Unit Operations I (MU0124101)

PART 1

Humidification Dehumidification and Cooling Towers

Water-Cooling Tower 1/3





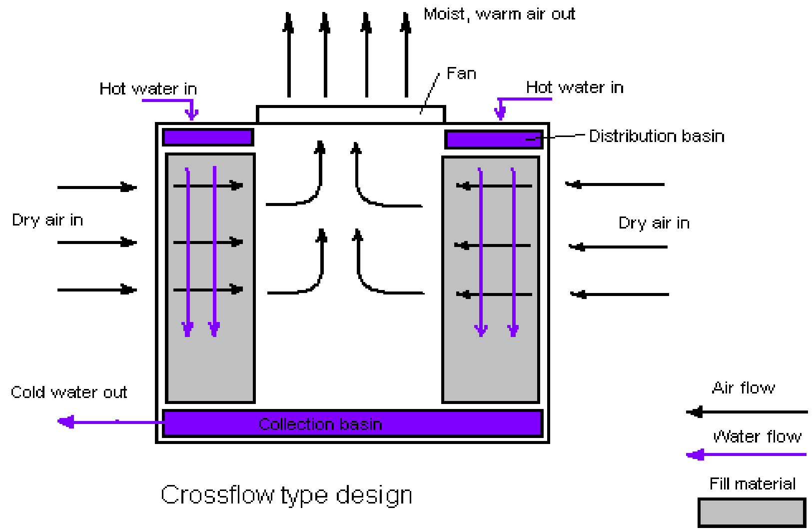

Water-Cooling Tower 2/3

Warm water flows counter-currently to an air stream. The warm water enters the top of a packed tower and cascades down through the packing, leaving at the bottom.

Air enters at the bottom of the tower and flows upward through the descending water by the natural draft or by the action of a fan.

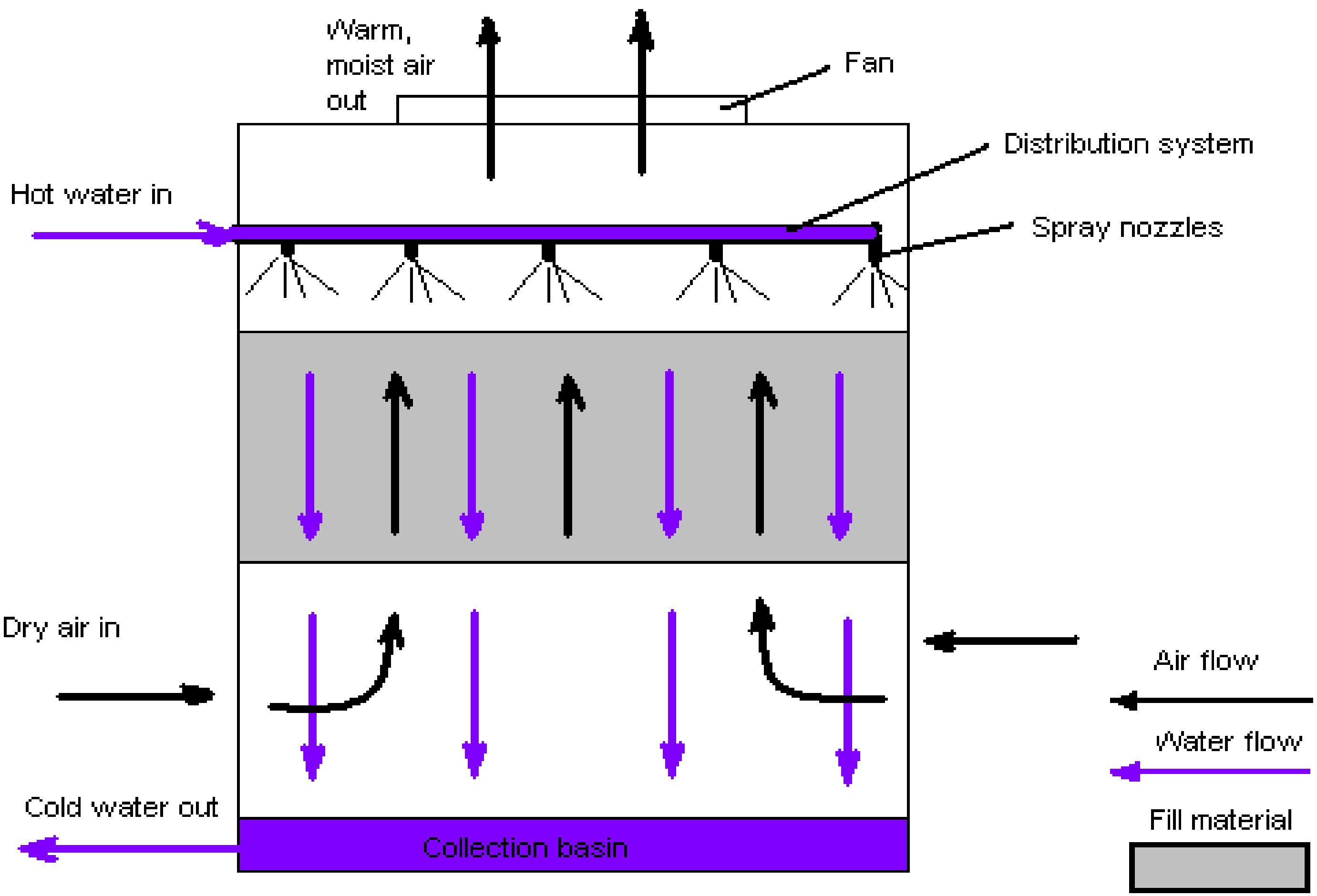
❖The water is distributed by troughs and overflows to cascade over slat gratings or packing that provide large interfacial areas of contact between the water and air in the form of droplets and film of water.

❖The tower packing often consists of slats of wood or plastic or of a packed bed.



Crossflow type design

Water-Cooling Tower 3/3



Counterflow type design

Theory and Calculation of Water-Cooling Towers

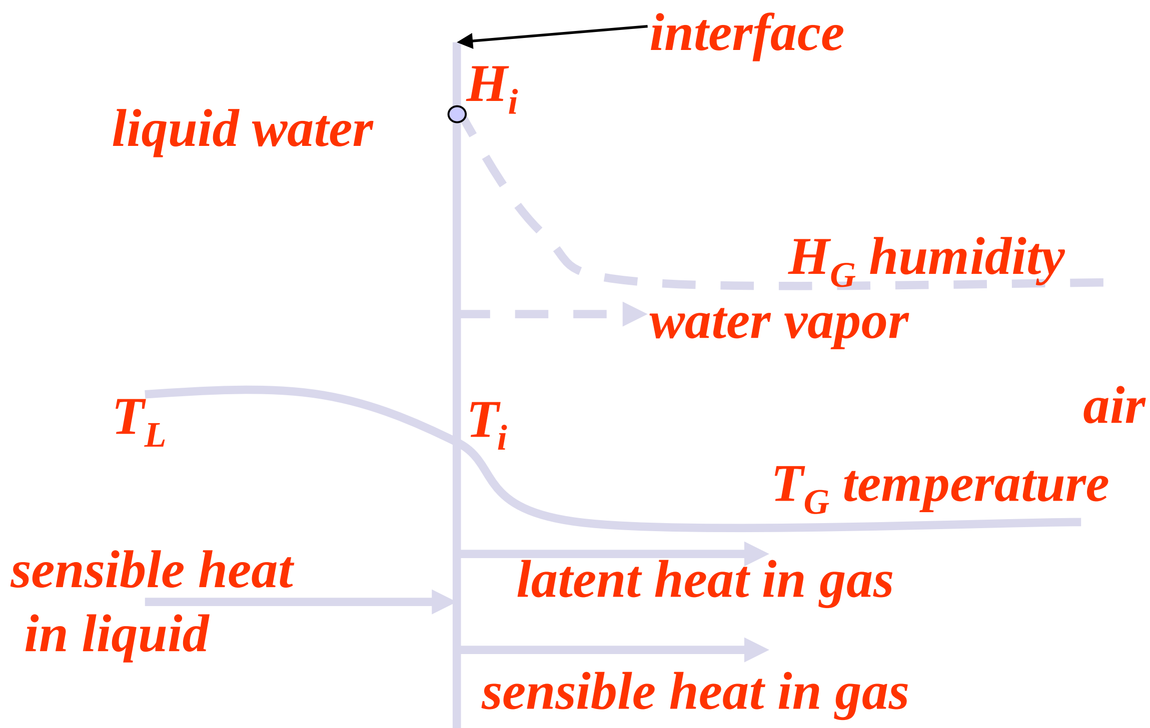


Figure10.5-1: Temperature and concentration profile in upper part of cooling tower.

Vapor Pressure of Water & Humidity

- Introduction
  - calculation involve properties and concentration of mixtures of water vapor and air.

- *Humidification*
  - transfer of water from the liquid phase into a gaseous mixture of air and water vapor.

- *Dehumidification*
  - reverse transfer where the water vapor is transferred from the vapor state to the liquid state.

Humidity & Humidity Chart 1/5

(1) <u>Humidity, *H*</u> : the kg of water vapor contained in 1 kg of dry air.

$$H = \frac{18.02}{28.97}\frac{p_A}{P - p_A}$$

where,

p_A = partial pressure of water vapor in the air.

Saturated air – water vapor in equilibrium with liquid water.

$$p_A = p_{AS} \qquad H_S = \frac{18.02}{28.97}\frac{p_{AS}}{P - p_{AS}}$$

where,

p_{AS} = **saturated vapor pressure**.

Humidity & Humidity Chart 2/5

2. Percentage humidity H_p

The percentage humidity H_P is defined as 100 times the actual humidity H of the air divided by the humidity H_S if the air were saturated at the same temperature and pressure:

Equation 9.3-3

$$H_P = 100 \frac{H}{H_S}$$

3. Percentage relative humidity H_R

The amount of saturation of an air–water vapor mixture is also given as percentage relative humidity H_R using partial pressures:

Equation 9.3-4

$$H_R = 100 \frac{p_A}{p_{AS}}$$

Humidity & Humidity Chart 3/5

(4) Humid volume, v_H

It can be defined as total volume (m^3) of 1 kg of dry air plus the vapor it contains at 1 atm abs pressure and the given gas temp.

$$v_H \ (m^3/\text{kg dry air}) = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} H)\ T\ (K).$$

(5) Total enthalpy of an air-water mixture, H_Y

- the total enthalpy of 1 kg of air plus its water vapor.
- sensible heat of the air-water vapor mixture plus the latent heat.

$$H_Y \ (\text{kJ/kg dry air}) = (1.005 + 1.88\ H)\ (T\ ^{o}C - 0) + 2501.4H$$

where,

T_{ref} for both components = 0 ºC

Humidity & Humidity Chart $^{4/5}$

6. Humid heat

The humid heat c_s is the amount of heat in J (or kJ) required to raise the temperature of 1 kg of dry air plus the water vapor present by 1 K or 1°C. The heat capacity of air and water vapor can be assumed constant over the temperature ranges usually encountered at 1.005 kJ/kg dry air • K and 1.88 kJ/kg water vapor • K, respectively. Hence, for SI and English units,

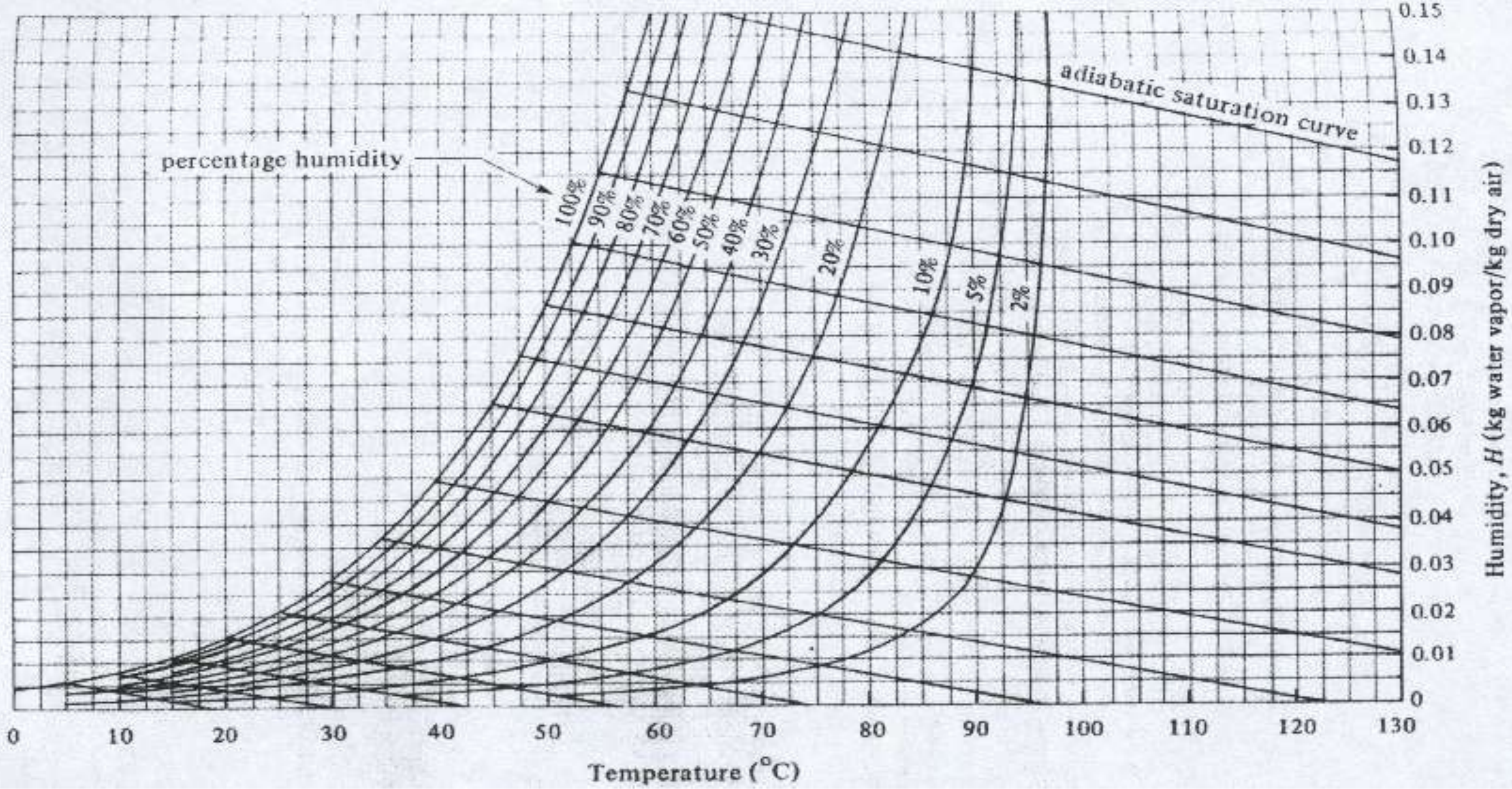
Equation 9.3-6

$$c_S \text{ kJ/kg dry air} \cdot \text{K} = 1.005 + 1.88H \qquad \text{(SI)}$$

$$c_S \text{ btu/lb}_m \text{ dry air} \cdot {}^\circ\text{F} = 0.24 + 0.45H \qquad \text{(English)}$$

Humidity & Humidity Chart 5/5

Humidity Chart



Example 9.3-1 1/2

Use of Humidity Chart

Air entering a dryer has a temperature (dry bulb temperature) of 60°C and a dew point of 26.7°C. Using the humidity chart, determine the actual humidity H, percentage humidity H_P, humid heat c_S, and humid volume ν_H in SI units.

The difference between dewpoint and wet bulb temperature is that dewpoint temperature is the temperature to which we should cool the air to saturate the air with water vapor whereas wet bulb temperature is the temperature that we get from a moistened thermometer bulb that is exposed to air flow

Solution: The dew point of 26.7°C is the temperature when the given mixture is at 100% saturation. Starting at 26.7°C (Fig. 9.3-2), and drawing a vertical line until it intersects the line for 100% humidity, a humidity of H = 0.0225 kg H_2O/kg dry air is read off the plot. This is the actual humidity of the air at 60°C. Stated in another way, if air at 60°C and having a humidity H = 0.0225 is cooled, its dew point will be 26.7°C.

Example 9.3-1 2/2

Locating this point where H = 0.0225 and t = 60°C on the chart, the percentage humidity H_P is found to be 14%, by linear interpolation vertically between the 10 and 20% lines. The humid heat for H = 0.0225 is, from Eq. (9.3-6),

$$c_S \text{ kJ/kg dry air} \cdot \text{K} = 1.005 + 1.88H \qquad \text{(SI)}$$

$$c_S = 1.005 + 1.88(0.0225)$$
$$= 1.047 \text{ kJ/kg dry air} \cdot \text{K} \qquad \text{or} \qquad 1.047 \times 10^3 \text{ J/kg} \cdot \text{K}$$

The humid volume at 60°C (140°F), from Eq. (9.3-7), is

$$v_H \text{ m}^3\text{/kg dry air} = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} H)T \text{ K}$$

$$v_H = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} \times 0.0225)(60 + 273)$$
$$= 0.977 \text{ m}^3\text{/kg dry air}$$