Calculation of Cooling Tower Performance and Required Fill Height

The tower coefficient is presented by the equation

$$\frac{KaV}{\dot{m}_w} = C + H\dot{m}_w^n + \dot{m}_a^m$$ or similar presentation.

Assume the performance of a particular cooling tower design follows the empirical equation:

$$\frac{KaV}{\dot{m}_w} = 0.02 + 0.1H(\frac{\dot{m}_w}{\dot{m}_a})^{-0.6}$$ at 'water to air' mass ratio = 1.2

Consider a chiller plant system (cooling capacity 500kW) with COP at 4.5 is designed with a cooling tower, the design entering and leaving condenser water temperature of the cooling tower are 37°C and 32°C respectively, the design wet bulb temperature of the outdoor air is 28°C (concurrent dry-bulb 33.5°C), what are:

a) the cooling tower coefficient
b) the required condenser water and air mass rate (in kg/s) in the cooling tower
c) the required height of the fill

Solution

a)

As the air and water temperature are not changing linearly, the entering / leaving water temperature should be cut down into small steps of, e.g. 1°C / 1K, in an iteration process to determine the heat transfer in each step.

The changing enthalpy of air in each step dh_a can be derived from the heat balance equation:

$$\dot{m}_w c_{pw} dT_w = \dot{m}_a dh_a$$

At $\dot{m}_w / \dot{m}_a = 1.2$, $c_{pw} = 4.18$ kJ/kgK, $dT_w = 1$K

$$dh_a = 1.2 \times 4.18 = 5.0 \text{ kJ/kg}$$

A table indicating the cumulative heat transfer is presented as shown:

Water Temperature t °C	Enthalpy of Film[1] h_s kJ/kg	Enthalpy of Air[2] h_a kJ/kg	Enthalpy Difference $h' - h_a$ kJ/kg	$\frac{1}{(h' - h_a)}$ kg/KJ	Δt K	NTU= $\frac{\Delta t}{(h' - h_a)_{avg}}$	$\sum NTU$
32	111.0	90.0 (33.5°C DB) (28°C WB)	21.0	0.0476	1		
						0.0467	0.0467
33	116.9	95.0	21.9	0.0457	1		
						0.0446	0.0913
34	123.0	100.0	23.0	0.0435	1		
						0.0422	0.1335
35	129.5	105.0	24.5	0.0408	1		
						0.0395	0.1730
36	136.2	110.0	26.2	0.0382	1		
						0.0368	0.2098
37	143.3	115.0	28.3	0.0353	1		

Note:

1. Enthalpy of saturated air film at different temperature obtained from thermodynamic tables of moist air.
2. Enthalpy of air starts at 28°C WB = 90.0 kJ/kg and then increases by 5.0kJ/kg per 1K increase in water temperature.

The tower coefficient NTU is calculated to be 0.210.

b)

The required condenser water can be obtained from the actual heat to be rejected at the cooling tower.

The chiller has a cooling capacity of 500kW and the COP is 4.5.

The work input for the compressor = 500kW / 4.5 = 111kW

Total heat to be rejected = (500 + 111) kW = 611 kW

The mass flow of condenser water can be calculated:

$$Q = \dot{m}_w c_{pw} (T_{wl} - T_{we})$$

611kW= $\dot{m}_w$ ×4.18kJ/kgK×(37-32)°C

$\dot{m}_w$ =29.2kg/s

Thus

$\dot{m}_a$ = (29.2 / 1.2) kg/s = 24.3 kg/s

The leaving air is near to saturation at 115kJ/kg. From the psychrometric chart, the air temperature is approximately 32.7°C when leaving the condenser.

c)

The height of the fill can be obtained from the equation

$$\frac{KaV}{\dot{m}_w} = 0.02 + 0.1H\left(\frac{\dot{m}_w}{\dot{m}_a}\right)^{-0.6}$$

$$0.210 = 0.02 + 0.1H(1.2)^{-0.6}$$

$$H = 2.1\text{m}$$