جلسه چهارم کلاس حل تمرین درس ترمودینامیک

منبع : کتاب ون وایلن ، کتاب سنجل، کتاب موران شپیرو و سایت اینترنتی www.sfsb.hr

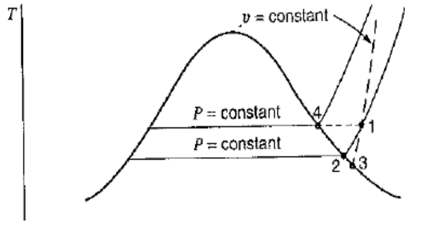
رطوبت نسبی (ϕ) : نسبت مولی بخار در مخلوط به نسبت مولی بخار در مخلوطی که در همان دما و فشار در حالت اشباع است.

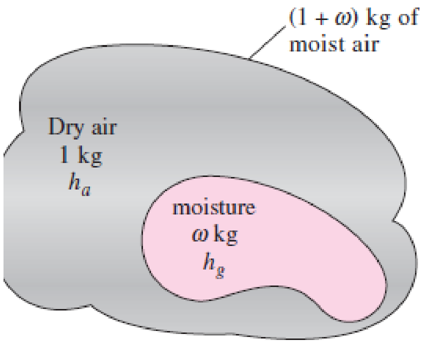
= نسبت فشار بخار به فشار بخار اشباع درهمان دما.

$$\phi = \frac{P_1}{P_4}$$

رطوبت نسبی (ω): نسبت جرم بخار به جرم هوای خشک

$$\omega = \frac{m_v}{m_a} = \frac{P_v V/R_v T}{P_a V/R_a T} = \frac{P_v/R_v}{P_a/R_a} = 0.622\ \frac{P_v}{P_a}$$



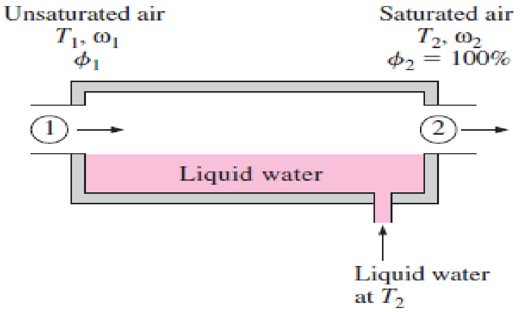


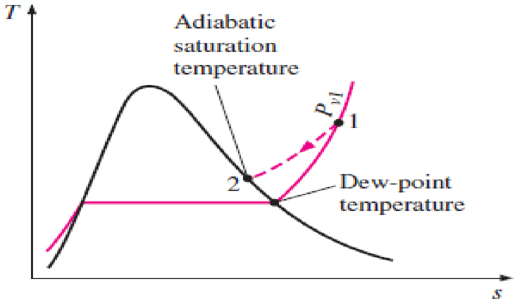
$h = h_a + \omega h_g$, kJ/kg dry air

$$H = H_a + H_v = m_a h_a + m_v h_v$$

$$h = \frac{H}{m_a} = h_a + \frac{m_v}{m_a} h_v = h_a + \omega h_v$$

$$h = h_a + \omega h_g \qquad \text{(kJ/kg dry air)}$$





$$\dot m_{w_1} + \dot m_f = \dot m_{w_2}$$

$$\dot m_a \omega_1 + \dot m_f = \dot m_a \omega_2$$

Thus,

$$\dot m_f = \dot m_a(\omega_2 - \omega_1)$$

Energy balance:

$$\dot E_{\text{in}} = \dot E_{\text{out}} \qquad (\text{since } \dot Q = 0 \text{ and } \dot W = 0)$$

$$\dot m_a h_1 + \dot m_f h_{f_2} = \dot m_a h_2$$

or

$$\dot m_a h_1 + \dot m_a(\omega_2 - \omega_1) h_{f_2} = \dot m_a h_2$$

Dividing by $\dot m_a$ gives

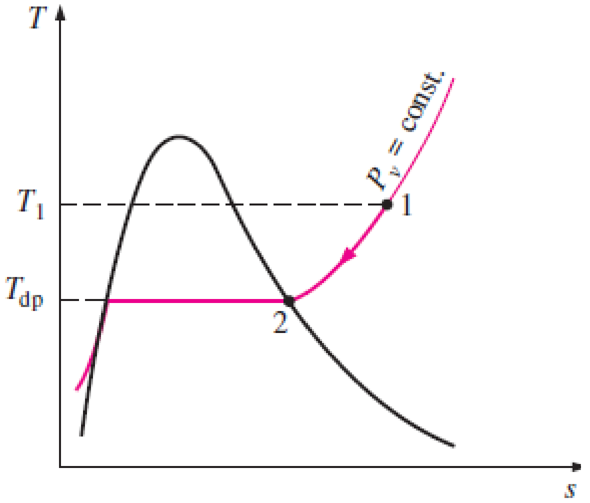
$$h_1 + (\omega_2 - \omega_1) h_{f_2} = h_2$$

or

$$(c_p T_1 + \omega_1 h_{g_1}) + (\omega_2 - \omega_1) h_{f_2} = (c_p T_2 + \omega_2 h_{g_2})$$

which yields

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}}$$



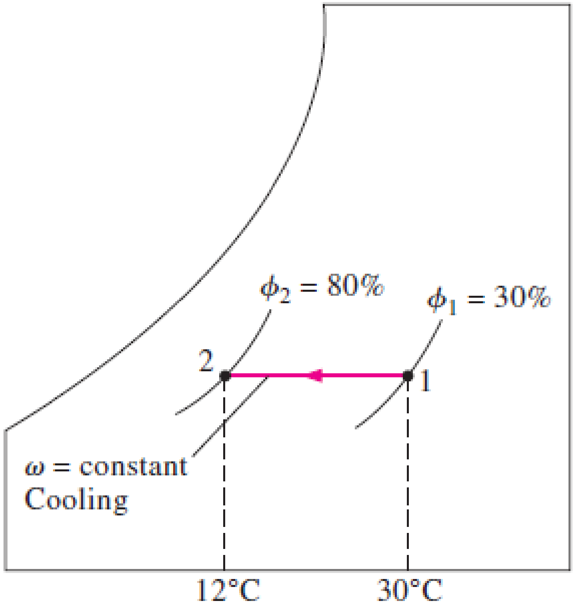
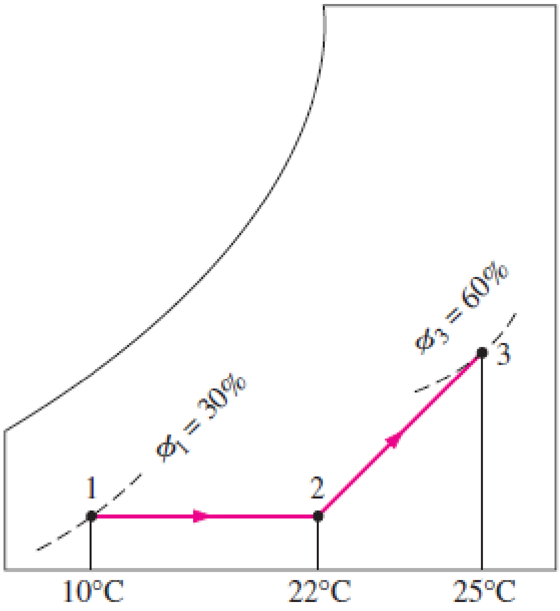


FIGURE 14–22

During simple cooling, specific humidity remains constant, but relative humidity increases.



EXAMPLE 14–5 Heating and Humidification of Air

An air-conditioning system is to take in outdoor air at 10°C and 30 percent relative humidity at a steady rate of 45 m^3/min and to condition it to 25°C and 60 percent relative humidity. The outdoor air is first heated to 22°C in the heating section and then humidified by the injection of hot steam in the humidifying section. Assuming the entire process takes place at a pressure of 100 kPa, determine (*a*) the rate of heat supply in the heating section and (*b*) the mass flow rate of the steam required in the humidifying section.

(*a*) Applying the mass and energy balances on the heating section gives

Dry air mass balance: $\dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a$

Water mass balance: $\dot{m}_{a_1}\omega_1 = \dot{m}_{a_2}\omega_2 \rightarrow \omega_1 = \omega_2$

Energy balance: $\dot{Q}_{\text{in}} + \dot{m}_a h_1 = \dot{m}_a h_2 \rightarrow \dot{Q}_{\text{in}} = \dot{m}_a(h_2 - h_1)$

The psychrometric chart offers great convenience in determining the properties of moist air. However, its use is limited to a specified pressure only, which is 1 atm (101.325 kPa) for the one given in the appendix. At pressures other than

1 atm, either other charts for that pressure or the relations developed earlier should be used. In our case, the choice is clear:

$$P_{v_1} = \phi_1 P_{g_1} = \phi P_{\text{sat @ }10^\circ\text{C}} = (0.3)(1.2281\text{ kPa}) = 0.368\text{ kPa}$$

$$P_{a_1} = P_1 - P_{v_1} = (100 - 0.368)\text{ kPa} = 99.632\text{ kPa}$$

$$v_1 = \frac{R_a T_1}{P_a} = \frac{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(283\text{ K})}{99.632\text{ kPa}} = 0.815\text{ m}^3/\text{kg dry air}$$

$$\dot{m}_a = \frac{\dot{V}_1}{v_1} = \frac{45\text{ m}^3/\text{min}}{0.815\text{ m}^3/\text{kg}} = 55.2\text{ kg/min}$$

$$\omega_1 = \frac{0.622 P_{v_1}}{P_1 - P_{v_1}} = \frac{0.622(0.368\text{ kPa})}{(100 - 0.368)\text{ kPa}} = 0.0023\text{ kg H}_2\text{O/kg dry air}$$

$$\begin{aligned} h_1 &= c_p T_1 + \omega_1 h_{g_1} = (1.005\text{ kJ/kg}\cdot{}^\circ\text{C})(10^\circ\text{C}) + (0.0023)(2519.2\text{ kJ/kg}) \\ &= 15.8\text{ kJ/kg dry air} \end{aligned}$$

$$\begin{aligned} h_2 &= c_p T_2 + \omega_2 h_{g_2} = (1.005\text{ kJ/kg}\cdot{}^\circ\text{C})(22^\circ\text{C}) + (0.0023)(2541.0\text{ kJ/kg}) \\ &= 28.0\text{ kJ/kg dry air} \end{aligned}$$

since $\omega_2 = \omega_1$. Then the rate of heat transfer to air in the heating section becomes

$$\begin{aligned} \dot{Q}_{\text{in}} &= \dot{m}_a(h_2 - h_1) = (55.2\text{ kg/min})[(28.0 - 15.8)\text{ kJ/kg}] \\ &= \mathbf{673\text{ kJ/min}} \end{aligned}$$

(*b*) The mass balance for water in the humidifying section can be expressed as

$$\dot{m}_{a_2}\omega_2 + \dot{m}_w = \dot{m}_{a_3}\omega_3$$

or

$$\dot{m}_w = \dot{m}_a(\omega_3 - \omega_2)$$

where

$$\begin{aligned} \omega_3 &= \frac{0.622\phi_3 P_{g_3}}{P_3 - \phi_3 P_{g_3}} = \frac{0.622(0.60)(3.1698\text{ kPa})}{[100 - (0.60)(3.1698)]\text{ kPa}} \\ &= 0.01206\text{ kg H}_2\text{O/kg dry air} \end{aligned}$$

Thus,

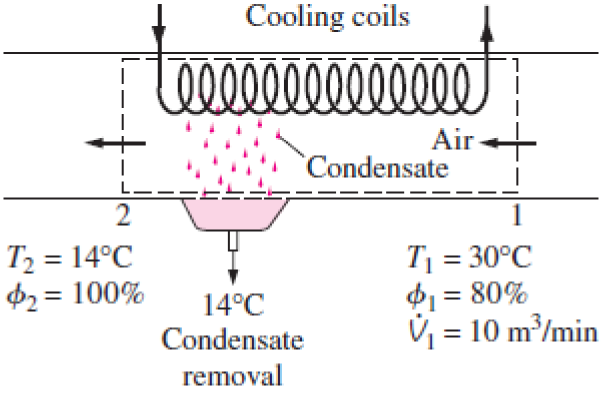
$$\begin{aligned} \dot{m}_w &= (55.2\text{ kg/min})(0.01206 - 0.0023) \\ &= \mathbf{0.539\text{ kg/min}} \end{aligned}$$

Discussion The result 0.539 kg/min corresponds to a water requirement of close to one ton a day, which is significant.

Cooling with Dehumidification

The specific humidity of air remains constant during a simple cooling process, but its relative humidity increases. If the relative humidity reaches undesirably high levels, it may be necessary to remove some moisture from the air, that is, to dehumidify it. This requires cooling the air below its dew-point temperature.

Cooling with Dehumidification



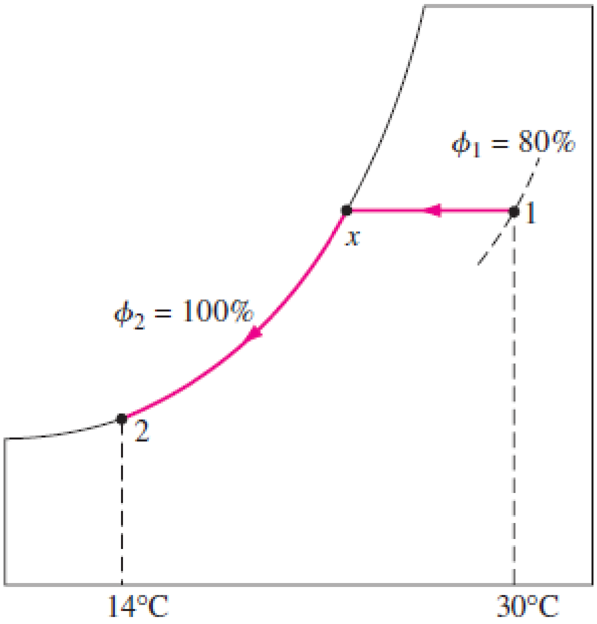


FIGURE 14–25

Schematic and psychrometric chart for Example 14–6.

Air enters a window air conditioner at 1 atm, 30°C, and 80 percent relative humidity at a rate of 10 m^3/min, and it leaves as saturated air at 14°C. Part of the moisture in the air that condenses during the process is also removed at 14°C. Determine the rates of heat and moisture removal from the air.

$$h_1 = 85.4 \text{ kJ/kg dry air} \qquad h_2 = 39.3 \text{ kJ/kg dry air}$$

$$\omega_1 = 0.0216 \text{ kg H}_2\text{O/kg dry air} \quad \text{and} \quad \omega_2 = 0.0100 \text{ kg H}_2\text{O/kg dry air}$$

$$v_1 = 0.889 \text{ m}^3\text{/kg dry air}$$

Dry air mass balance: $\dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a$

Water mass balance: $\dot{m}_{a_1}\omega_1 = \dot{m}_{a_2}\omega_2 + \dot{m}_w \quad \rightarrow \quad \dot{m}_w = \dot{m}_a(\omega_1 - \omega_2)$

Energy balance: $\sum_{\text{in}} \dot{m}h = \dot{Q}_{\text{out}} + \sum_{\text{out}} \dot{m}h \quad \rightarrow \quad \dot{Q}_{\text{out}} = \dot{m}(h_1 - h_2) - \dot{m}_w h_w$

Then,

$$\dot{m}_a = \frac{\dot{V}_1}{v_1} = \frac{10 \text{ m}^3\text{/min}}{0.889 \text{ m}^3\text{/kg dry air}} = 11.25 \text{ kg/min}$$

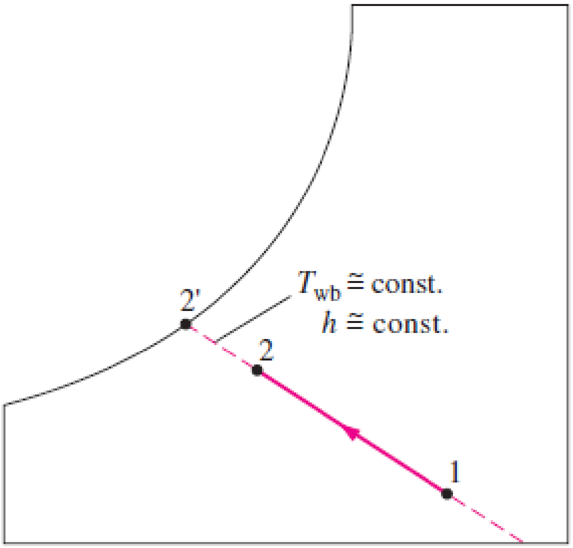
$$\dot{m}_w = (11.25 \text{ kg/min})(0.0216 - 0.0100) = \mathbf{0.131 \text{ kg/min}}$$

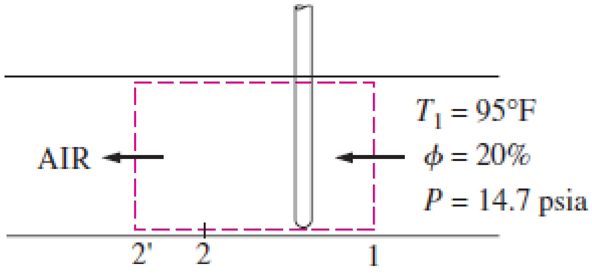
$$\dot{Q}_{\text{out}} = (11.25 \text{ kg/min})[(85.4 - 39.3) \text{ kJ/kg}] - (0.131 \text{ kg/min})(58.8 \text{ kJ/kg})$$

$$= \mathbf{511 \text{ kJ/min}}$$

Therefore, this air-conditioning unit removes moisture and heat from the air at rates of 0.131 kg/min and 511 kJ/min, respectively.

Evaporative Cooling





Air enters an evaporative (or swamp) cooler at 14.7 psi, 95°F, and 20 percent relative humidity, and it exits at 80 percent relative humidity. Determine (*a*) the exit temperature of the air and (*b*) the lowest temperature to which the air can be cooled by this evaporative cooler.

(*a*) If we assume the liquid water is supplied at a temperature not much different from the exit temperature of the airstream, the evaporative cooling process follows a line of constant wet-bulb temperature on the psychrometric chart. That is,

$$T_{wb} \cong \text{constant}$$

The wet-bulb temperature at 95°F and 20 percent relative humidity is determined from the psychrometric chart to be 66.0°F. The intersection point of the T_{wb} = 66.0°F and the ϕ = 80 percent lines is the exit state of the air. The temperature at this point is the exit temperature of the air, and it is determined from the psychrometric chart to be

$$T_2 = \mathbf{70.4°F}$$

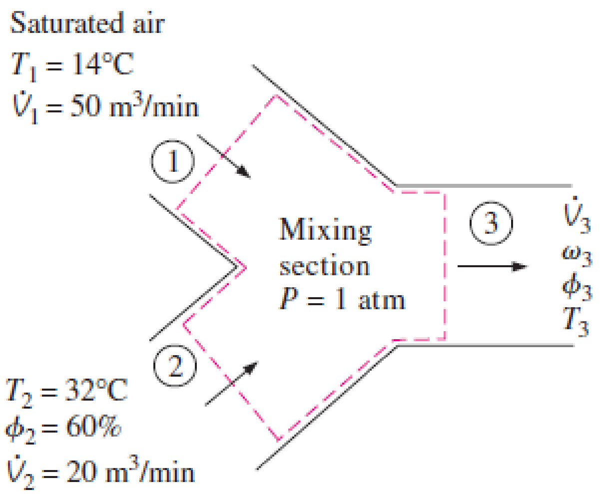
(*b*) In the limiting case, air leaves the evaporative cooler saturated (ϕ = 100 percent), and the exit state of the air in this case is the state where the T_{wb} = 66.0°F line intersects the saturation line. For saturated air, the dry- and the wet-bulb temperatures are identical. Therefore, the lowest temperature to which air can be cooled is the wet-bulb temperature, which is

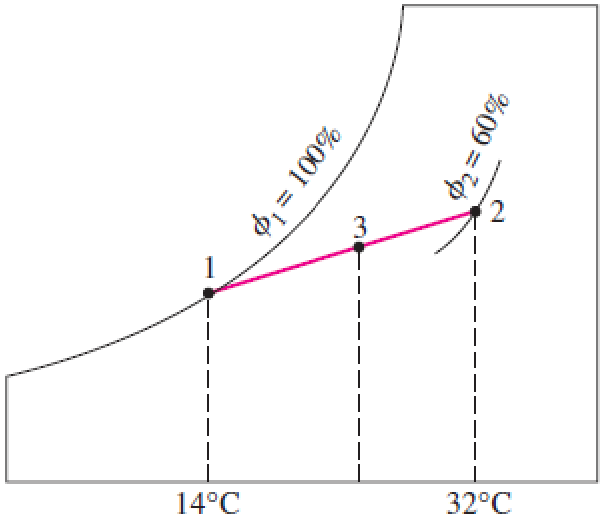
$$T_{\min} = T_{2'} = \mathbf{66.0°F}$$

Discussion Note that the temperature of air drops by as much as 30°F in this case by evaporative cooling.

EXAMPLE 14–8 Mixing of Conditioned Air with Outdoor Air

Saturated air leaving the cooling section of an air-conditioning system at 14°C at a rate of 50 m³/min is mixed adiabatically with the outside air at 32°C and 60 percent relative humidity at a rate of 20 m³/min. Assuming that the mixing process occurs at a pressure of 1 atm, determine the specific humidity, the relative humidity, the dry-bulb temperature, and the volume flow rate of the mixture.





$$\dot{m}_{a_1} + \dot{m}_{a_2} = \dot{m}_{a_3}$$
$$\omega_1\dot{m}_{a_1} + \omega_2\dot{m}_{a_2} = \omega_3\dot{m}_{a_3}$$
$$\dot{m}_{a_1}h_1 + \dot{m}_{a_2}h_2 = \dot{m}_{a_3}h_3$$

$$\Longrightarrow$$

$$\frac{\dot{m}_{a_1}}{\dot{m}_{a_2}} = \frac{\omega_2 - \omega_3}{\omega_3 - \omega_1} = \frac{h_2 - h_3}{h_3 - h_1}$$

$$h_1 = 39.4\ \text{kJ/kg dry air}$$
$$\omega_1 = 0.010\ \text{kg H}_2\text{O/kg dry air}$$
$$v_1 = 0.826\ \text{m}^3\text{/kg dry air}$$

$$h_2 = 79.0\ \text{kJ/kg dry air}$$
$$\omega_2 = 0.0182\ \text{kg H}_2\text{O/kg dry air}$$
$$v_2 = 0.889\ \text{m}^3\text{/kg dry air}$$

$$\dot{m}_{a_1} = \frac{\dot{V}_1}{v_1} = \frac{50\ \text{m}^3/\text{min}}{0.826\ \text{m}^3/\text{kg dry air}} = 60.5\ \text{kg/min}$$

$$\dot{m}_{a_2} = \frac{\dot{V}_2}{v_2} = \frac{20\ \text{m}^3/\text{min}}{0.889\ \text{m}^3/\text{kg dry air}} = 22.5\ \text{kg/min}$$

From the mass balance of dry air,

$$\dot{m}_{a_3} = \dot{m}_{a_1} + \dot{m}_{a_2} = (60.5 + 22.5)\ \text{kg/min} = 83\ \text{kg/min}$$

The specific humidity and the enthalpy of the mixture can be determined from Eq. 14–24,

$$\frac{\dot{m}_{a_1}}{\dot{m}_{a_2}} = \frac{\omega_2 - \omega_3}{\omega_3 - \omega_1} = \frac{h_2 - h_3}{h_3 - h_1}$$

$$\frac{60.5}{22.5} = \frac{0.0182 - \omega_3}{\omega_3 - 0.010} = \frac{79.0 - h_3}{h_3 - 39.4}$$

which yield

$$\omega_3 = \mathbf{0.0122\ kg\ H_2O/kg\ dry\ air}$$

$$h_3 = 50.1\ \text{kJ/kg dry air}$$

These two properties fix the state of the mixture. Other properties of the mixture are determined from the psychrometric chart:

$$T_3 = \mathbf{19.0^\circ C}$$

$$\phi_3 = \mathbf{89\%}$$

$$v_3 = 0.844\ \text{m}^3/\text{kg dry air}$$

Finally, the volume flow rate of the mixture is determined from

$$\dot{V}_3 = \dot{m}_{a_3} v_3 = (83\ \text{kg/min})(0.844\ \text{m}^3/\text{kg}) = \mathbf{70.1\ m^3/min}$$

Wet Cooling Towers

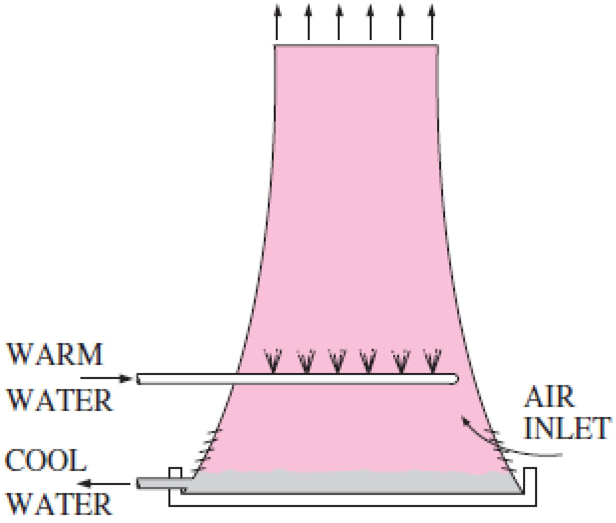


FIGURE 14–32

A natural-draft cooling tower.

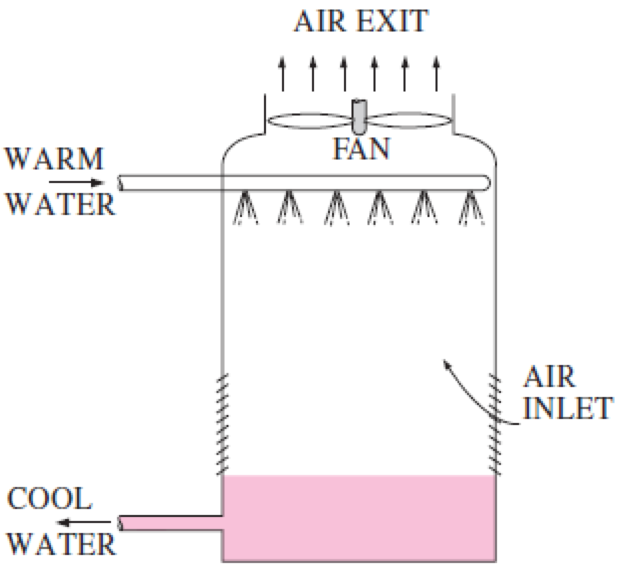


FIGURE 14–31

An induced-draft counterflow cooling tower.

EXAMPLE 14–9 Cooling of a Power Plant by a Cooling Tower

Cooling water leaves the condenser of a power plant and enters a wet cooling tower at 35°C at a rate of 100 kg/s. Water is cooled to 22°C in the cooling tower by air that enters the tower at 1 atm, 20°C, and 60 percent relative humidity and leaves saturated at 30°C. Neglecting the power input to the fan, determine (*a*) the volume flow rate of air into the cooling tower and (*b*) the mass flow rate of the required makeup water.

Properties The enthalpy of saturated liquid water is 92.28 kJ/kg at 22°C and 146.64 kJ/kg at 35°C (Table A–4). From the psychrometric chart,

$h_1 = 42.2$ kJ/kg dry air $\qquad h_2 = 100.0$ kJ/kg dry air

$\omega_1 = 0.0087$ kg H_2O/kg dry air $\qquad \omega_2 = 0.0273$ kg H_2O/kg dry air

$v_1 = 0.842$ m^3/kg dry air

Analysis We take the entire *cooling tower* to be the system, which is shown schematically in Fig. 14–34. We note that the mass flow rate of liquid water decreases by an amount equal to the amount of water that vaporizes in the tower during the cooling process. The water lost through evaporation must be made up later in the cycle to maintain steady operation.

(*a*) Applying the mass and energy balances on the cooling tower gives

Dry air mass balance: $$\dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a$$

Water mass balance: $$\dot{m}_3 + \dot{m}_{a_1}\omega_1 = \dot{m}_4 + \dot{m}_{a_2}\omega_2$$

or $$\dot{m}_3 - \dot{m}_4 = \dot{m}_a(\omega_2 - \omega_1) = \dot{m}_{\text{makeup}}$$

Energy balance: $$\sum_{\text{in}} \dot{m}h = \sum_{\text{out}} \dot{m}h \rightarrow \dot{m}_{a_1}h_1 + \dot{m}_3 h_3 = \dot{m}_{a_2}h_2 + \dot{m}_4 h_4$$

or

$$\dot{m}_3 h_3 = \dot{m}_a(h_2 - h_1) + (\dot{m}_3 - \dot{m}_{\text{makeup}})h_4$$

Solving for $\dot{m}_a$ gives

$$\dot{m}_a = \frac{\dot{m}_3(h_3 - h_4)}{(h_2 - h_1) - (\omega_2 - \omega_1)h_4}$$

Substituting,

$$\dot{m}_a = \frac{(100 \text{ kg/s})[(146.64 - 92.28) \text{ kJ/kg}]}{[(100.0 - 42.2) \text{ kJ/kg}] - [(0.0273 - 0.0087)(92.28) \text{ kJ/kg}]} = 96.9 \text{ kg/s}$$

Then the volume flow rate of air into the cooling tower becomes

$$\dot{V}_1 = \dot{m}_a v_1 = (96.9 \text{ kg/s})(0.842 \text{ m}^3/\text{kg}) = \mathbf{81.6 \text{ m}^3/\text{s}}$$

(*b*) The mass flow rate of the required makeup water is determined from

$$\dot{m}_{\text{makeup}} = \dot{m}_a(\omega_2 - \omega_1) = (96.9 \text{ kg/s})(0.0273 - 0.0087) = \mathbf{1.80 \text{ kg/s}}$$

Discussion Note that over 98 percent of the cooling water is saved and recirculated in this case.

EXAMPLE *E12-9* A swamp cooler takes outdoor air at 100 kPa, 30°C, 10% R. H. at a steady rate of 20 m^3/min. At the exit the relative humidity is 90%. Determine (a) the exit temperature, and (b) the rate of water consumption. (c) What-if-Scenario: What would the exit temperature and rate of water consumption be if the outdoor air had a R.H. of 50%? [Manual Solution] [TEST Solution]

SOLUTION Use the energy equation to determine the exit state. Perform a mass balance to obtain the flow rate of makeup water.

Assumptions Moist air model is applicable. Equilibrium at the inlet and exit states, state-1 and state-2. Negligible changes in ke and pe. The pressure remains constant.

Analysis Use the psychrometric chart to evaluate state-1. To find the wet-bulb temperature, follow the constant T_{wb} line to the saturation curve, where the dry-bulb and wet-bulb temperatures are the same. At state-2 (see Fig. 12.23), the wet-bulb temperature and the relative humidity are known.

State-1 (given $T_1 = 30^\circ\text{C}$, $\phi_1 = 10\%$ and $\dot{V}_1$)

$$\omega_1 = 2.6\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}};\ T_{wb,1} = 13^\circ\text{C};\ v_1 = 0.862\ \frac{\text{m}^3}{\text{kg d.a.}};$$

$$\dot{m}_{a1} = \frac{\dot{V}_1}{v_1} = \frac{(20/60)}{0.862} = 0.387\ \frac{\text{kg d.a.}}{\text{s}};$$

State-2 (given $T_{wb,2} = T_{wb,1}$ and $\phi_2 = 90\%$)

$$T_2 = 14^\circ\text{C};\ \omega_2 = 9\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}}$$

The flow rate of makeup water, therefore, is

$$\dot{m}_{w3} = \dot{m}_a(\omega_2 - \omega_1) = (0.387)(0.009 - 0.0026)(60) = 0.148\ \text{kg/min};$$

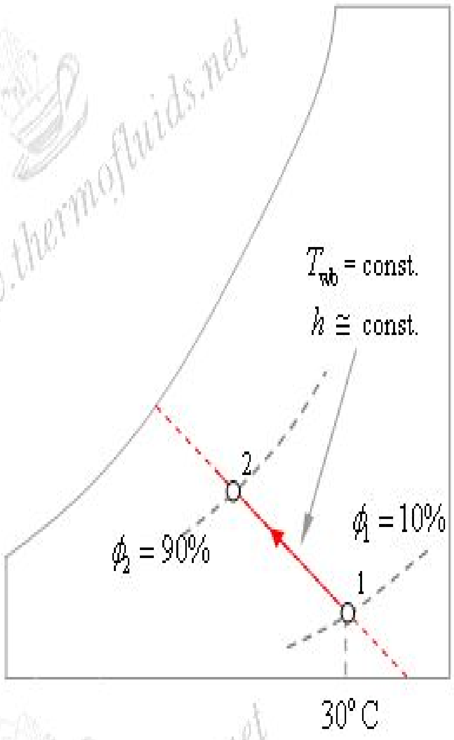
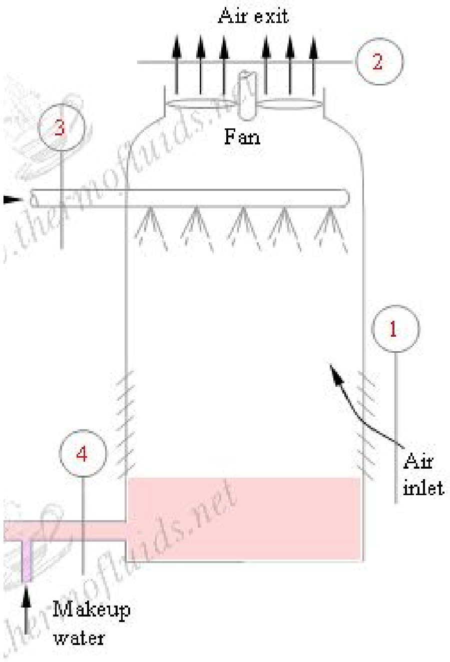


Fig. 12.23 Psychrometric plot for Ex. 12-9.

EXAMPLE *E12-11* Warm water leaving the condenser of a power plant enters a wet cooling tower at 35°C with a mass flow rate of 120 kg/s. The water is cooled to 20°C by the counter-flow air which enters at 15°C, 50% R.H, and leaves at 30°C, 90% R.H. Neglecting the power input to the fan, determine the volume flow rate of air at the (a) inlet and (b) exit, and (c) mass flow rate of the makeup water. (d) What-if-Scenario: What would the mass flow rate be if the air left the cooling tower at saturated condition?



ig.12.28 Schematic for Ex. 12-11 (see Anim. 2.B.coolingTower).

State-1 (Moist air. Given $T_1 = 15^\circ\text{C}$, $\phi_1 = 50\%$):

$$\omega_1 = 5.3\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}};\quad h_1 = 28.5\ \frac{\text{kJ}}{\text{kg d.a}};\quad v_1 = 0.82\ \frac{\text{m}^3}{\text{kg d.a.}};$$

State-2 (Moist air. Given $T_2 = 30^\circ\text{C}$, $\phi_2 = 90\%$):

$$\omega_2 = 24.4\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}};\quad h_2 = 92.5\ \frac{\text{kJ}}{\text{kg d.a}};\quad v_2 = 0.89\ \frac{\text{m}^3}{\text{kg d.a.}};$$

State-3 (Liquid water. Given $T_3 = 35^\circ\text{C}$, $\dot{m}_3 = 120\ \text{kg/s}$):

$$h_3 = h_{f@T_3} = 147\ \frac{\text{kJ}}{\text{kg d.a.}};$$

State-4 (Liquid Water. Given $T_4 = 20^\circ\text{C}$, saturated liquid):

$$h_4 = h_{f@T_4} = 84\ \frac{\text{kJ}}{\text{kg}};$$

Manipulation of Eqs. (12.30) and (12.31) leads to

$$\dot{m}_{a1} = \dot{m}_{a1} = \dot{m}_a = \frac{\dot{m}_3\left(h_3 - h_4\right)}{\left(h_2 - h_1\right) - h_4\left(\omega_2 - \omega_1\right)}$$

$$= \frac{(120)(147 - 84)}{(92.5 - 28.5) - (84)(0.0244 - 0.0053)} = 121\ \frac{\text{kg}}{\text{s}};$$

$$\Rightarrow \dot{V}_1 = \dot{m}_a v_1 = (121)(0.82) = 99\ \text{m}^3/\text{s};$$

$$\dot{V}_2 = \dot{m}_a v_2 = (121)(0.89) = 108\ \text{m}^3/\text{s};$$

$$\dot{m}_{\text{makeup}} = \dot{m}_{w3} - \dot{m}_{w4} = \dot{m}_a\left(\omega_2 - \omega_1\right) = \frac{(121)(24.4 - 5.3)}{1000} = 2.3\ \frac{\text{kg}}{\text{s}};$$

EXAMPLE *E12-10* A saturated stream of air at 30°C with a volume flow rate of 50 m^3/min mixes with a stream of cooled air consisting of a flow rate of 25 m^3/min at 15°C and 30% R.H. Assuming the total pressure to remain constant at 1 atm, determine (a) the exit temperature, and (b) relative humidity. (c) How would the volume flow rate of the cooler stream change if the desired relative humidity at the exit were 65 %? [Manual Solution] [TEST Solution]

State-1 (given $T_1 = 30^\circ\text{C}$, $\phi_1 = 100\%$ and $\dot{V}_1$):

$$\omega_1 = 27\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}};\quad h_1 = 100\ \frac{\text{kJ}}{\text{kg d.a.}};\quad v_1 = 0.9\ \frac{\text{m}^3}{\text{kg d.a.}};$$

$$\dot{m}_{a1} = \frac{\dot{V}_1}{v_1} = \frac{(50/60)}{0.9} = 0.926\ \frac{\text{kg d.a.}}{\text{s}};\quad \dot{m}_{v1} = \omega_1 \dot{m}_{a1} = 25\ \frac{\text{g}}{\text{s}};$$

State-2 (given $T_2 = 15^\circ\text{C}$, $\phi_2 = 30\%$ and $\dot{V}_2$):

$$\omega_2 = 3.2\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}};\quad h_2 = 23.1\ \frac{\text{kJ}}{\text{kg d.a.}};\quad v_2 = 0.82\ \frac{\text{m}^3}{\text{kg d.a.}};$$

$$\dot{m}_{a2} = \frac{\dot{V}_2}{v_2} = \frac{(25/60)}{0.9} = 0.508\ \frac{\text{kg}}{\text{s}};\quad \dot{m}_{v2} = \omega_2 \dot{m}_{a2} = 1.63\ \frac{\text{g}}{\text{s}};$$

State-3: $\dot{m}_{a3} = \dot{m}_{a1} + \dot{m}_{a2} = 0.926 + 0.508 = 1.434\ \frac{\text{kg d.a.}}{\text{s}}$;

$$\omega_3 = \frac{\dot{m}_{v3}}{\dot{m}_{a3}} = \frac{\dot{m}_{v1} + \dot{m}_{v2}}{\dot{m}_{a3}} = \frac{25 + 1.63}{1.434} = 18.6\ \frac{\text{g H}_2\text{O}}{\text{kg d.a.}};$$

$$h_3 = \frac{\dot{m}_{a1}h_1 + \dot{m}_{a2}h_2}{\dot{m}_{a3}} = \frac{(0.926)(100) + (0.508)(23.1)}{1.434} = 72.8\ \frac{\text{k}}{\text{kg d.a.}},$$

$$\Rightarrow\quad T_3 = 25^\circ\text{C};\quad \phi_3 = 95\%;$$

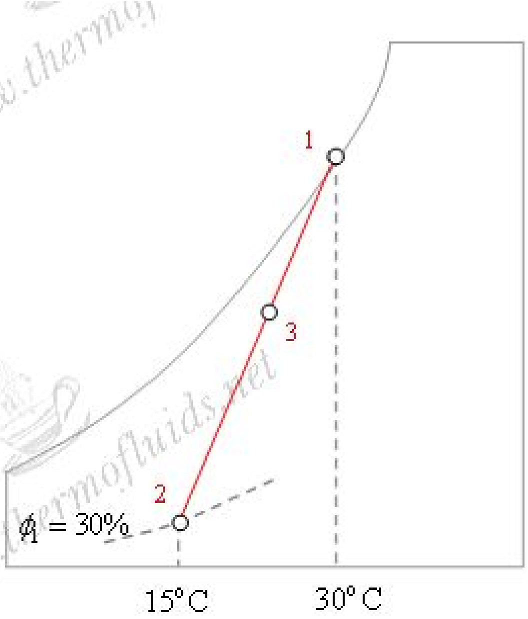


Fig. 12.25 Psychrometric plot for Ex. 12-10.