UCH 1201 Principles of Chemical Engineering

Humidification

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Contents

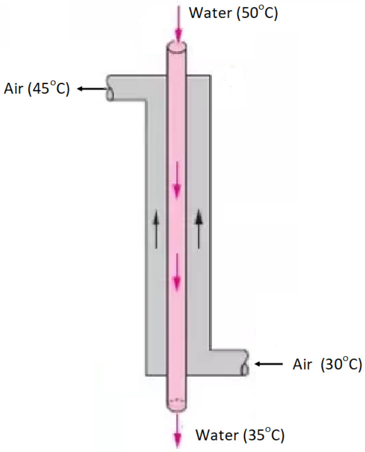
Humidity & saturation.

Outcome

- To compare the cooling process of water by contacting with air.

Cooling of Cooling Water

Indirect Contact — Heat Exchanger



$$(mC_P\Delta T)_{\text{water}} = (mC_P\Delta T)_{\text{air}}$$

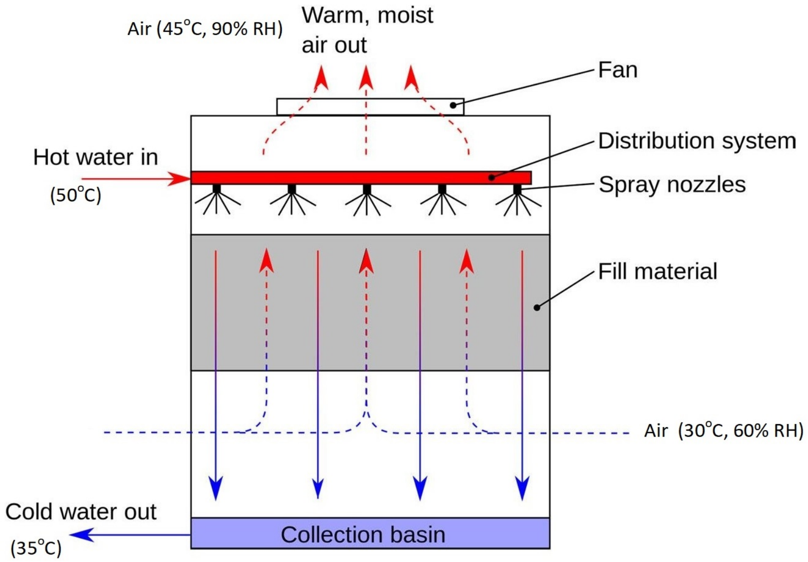
Specific heat of water = 4.2 kJ/kg.°C
Specific heat of air = 1 kJ/kg.°C

For cooling of cooling-water with air in a heat exchanger, i.e., by indirect contacting of water with air, from energy balance, we can prove that 4.2 kg of air is needed for for 1 kg of water.

Density of water = 1000 kg/m^3
Density of air ≈ 1 kg/m^3
Air being lighter, we need to circulate a large volume of air — 4200 ltr of air per ltr of water.

Cooling of Cooling Water

Direct Contact — Cooling Tower



Cooling of Cooling Water

Direct Contact — Cooling Tower (contd..)

For the entry and exit conditions, kg of water vapor per kg of dry air, are obtained from the definition of absolute humidity (H_a), given as:

$$H_a = \frac{\text{mass of water vapor}}{\text{mass of dry air}} = \frac{n_W}{n_A}\frac{M_W}{M_A} = \frac{P_W}{P - P_W}\frac{M_W}{M_A} \quad \frac{\text{kg vapor}}{\text{kg dry air}}$$

where P_W is partial pressure of water vapor; and, P is total pressure. M_W, M_A are molecular weight of water and air respectively.

Cooling of Cooling Water

Direct Contact — Cooling Tower (contd..)

Vapor pressure of water (from table of data):

$$\text{At } 30^\circ\mathrm{C}: \; 31.8 \text{ mm Hg}$$
$$\text{At } 45^\circ\mathrm{C}: \; 71.9 \text{ mm Hg}$$

From the definition of relative humidity (RH), we have

$$\mathrm{RH} = \frac{P_W}{P_W^{\mathrm{sat}}}$$

Hence,

$$\text{inlet air}: 30^\circ\mathrm{C},\ 60\%\ \mathrm{RH} \qquad P_W = 0.6 \times 31.8 = 19.08 \text{ mm Hg}$$
$$\text{exit air}: 45^\circ\mathrm{C},\ 90\%\ \mathrm{RH} \qquad P_W = 0.9 \times 71.9 = 64.71 \text{ mm Hg}$$

Cooling of Cooling Water

Direct Contact — Cooling Tower (contd..)

The amount of water vapor in the inlet and exit are:

$$\frac{19.08}{760 - 19.08} \times \frac{18}{29} = 0.016 \text{ kg water vapor/kg dry air}$$
$$\frac{64.71}{760 - 64.71} \times \frac{18}{29} = 0.058 \text{ kg water vapor/kg dry air}$$

Amount of water vapor picked-up per kg of air $=$ $0.058 - 0.016 = 0.042$ kg.

Cooling of Cooling Water

Direct Contact — Cooling Tower (contd..)

Amount of heat removal required for $15^{\circ}\mathrm{C}$ drop in temperature for water $= C_P \Delta T = 4.2 \times 15 = 63$ kJ/kg.
Average latent heat of water in the range of 30–$45^{\circ}\mathrm{C} = 2408$ kJ/kg.
Water to be vaporized for removal of 63 kJ of energy removal $= \dfrac{63}{2408} = 0.026$ kg.

0.042 kg of water vapor is picked-up by 1 kg of dry air (for the entry condition of $30^{\circ}\mathrm{C}$ air with 60% RH, and exit condition of $45^{\circ}\mathrm{C}$ air with 90% RH). Hence for 0.026 kg of water, we need:

$$\frac{0.026}{0.042} = 0.62 \text{ kg of air}$$

Cooling of Cooling Water

Direct Contact — Cooling Tower (contd..)

For 1 kg of water, we need to contact it with 0.62 kg of air. So as to humidify the air, water is vaporizing to air. This leads to cooling of water.

Note: there is a loss of water to the air by the amount 0.026 kg per kg of water entering i.e., 2.6%.

Cooling of Cooling Water

Comparison of Indirect Contact and Direct Contact

Summary: For the following conditions of water, and air:
Water: in $= 50^\circ\mathrm{C}$, out $= 35^\circ\mathrm{C}$
Air: in $= 30^\circ\mathrm{C}$; 60% RH, out $= 45^\circ\mathrm{C}$; 90% RH
For a reduction of $1^\circ\mathrm{C}$ of water, and increase of air temperature by $1^\circ\mathrm{C}$:
In indirect contact arrangement with heat exchanger, we need 4.2 kg of air / kg of water.
In direct contact arrangement with cooling tower, we need 0.62 kg of air / kg of water. (which is only 15% of 4.2 kg).

Hence there is a **huge** reduction in air requirement, which is simply the reduction in size of the equipment.

Quiz

1. “For cooling of cooling-waters, cooling-towers are much better than heat exchangers using ambient-air as the heat carrier”—Prove this statement, with simple calculation.