Ammar Abdulkadhim
E-mail: AmmarAbdulkadhim@uomus.edu.iq

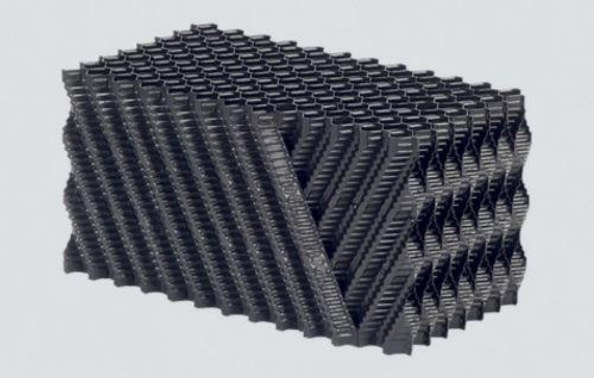
CHAPTER FIVE: COOLING TOWERS

INTRODUCTION

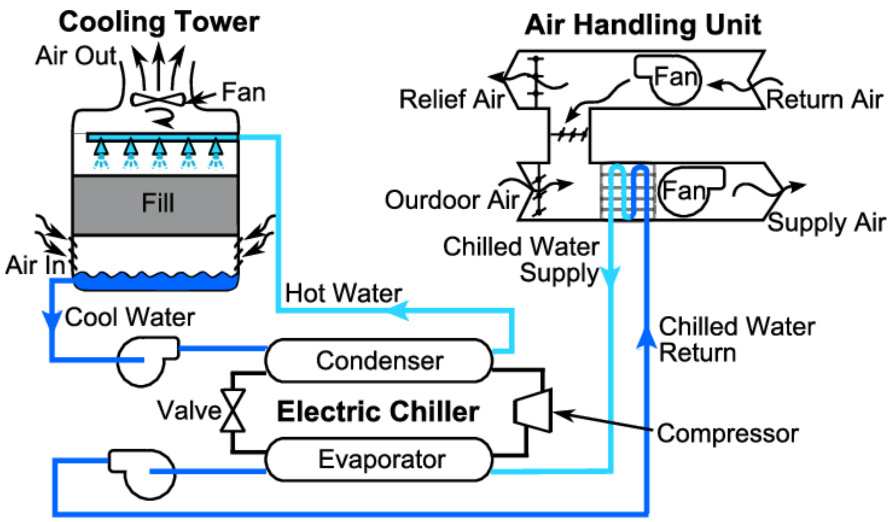
1. What is cooling tower?

- A cooling tower is a specialized heat exchanger in which air and water are brought into direct contact with each other in order to reduce the water's temperature.
- As this occurs, a small volume of water is evaporated, reducing the temperature of the water being circulated through the tower.

2. Explain the cooling tower role in refrigeration systems?



- In water – cooled chiller in which the condenser is water – cooled type, the refrigerant is hot while the water is cooled. The refrigerant loss its heat to the water.
- As soon as the water absorb this heat, its temperature will rise. So the water will go into a cooling tower and enters the tower from the top and flow through the fills while the air will be moved from bottom side into the top of the tower to make direct exchange between the hot water and cold air in which the water will lose its heat to the air which lead the water to be cooled and enters the water – cooled condenser again and the cycle will repeated in this manner.

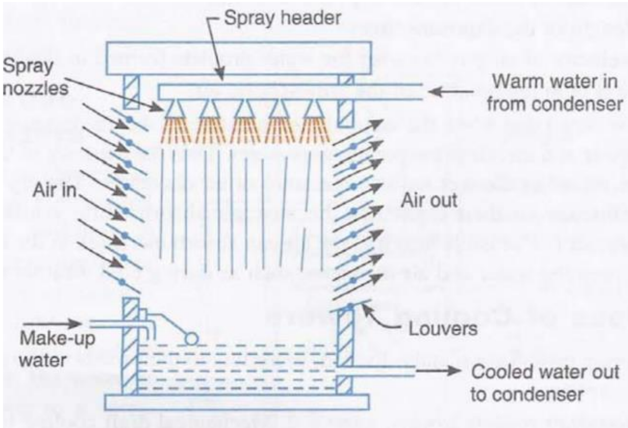


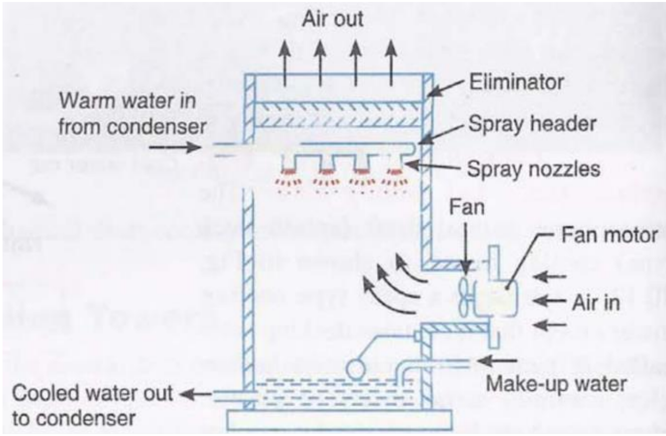
3. Types of cooling tower

The cooling towers are mainly divided, according to their method of air circulation, into the following two groups :

1. Natural draft cooling towers, and 2. Mechanical draft cooling towers.

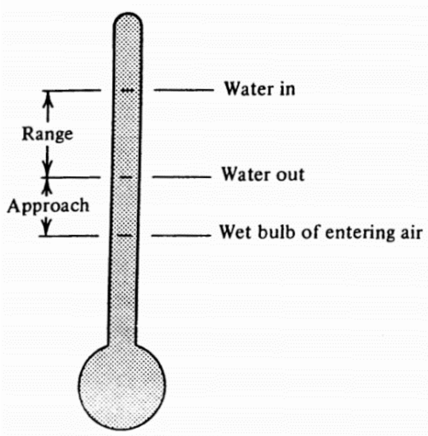
In *natural draft cooling towers*, the air circulates through the tower by natural convection whereas in *mechanical draft cooling towers*, the air is forced through the tower by means of fans



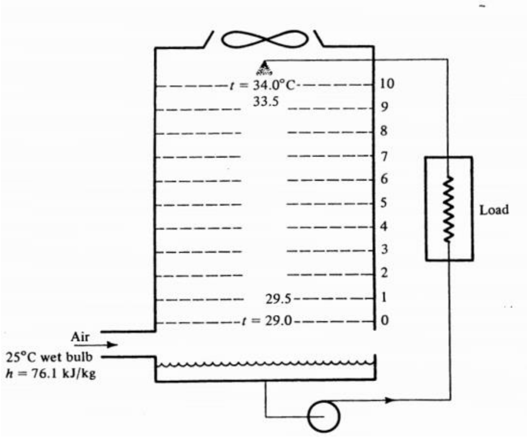


4. Range and Approach in Cooling Towers

- The range is the reduction in temperature of the water through the cooling tower.
- The approach is the difference between the wet-bulb temperature of the entering air and temperature of the leaving water.



Applied Thermodynamics to Cooling Towers



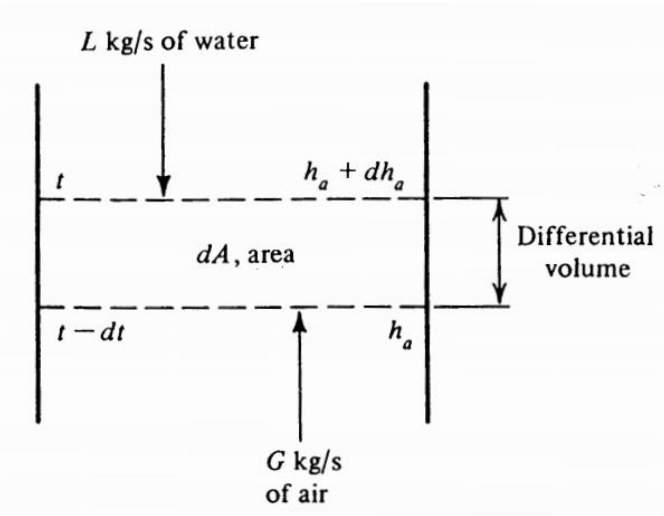
19-3 Analysis of a counterflow cooling tower One design of cooling tower is the counterflow type, in which air passes upward through a falling spray of water. Figure 19-3 shows a differential volume of a counterflow cooling tower with L kg/s of water entering from the top and G kg/s of air entering from the bottom. For simplicity, the small quantity of water which evaporates is neglected, so that both L and G remain constant throughout the tower.

Water enters the section at a temperature t°C and leaves at a slightly lower temperature $t - dt$. Air enters the section with an enthalpy of h_a kJ per kilogram of dry air and leaves with an enthalpy of $h_a + dh_a$. The total area of the wetted surface dA includes the surface area of the drops of water as well as the wetted slats or other fill material.

The rate of heat removed from the water dq is equal to the rate gained by the air:

$$dq = G\,dh_a = L(4.19\text{ kJ/kg}\cdot\text{K})\,dt \quad \text{kW} \qquad (19\text{-}1)$$

$$G\left(h_{a,1} - h_{a,0}\right) = L * 4.19 * \Delta t$$



From the principles of enthalpy potential in Sec. 3-15 another expression for dq is

$$dq = \frac{h_c\,dA}{c_{pm}}(h_i - h_a) \qquad (19\text{-}2)$$

where h_c = convection coefficient, kW/m^2 · K
h_i = enthalpy of saturated air at the water temperature, kJ/(kg dry air)
h_a = enthalpy of air, kJ/(kg dry air)
c_{pm} = specific heat of moist air, kJ/kg · K

19-4 Stepwise integration To find the rate of heat transferred by the entire cooling tower, Eq. (19-2) must be integrated. Both h_i and h_a vary with respect to the variable of integration A. Combining Eqs. (19-1) and (19-2), rearranging, and integrating gives

$$4.19\,L\int_{t_{out}}^{t_{in}}\frac{dt}{h_i - h_a} = \int_0^A \frac{h_c\,dA}{c_{pm}} = \frac{h_c A}{c_{pm}} \qquad (19\text{-}3)$$

where t_{in} and t_{out} are the water temperatures entering and leaving the tower, respectively.

$$\frac{h_c A}{c_{pm}} = 4.19L\,\Delta t \sum \frac{1}{(h_i - h_a)_m} \qquad (19\text{-}4)$$

Cooling Tower

Example:

A counter flow cooling tower operates with a water flow rate of 18.8 kg/s and an air flow rate of 15.6 kg/s, when the wet bulb temperature of entering air is 25°C ($h_a = 76$ kJ/kg) and entering water temperature is 34°C, the leaving water temperature is 28°C. Calculate $(h_c A / c_{pm})$ for three sections using stepwise integration with 2°C increments change in water temperature

T [°C]	28	29	30	31	32	33	34	35	36
h_i [kJ/kg]	89.9	94.8	99.9	105.3	110.9	116.8	122.9	129.4	136.1

Sol: $L = 18.8$ kg/s ; $G = 15.6$ kg/s

$t_{w,in} = 34$ °C ; $h_{a_o} = 76$ kJ/kg

$t_{w,out} = 28$°C

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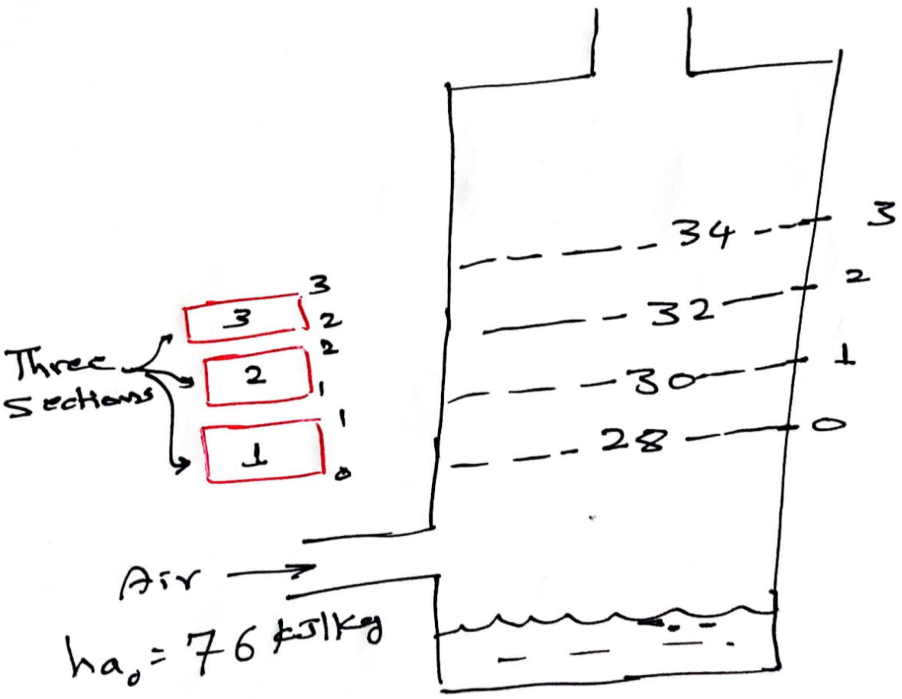
$$\Delta t_{water} = \frac{t_{w,in} - t_{w,out}}{\text{number of sections}}$$

$$\Rightarrow \text{Number of sections} = \frac{34-28}{2}$$

$$= \frac{6}{2} = \underline{\underline{3}}$$



Schematic Diagram of the Computation Domain

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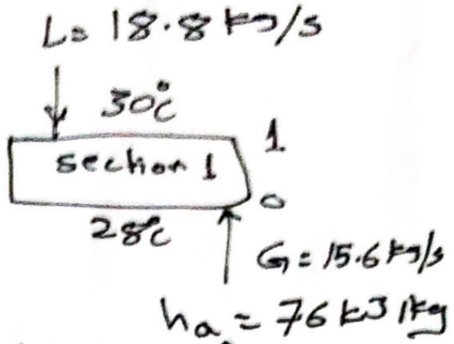
Ammar Abdulkadhim
E-mail: AmmarAbdulkadhim@uomus.edu.iq

section 1



$h_{a_1} = ?$

$h_{a_o} = 76$ kJ/kg

$\therefore G(h_{a_1} - h_{a_o}) = L * 4.19 * \Delta t$

$h_{a_1} - h_{a_o} = \left(\frac{L}{G}\right)(4.19)(\Delta t)$

$\therefore h_{a_1} = \left(\frac{L}{G}\right)(4.19)(\Delta t) + h_{a_o}$

$= \left(\frac{18.8}{15.6}\right)(4.19)(2) + 76$

$\therefore h_{a_1} = 86.09897436$ kJ/kg

$h_{a_m} = \frac{h_{a_1} + h_{a_o}}{2} = \frac{86.0989 + 76}{2}$

$\Rightarrow h_{a_m} = 81.04948718$ kJ/kg

$t_{w_m} = \frac{30 + 28}{2} = 29°C$

From the given table in the example; we find : at $t_{w_m} = 29°C \rightarrow h_i)_m = 94.8$ kJ/kg

$\therefore \left.\frac{h_c A}{C_{pm}}\right)_1 = 4.19 * L * \Delta t_w * \frac{1}{(h_i - h_a)_m}$

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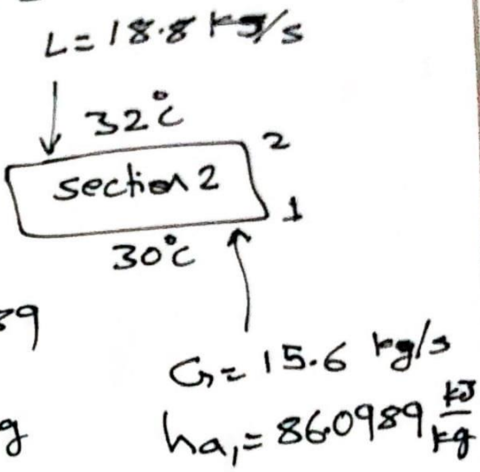
$$\left.\frac{h_c A}{C_{pm}}\right)_1 = 4.19 * 18.8 * 2 * \frac{1}{94.8 - 81.0494}$$

$$\left.\frac{h_c A}{C_{pm}}\right)_1 = 11.4572 \text{ KW/(KJ/kg of enthalpy diff)}$$

Similarly; For Section 2:



$$h_{a2} = \frac{L}{G} * 4.19 * Dt + h_{a1}$$

$$= \frac{18.8}{15.6} * 4.19 * 2 + 86.0989$$

$$\therefore h_{a2} = 96.1978 \text{ KJ/kg}$$

$$h_{am} = \frac{h_{a2} + h_{a1}}{2} = \frac{96.1978 + 86.0989}{2}$$

$$\Rightarrow h_{am} = 91.1483 \text{ KJ/kg}$$

$$t_{wm} = \frac{32 + 30}{2} = 31°C$$

From Table @ $t_{wm} = 31°C \rightarrow h_i)_m = 105.3$ KJ/kg

$$\therefore \left.\frac{h_c A}{C_{pm}}\right)_2 = 4.19 * 18.8 * 2 * \frac{1}{105.3 - 91.1483}$$

$$\Rightarrow \left.\frac{h_c A}{C_{pm}}\right)_2 = 11.13258 \text{ KW/(KJ/kg)}$$

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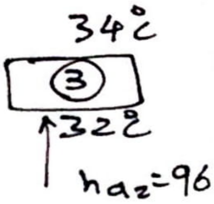
Ammar Abdulkadhim
E-mail: AmmarAbdulkadhim@uomus.edu.iq

Finally; For Section 3 :



$$h_{a3} = \frac{L}{G} * 4.19 * \Delta t + h_{a2}$$

$$h_{a3} = \frac{18.8}{15.6} * 4.19 * 2 + 96.1978$$

$$\Rightarrow h_{a3} = 106.2967 \text{ KJ/Kg}$$

$$h_{am} = \frac{h_{a3} + h_{a2}}{2} = \frac{106.2967 + 96.1978}{2}$$

$$\Rightarrow h_{am} = 101.2472 \text{ KJ/Kg}$$

Again; $t_{wm} = \frac{32+34}{2} = 33°C$

From Table at $t_{wm} = 33°C$:

$$h_i)_m = 116.8 \text{ KJ/Kg}$$

$$\therefore \frac{h_c A}{C_{pm}}\Big)_3 = 4.19 * 18.8 * 2 * \frac{1}{116.8 - 101.2472}$$

$$= 10.1296 \text{ KW/(KJ/Kg)}$$

$$\therefore \frac{h_c A}{C_{pm}} = \frac{h_c A}{C_{pm}}\Big)_1 + \frac{h_c A}{C_{pm}}\Big)_2 + \frac{h_c A}{C_{pm}}\Big)_3$$

$$= 11.4572 + 11.1325 + 10.1296$$

$$= 32.7193 \text{ KW/(KJ/Kg)}$$