) / 0.875$

$M_{mak} = 202.7736$ Kg / hr

Now, taking Evaporating loss in calculation

$M_{mak} = 202.7736 \times [1 + (1.44 / 100)]$

$M_{mak} = 205.70$ Kg / hr

$M_{mak} = 205.70 / 60$

$M_{mak} = 3.43$ Kg / min

VELOCITY OF WATER INSIDE THE WATER PIPE (V_W)

Volume of water transfer through cooling tower per hour is 30 m^3 / hr. So the velocity of water through pipe is

V_w = 30 / Area of pipe

Now, Area of pipe is given by

$a = (\pi / 4) \times d_i^2$

$a = (\pi / 4) \times (0.1)^2$

$a = 0.00785\ m^2$

So, $V_w = 30 / 0.00785$

$V_w = 3821.65$ m / hr

$V_w = 1.06$ m / s

LENGTH OF WATER PIPE REQUIRED (L)

$HL = 2\pi KL (T_1 – T_2) / \log (r_o /r_i)$ (1.1)

Material of the pipe used in cooling tower is S.S, So the thermal conductivity for the steel material is 40 W / m-deg. So,

K = 40 W / m-deg

Put value of K in equation (1.1)

$753480 = 2\pi \times 40 \times L \times (38 - 32) / \log (0.06 /0.05)$

$753480 = 19045 \times L$

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

$(KaV / m_{w1}) = [(T_1 – T_2) / 4] \times \{(1 /\Delta h_1) +$

$(1 / \Delta h_2) + (1 / \Delta h_3) + (1 / \Delta h_4)\}$ (1.2)

Where,

K = Mass transfer co-efficient (Kg / hr m^2)

a = Constant area (m^2)

V = Active cooling volume (m^3)

m_{w1} = Mass of water (Kg / hr)

T_1 = Hot water temperature (^{0} C)

T_2 = Cold water temperature (^{0} C)

Now,

Δh_1 = Value of $H_w - H_a$ at $T_2 + 0.1 (T_1 - T_2)$

Δh_2 = Value of $H_w - H_a$ at $T_2 + 0.4 (T_1 - T_2)$

Δh_3 = Value of $H_w - H_a$ at $T_1 - 0.4 (T_1 - T_2)$

Δh_4 = Value of $H_w - H_a$ at $T_1 - 0.1 (T_1 - T_2)$

CALCULATION FOR ΔH$_1$

$= T_2 + 0.1 (T_1 - T_2)$

= 32 + 0.1 (38 - 32)

= 32.60^0 C

Value of H_w at 32.60^0 C is 136.11 KJ / Kg

Value of H_a at 32.60^0 C is 89 KJ / Kg

$\Delta h_1 = H_w - H_a$

$\Delta h_1 = 136.11 - 89$

Δh_1 = 47.11 KJ / Kg

CALCULATION FOR ΔH$_2$

$= T_2 + 0.4 (T_1 - T_2)$

= 32 + 0.4 (38 - 32)

= 34.40^0 C

Value of H_w at 34.40^0 C is 144.47 KJ / Kg

Value of H_a at 34.40^0 C is 105 KJ / Kg

$\Delta h_2 = H_w - H_a$

$\Delta h_2 = 144.47 - 105$

Δh_2 = 39.47 KJ / Kg

CALCULATION FOR ΔH$_3$

$= T_1 - 0.4 (T_1 - T_2)$

= 38 – 0.4 (38 - 32)

= 35.60^0 C

Value of H_w at 35.60^0 C is 148.65 KJ / Kg

Value of H_a at 35.60^0 C is 111.80 KJ / Kg

$\Delta h_3 = H_w - H_a$

$\Delta h_3 = 148.65 - 111.80$

Δh_3 = 36.85 KJ / Kg

CALCULATION FOR ΔH$_4$

$= T_1 - 0.1 (T_1 - T_2)$

= 38 – 0.1 (38 - 32)

= 37.40^0 C

Value of H_w at 37.40^0 C is 157 KJ / Kg

Value of H_a at 37.40^0 C is 122.50 KJ / Kg

$\Delta h_4 = H_w - H_a$

$\Delta h_4 = 157 - 122.50$

Δh_4 = 34.50 KJ / Kg

Now put all above value in equation (1.2)

$(KaV / m_{w1}) = 0.1540$

EFFICIENCY OF COOLING TOWER

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

η = (38 - 32) / (38 - 29)

η = 66.67 %

EFFECTIVENESS OF COOLING TOWER

$\varepsilon = (T_1 - T_2) / (T_1 - Ta_1)$

ε = (38 - 32) / (38 - 20)

ε = 0.33

DIFFERENT TYPES OF LOSSES

DRIFT LOSSES (DL)

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

DL = 0.20 x m_{w1} / 100

DL = 0.20 x 30000 / 100

DL = 60 Kg / hr

WINDAGE LOSSES (WL)

Windage losses are generally taken as 0.005 of circulating water.

WL = 0.005 x m_{w1}

WL = 0.005 x 30000

WL = 150 Kg / hr

EVAPORATION LOSSES (EL)

Evaporation losses are generally taken as 0.00085 of circulating water.

EL = 0.00085 x m_{w1} x $(T_1 - T_2)$

EL = 0.00085 x 30000 x (38 - 32)

EL = 153 Kg / hr

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

M = 150 + 153 + 60

M = 363 Kg / hr

XC / XM = M / (M - EL)

XC / XM = 363 / (363 - 153)

XC / XM = Cycles = 1.7286

So, Blow down loss

BL = EL / (Cycles - 1)

BL = 153 / (1.7286 - 1)

BL = 210 Kg / hr

CONCLUSION

The design of cooling tower is closely related to tower Characteristic and different types of losses generated in cooling tower. Even though losses are generated in the cooling tower, the cooling is achieved due to heat transfer between air and water. In ideal condition, the heat loss by water must be equal to heat gain by air. But in actual practice it is not possible because of some type of losses. Cooling tower performance increases with increase in air flow rate and characteristic decreases with increase in water to air mass ratio.

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