

Exercises on Psychrometry

1. Moist air exists at 40°C dry-bulb temperature, 20°C thermodynamic wet-bulb temperature, and 101.325 kPa pressure. Determine the humidity ratio, enthalpy, dew-point temperature, relative humidity, and specific volume.

Solution:

Locate state point on the psychrometric chart at the intersection of 40°C dry-bulb temperature and 20°C thermodynamic wet-bulb temperature lines. Read humidity ratio $W = 6.5$ g (water)/kg (dry air).

The enthalpy can be found by using two triangles to draw a line parallel to the nearest enthalpy line [60 kJ/kg (dry air)] through the state point to the nearest edge scale. Read $h = 56.7$ kJ/kg (dry air).

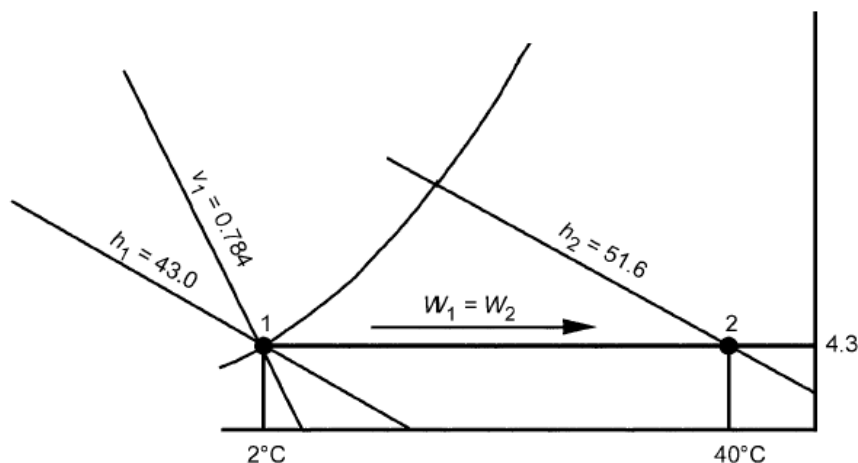
Dew-point temperature can be read at the intersection of $W = 6.5$ g (water)/kg (dry air) with the saturation curve. Thus, $t_d = 7^\circ\text{C}$.

Relative humidity ϕ can be estimated directly. Thus, $\phi = 14\%$.

Specific volume can be found by linear interpolation between the volume lines for 0.88 and 0.90 m³/kg (dry air). Thus, $v = 0.896$ m³/kg (dry air).

2. Moist air, saturated at 2°C, enters a heating coil at a rate of 10 m³/s. Air leaves the coil at 40°C. Find the required rate of heat addition.

Solution:



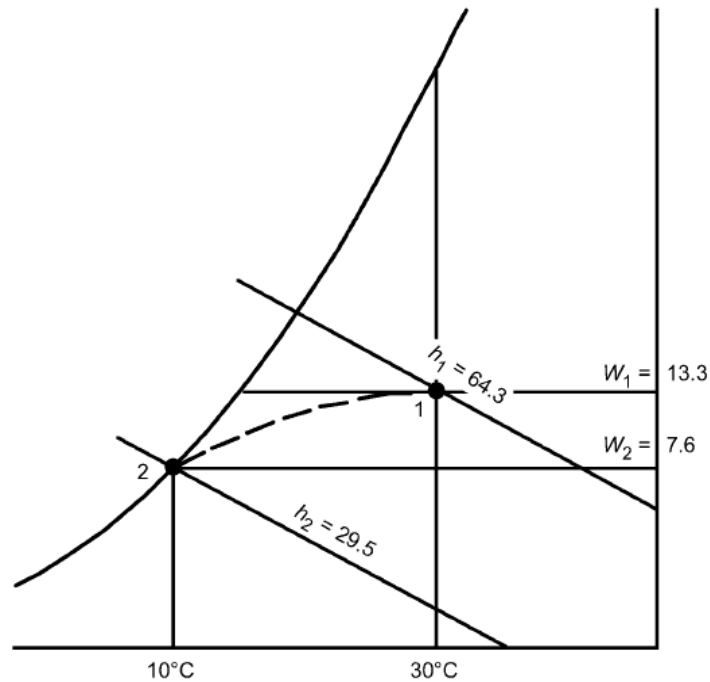
The above figure schematically shows the solution. State 1 is located on the saturation curve at 2°C. Thus, $h_1 = 13.0$ kJ/kg (dry air), $W_1 = 4.3$ g (water)/kg (dry air), and $v_1 = 0.784$ m³/kg (dry air). State 2 is located at the intersection of $t = 40^\circ\text{C}$ and $W_2 = W_1 = 4.3$ g (water)/kg (dry air). Thus, $h_2 = 51.6$ kJ/kg (dry air). The mass flow of dry air is:

$$\dot{m}_{da} = 10 / 0.784 = 12.76 \text{ kg/s (dry air)}$$

$$\text{The rate of heat addition} = \dot{m}_{da} (h_2 - h_1) = 12.76 (51.6 - 13.0) = 492 \text{ kW}$$

3. Moist air at 30°C dry-bulb temperature and 50% rh enters a cooling coil at 5 m³/s and is processed to a final saturation condition at 10°C. Find the kW of refrigeration required.

Solution:



The above figure shows the schematic solution. State 1 is located at the intersection of $t = 30^\circ\text{C}$ and $\phi = 50\%$. Thus, $h_1 = 64.3$ kJ/kg (dry air), $W_1 = 13.3$ g (water)/kg (dry air), and $v_1 = 0.877$ m³/kg (dry air). State 2 is located on the saturation curve at 10°C. Thus, $h_2 = 29.5$ kJ/kg (dry air) and $W_2 = 7.66$ g (water)/kg (dry air). Given: $h_{w2} = 42.11$ kJ/kg (water). The mass flow of dry air is:

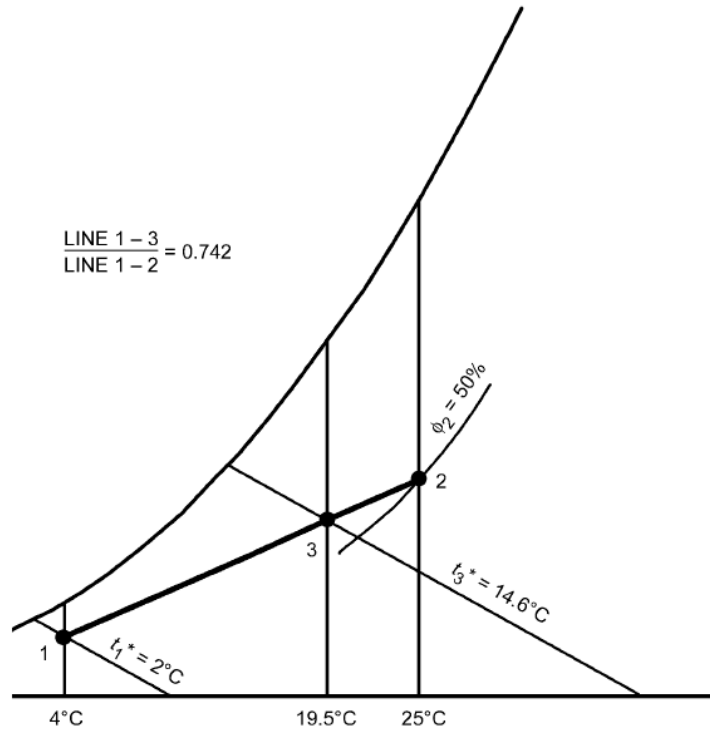
$$\dot{m}_{da} = 5 / 0.877 = 5.70 \text{ kg/s (dry air)}$$

The kW of refrigeration = ${}_1q_2$

$$\begin{aligned} &= \dot{m}_{da} [(h_1 - h_2) - (W_1 - W_2) h_{w2}] \\ &= 5.70 [(64.3 - 29.5) - (0.0133 - 0.00766) 42.11] \\ &= 197 \text{ kW} \end{aligned}$$

4. A stream of 2 m³/s of outdoor air at 4°C dry-bulb temperature and 2°C thermodynamic wet-bulb temperature is adiabatically mixed with 6.25 m³/s of recirculated air at 25°C dry-bulb temperature and 50% rh. Find the dry-bulb temperature and thermodynamic wet-bulb temperature of the resulting mixture.

Solution:



The above figure shows the schematic solution. States 1 and 2 are located on the ASHRAE chart, revealing that $v_1 = 0.789 \text{ m}^3/\text{kg}$ (dry air), and $v_2 = 0.858 \text{ m}^3/\text{kg}$ (dry air). Therefore,

$$\dot{m}_{da1} = 2 / 0.789 = 2.535 \text{ kg/s (dry air)}$$

$$\dot{m}_{da2} = 6.25 / 0.858 = 7.284 \text{ kg/s (dry air)}$$

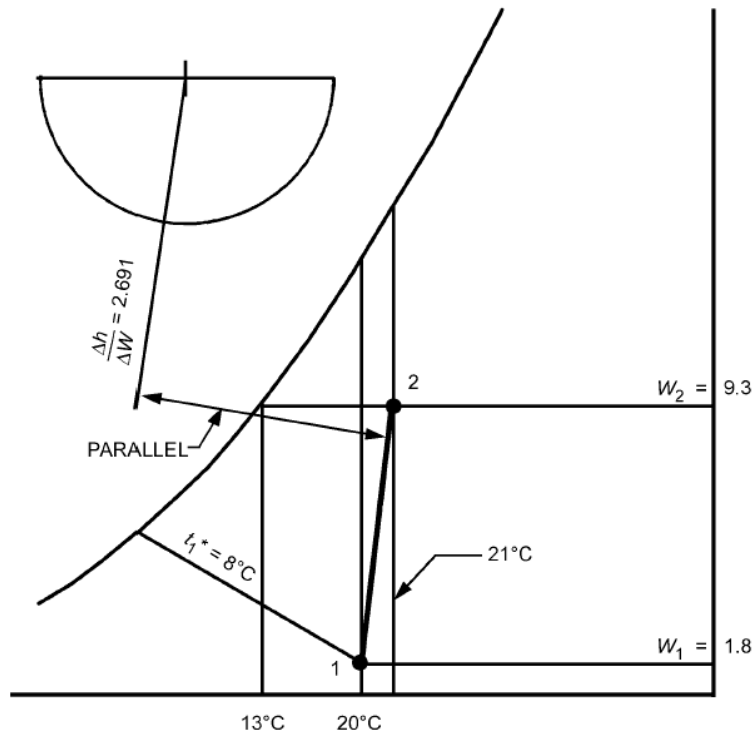
By comparing the proportion of the lines,

$$\frac{\text{Line 3-2}}{\text{Line 1-3}} = \frac{\dot{m}_{da1}}{\dot{m}_{da2}} \quad \text{or} \quad \frac{\text{Line 1-3}}{\text{Line 1-2}} = \frac{\dot{m}_{da2}}{\dot{m}_{da3}} = \frac{7.284}{9.819} = 0.742$$

Consequently, the length of line segment 1-3 is 0.742 times the length of entire line 1-2. Using a ruler, State 3 is located, and the values $t_3 = 19.5^\circ\text{C}$ and $t_3^* = 14.6^\circ\text{C}$ found.

- Moist air at 20°C dry-bulb and 8°C thermodynamic wet-bulb temperature is to be processed to a final dew-point temperature of 13°C by adiabatic injection of saturated steam at 110°C. The rate of dry airflow is 2 kg/s (dry air). Find the final dry-bulb temperature of the moist air and the rate of steam flow.

Solution:



The above figure shows the schematic solution. From a steam properties table, the enthalpy of the steam $h_g = 2691$ kJ/kg (water). Therefore, according to the psychrometric equation, the condition line on the psychrometric chart connecting States 1 and 2 must have a direction:

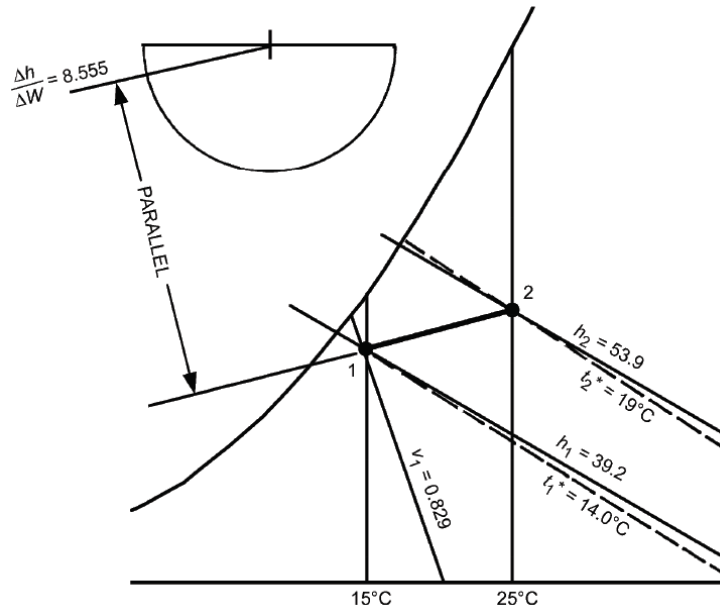
$$\Delta h/\Delta W = 2.691 \text{ kJ/g (water)}$$

The condition line can be drawn with the $\Delta h/\Delta W$ protractor. First, establish the reference line on the protractor by connecting the origin with the value $\Delta h/\Delta W = 2.691$ kJ/g (water). Draw a second line parallel to the reference line and through the initial state point of the moist air. This second line is the condition line. State 2 is established at the intersection of the condition line with the horizontal line extended from the saturation curve at 13°C ($t_{d2} = 13^\circ\text{C}$). Thus, $t_2 = 21^\circ\text{C}$. Values of W_2 and W_1 can be read from the chart. The required steam flow is,

$$\dot{m}_w = \dot{m}_{da} (W_2 - W_1) = 2 \times 1000 (0.0093 - 0.0018) = 15 \text{ g/s (steam)}$$

6. Moist air is withdrawn from a room at 25°C dry-bulb temperature and 19°C thermodynamic wet-bulb temperature. The sensible rate of heat gain for the space is 9 kW. A rate of moisture gain of $0.0015 \text{ kg}_w/\text{s}$ occurs from the space occupants. This moisture is assumed as saturated water vapor at 30°C . Moist air is introduced into the room at a dry-bulb temperature of 15°C . Find the required thermodynamic wet-bulb temperature and volume flow rate of the supply air.

Solution:



The above figure shows the schematic solution. State 2 is located on the ASHRAE chart. From thermodynamic properties table, the specific enthalpy of the added water vapor is $h_g = 2555.58$ kJ/kg. From the psychrometric equation,

$$\frac{\Delta h}{\Delta W} = \frac{9 + (0.0015 \times 2555.58)}{0.0015} = 8555 \text{ kJ/kg}_w$$

With the $\Delta h/\Delta W$ protractor, establish a reference line of direction $\Delta h/\Delta W = 8.555$ kJ/g_w. Parallel to this reference line, draw a straight line on the chart through State 2. The intersection of this line with the 15°C dry-bulb temperature line is State 1. Thus, $t_1^* = 14.0^\circ\text{C}$.

An alternative (and approximately correct) procedure in establishing the condition line is to use the protractor's sensible/total heat ratio scale instead of the $\Delta h/\Delta W$ scale. The quantity $\Delta H_s / \Delta H_t$ is the ratio of rate of sensible heat gain for the space to rate of total energy gain for the space. Therefore,

Table 4 Calculated Diffusion Coefficients for Water–Air at 101.325 kPa

Temp., °C	mm ² /s	Temp., °C	mm ² /s	Temp., °C	mm ² /s
-70	13.2	0	22.2	50	29.5
-50	15.6	5	22.9	55	30.3
-40	16.9	10	23.6	60	31.1
-35	17.5	15	24.3	70	32.7
-30	18.2	20	25.1	100	37.6
-25	18.8	25	25.8	130	42.8
-20	19.5	30	26.5	160	48.3
-15	20.2	35	27.3	190	54.0
-10	20.8	40	28.0	220	60.0
-5	21.5	45	28.8	250	66.3

$$\frac{\Delta H_s}{\Delta H_t} = \frac{q_s}{q_s + \Sigma(\dot{m}_w h_w)} = \frac{9}{9 + (0.0015 \times 2555.58)} = 0.701$$

Note that $\Delta H_s / \Delta H_t = 0.701$ on the protractor coincides closely with $\Delta h/\Delta W = 8.555$ kJ/g_w. The flow of dry air can be calculated from the psychrometric equations.

$$\dot{m}_{da} = \frac{q_s + \Sigma(\dot{m}_w h_w)}{h_2 - h_1} = \frac{9 + (0.0015 \times 2555.58)}{53.9 - 39.2} = 0.873 \text{ kg}_w/\text{s}$$

At State 1, $v_1 = 0.829$ m³/kg_w. Therefore, supply volume = $\dot{m}_{da} v_1 = 0.873 \times 0.829 = 0.724$ m³/s