Research Article

THERMAL DESIGN OF COOLING TOWER

Ronak Shah, Trupti Rathod

Address for Correspondence
1 Student, 2 Asst. Prof., Mechanical Engineering, L.D.R.P. Institute of Technology and Research, Gandhinagar, Gujarat Technological University, India

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 trickle 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.

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

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:

\[ \text{Range} = \text{Inlet Temperature} - \text{Outlet Temperature} \]
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 m³/hr |
| Inlet temperature of water (T1) | 38° C |
| Outlet temperature of water (T2) | 32° C |
| Wet bulb temperature (WBT) | 29° C |
| Height of cooling tower (H) | 2.3 m |
| Material of pipe used for water flow | S.S. |
| Inside diameter of pipe (d1) | 0.10 m |
| Outside diameter of pipe (d2) | 0.12 m |
| Inlet temperature of air (T1a) | 20° C |
| Outlet temperature of air (T2a) | 27° C |
| Design relative humidity (Φ) | 80 % |
| Allowable Evaporating losses | 1.44 % |

DATA FROM PSYCHOMETRIC CHART AND STEAM TABLE

| Enthalpy of air at inlet temperature (H_in) | 50 KJ/Kg |
| Enthalpy of air at outlet temperature (H_out) | 73 KJ/Kg |
| Specific Humidity of air at inlet temperature (W1) | 0.0118 Kg/Kg of air |
| Specific Humidity of air at outlet temperature (W2) | 0.018 Kg/Kg of air |
| Specific Volume of air at inlet temperature (V1) | 0.842 m³/Kg |
| Specific Volume of air at outlet temperature (V2) | 0.875 m³/Kg |
| Enthalpy of water at inlet temperature (H1) | 159.10 KJ/Kg |
| Enthalpy of water at outlet temperature (H2) | 134.00 KJ/Kg |

DESIGN CALCULATION

COOLING TOWER APPROACH (CTA)
CTA = T2 - WBT = 32 - 29 = 3° C

COOLING TOWER RANGE (CTR)
CTR = T1 - T2 = 38 - 32 = 6° C

Now, Mass of water circulated in cooling tower
M_w1 = Volume of circulating water x Mass density of water
M_w1 = 30 x 1000
M_w1 = 30000 Kg/hr

HEAT LOSS BY WATER (HL)
HL = M_w1 x C_pw x (T1 - T2)
HL = 30000 x 4.186 x (38 - 32)
HL = 753480 KJ/hr

VOLUME OF AIR REQUIRED (V)
V = (HL x V_s1) / [(H_12 - H_11) - (W_2 - W_1) x C_pw x T2]

HEAT GAIN BY AIR (HG)
HG = V x [(H_12 - H_11) - (W_2 - W_1) x C_pw x T2] / V_s1
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 (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_max)
M_max = V x (W_2 - W_1) / V_s1
M_max = 28617.25 x (0.018 - 0.0118) / 0.875
M_max = 202.7736 Kg/hr

Now, taking Evaporating loss in calculation
M_max = 202.7736 x [1 + (1.44 / 100)]
M_max = 205.70 Kg/hr

VOLUME 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

V_w = 30 / Area of pipe

Now, Area of pipe is given by
a = (π / 4) x d^2
a = (π / 4) x (0.05)^2
a = 0.00785 m²

So, V_w = 30 / 0.00785
V_w = 3821.65 m³/hr
V_w = 1.06 m/s

LENGTH OF WATER PIPE REQUIRED (L)

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 = 2π 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

COOLING TOWER CHARACTERISTIC

Merkel gives the cooling tower characteristic equation as
(KaV / m_w1) = [(T_1 - T_2) / 4] x {(1 / Δ h_1) + V = (753480 x 0.842) / [(73 - 50) - (0.018 – 0.0118) x 4.186 x 32] V = 28617.25 m³/hr

Now, 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] x {(1 / Δ h_1) +
η = (T_{\text{EFFICIENCY OF COOLING TOWER}} - T_2) / (T_1 - T_2)  
K = Mass transfer co-efficient (Kg / hr m\(^2\))  
V = Active cooling volume (m\(^3\))  
m\(_a\) = Mass of water (Kg / hr)  
T_1 = Hot water temperature (\(^\circ\)C)  
T_2 = Cold water temperature (\(^\circ\)C)  

\[ \Delta h = \frac{(38 - 32) - (38 - 20)}{38 - 20} = 0.1540 \]

Now,  
\[ \Delta h_1 = \text{Value of H}_a - \text{H}_t \]  
\[ \Delta h_2 = \text{Value of H}_a - \text{H}_t + 0.1 (T_1 - T_2) \]  
\[ \Delta h_3 = \text{Value of H}_a - \text{H}_t + 0.4 (T_1 - T_2) \]  
\[ \Delta h_4 = \text{Value of H}_a - \text{H}_t - 0.4 (T_1 - T_2) \]  
\[ \Delta h_5 = \text{Value of H}_a - \text{H}_t - 0.1 (T_1 - T_2) \]

\[ \eta = (1 / \Delta h_1) + (1 / \Delta h_3) + (1 / \Delta h_5) \]  
\[ (1 / \Delta h_2) + (1 / \Delta h_4) + (1 / \Delta h_5) \]  
\[ 1.2 \]

Where,

\[ \Delta h = \text{Value of H}_a - \text{H}_t \]  
\[ \Delta h = 32.60 \]  
\[ \Delta h = 153 \]  
\[ \Delta h = 0.00085 \times m_\text{a} \]  
\[ \Delta h = 0.005 \times m_\text{a} \]  
\[ \Delta h = 0.20 \times 30000 \times (38 - 32) \]  
\[ \Delta h = 153 \times 100 \]  
\[ \Delta h = 0.00085 \times 30000 \times (38 - 32) \]  
\[ \Delta h = 153 \times 100 \]  

\[ \text{DL} = 0.20 \times m_\text{a} / 100 \]  
\[ \text{DL} = 0.20 \times 30000 / 100 \]  

\[ \text{DL} = 60 \times \text{Kg / hr} \]

**WIN DAGE LOSSES (WL)**  
Windage losses are generally taken as 0.005 of circulating water.  
WL = 0.005 \times m_\text{a}  
WL = 0.005 \times 30000  
WL = 150 \times \text{Kg / hr}  

**EVAPORATION LOSSES (EL)**  
Evaporation losses are generally taken as 0.00085 of circulating water.  
EL = 0.00085 \times m_\text{a} \times (T_1 - T_2)  
EL = 0.00085 \times 30000 \times (38 - 32)  
EL = 153 \times \text{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  

\[ \text{WL} = 0.005 \times m_\text{a} \]  
\[ \text{WL} = 0.005 \times 30000 \]  

\[ \text{M} = \text{WL} + \text{EL} + \text{DL} \]  
\[ \text{M} = 150 + 153 + 60 \]  
\[ \text{M} = 363 \times \text{Kg / hr} \]  
\[ \text{XC} / \text{XM} = \text{M} / (\text{M} - \text{EL}) \]  
\[ \text{XC} / \text{XM} = 363 / (363 - 153) \]  

\[ \text{XC} = 47.11 \times \text{KJ / Kg} \]

\[ \text{EVAPORATION LOSSES (EL)} \]  
\[ \text{EL} = 0.00085 \times 30000 \times (38 - 32) \]  
\[ \text{EL} = 153 \times \text{Kg / hr} \]

\[ \text{BLOW DOWN LOSSES (BL)} \]  
\[ \text{Number of cycles required for cooling tower is given by} \]  
\[ \text{Cycles} = \text{XC} \div \text{XM} \]  
\[ \text{Where,} \]  
\[ \text{XC} = \text{Concentration of solids in circulating water} \]  
\[ \text{XM} = \text{Concentration of solids in Make-up water} \]  

\[ \text{WL} = 0.005 \times m_\text{a} \]  
\[ \text{WL} = 0.005 \times 30000 \]  

\[ \text{M} = \text{WL} + \text{EL} + \text{DL} \]  
\[ \text{M} = 150 + 153 + 60 \]  
\[ \text{M} = 363 \times \text{Kg / hr} \]  
\[ \text{XC} / \text{XM} = \text{M} / (\text{M} - \text{EL}) \]  
\[ \text{XC} / \text{XM} = 363 / (363 - 153) \]  
\[ \text{XC} / \text{XM} = 1.7286 \]  

\[ \text{So, Blow down loss} \]  
\[ \text{BL} = \text{EL} \div (\text{Cycles} - 1) \]  
\[ \text{BL} = 153 \div (1.7286 - 1) \]  
\[ \text{BL} = 210 \times \text{Kg / hr} \]

**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.

**REFERENCES**

1. Kai Wang, Feng - zhong Sun, Yuan-bin Zhao, Ming Gao, Lei Ruan, Experimental research of the guiding channels effect on the thermal performance of wet cooling towers subjected to crosswinds – Air guiding effect on cooling tower, Applied Thermal Engineering 30 (2010) 533–538.
6. M. Lucas, P. J. Martinez, A. Viedma, Experimental study on the thermal performance of a mechanical...
cooling tower with different drift eliminators, Energy conversion and Management 50 (2009) 490-497.
