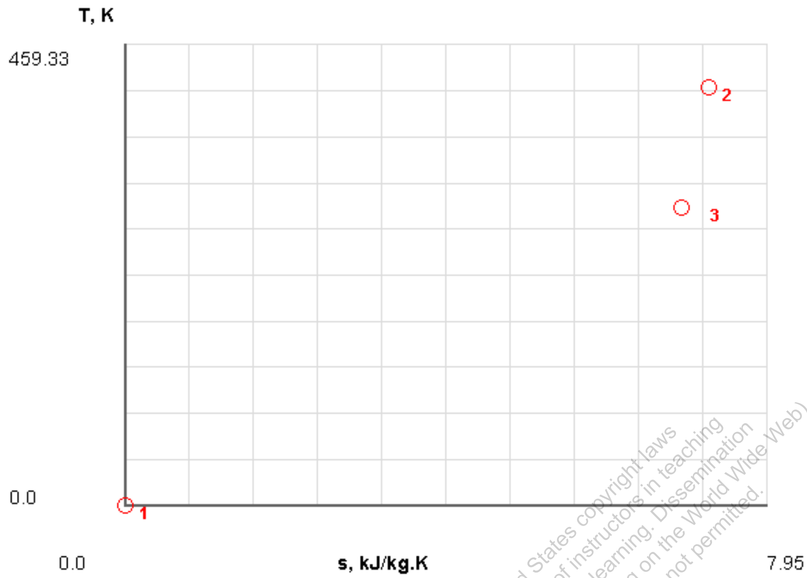
5-4-1 [OHT] An insulated rigid tank is initially evacuated. A valve is opened and air at 100 kPa and 25°C enters the tank until the pressure in the tank reaches 100 kPa when the valve is closed. (a) Determine the final temperature of the air in the tank. Use the PG model. (b) What-if scenario: What would the final temperature be if the IG model were used?

SOLUTION



State-1 (given p_1)

State-2 (given p_2)

State-3 (given p_3, T_3, inlet)

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + \cancel{\dot{Q}}^{0} - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow \Delta E = m_i j_i;$$

$$j_i = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (-85.565) + (100)(0.85565);$$

$$\Rightarrow j_3 = 0;$$

$$\Delta E = m_2 e_2 - m_1 e_1;$$

$$\Rightarrow m_2e_2 - \cancel{m_1e_1}^0 = \cancel{m_ij_i}^0;$$
$$\Rightarrow m_2e_2 = 0;$$

$$m_2 \neq 0 \;\therefore\; e_2 = 0$$
$$\Rightarrow e_2 = \cancel{ke_2}^0 + \cancel{pe_2}^0 + u_2;$$
$$\Rightarrow e_2 = u_2 = 0;$$

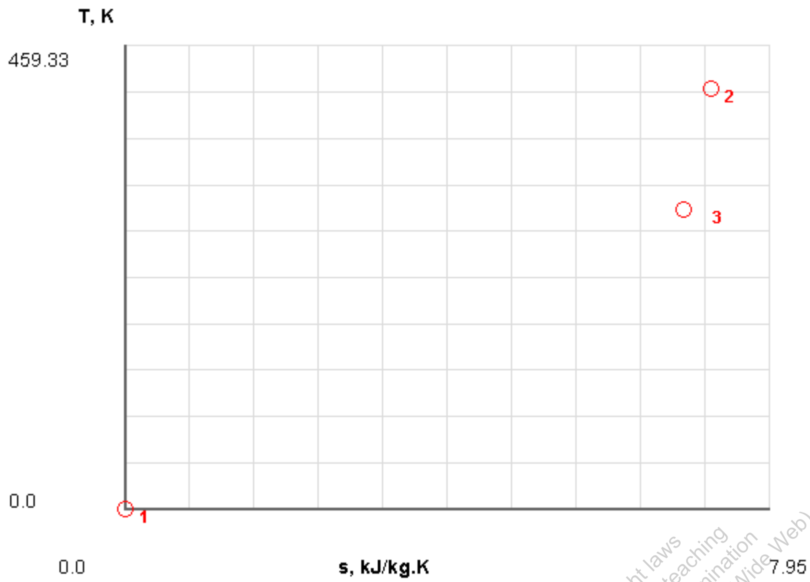
(a) $T_2\left(p_2, u_2\right) = 144.4°\text{C}$

TEST Solution and What-if Scenario:

Launch the PG open process system TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-4-2 [OHD] In the problem described above, determine the entropy generated during the process if the volume of the tank is 2 m^3.

SOLUTION



Given:

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 (given p_1, s_1)

State-2 (given $p_2, \cancel{V_2}, m_2 = m_3$)

State-3 (given p_3, T_3, inlet):

$$s_3\left(p_3, T_3\right) = 6.8867 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + \cancel{Q}^{0} - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow \Delta E = m_i j_i;$$

$$j_i = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{ke}^{0} + \cancel{pe}^{0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (-85.565) + (100)(0.85565);$$

$$\Rightarrow j_3 = 0;$$

$$\Delta E = m_2 e_2 - m_1 e_1;$$

$$\Rightarrow m_2 e_2 - \cancel{m_1 e_1}^{0} = \cancel{m_i j_i}^{0};$$

$$\Rightarrow m_2 e_2 = 0;$$

$$m_2 \neq 0 \;\therefore\; e_2 = 0$$

$$\Rightarrow e_2 = \cancel{ke_2}^{0} + \cancel{pe_2}^{0} + u_2;$$

$$\Rightarrow e_2 = u_2 = 0;$$

$$T_2 = 417.4 \text{ K}; \; s_2\left(p_2, u_2\right) = 7.2247 \; \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_2 = \frac{p_2 \cancel{V_2}}{RT_2} = \frac{(100)(2)}{(0.287)(417.4)} = 1.67 \text{ kg};$$

From the entropy balance equation

$$S_{\text{gen,univ}} = \Delta S - \left(m_i s_i - m_e s_e\right) - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = \left(m_f s_f - \cancel{m_b m_b}^{0}\right) - \left(m_i s_i - \cancel{m_e s_e}^{0}\right) - \cancel{\frac{Q}{T_B}}^{0};$$

$$\Rightarrow S_{\text{gen,univ}} = m_f s_f - m_i s_i;$$

$$\Rightarrow S_{\text{gen,univ}} = m\left(s_2 - s_3\right);$$

$$\Rightarrow S_{\text{gen,univ}} = (1.67)(7.2247 - 6.8867);$$

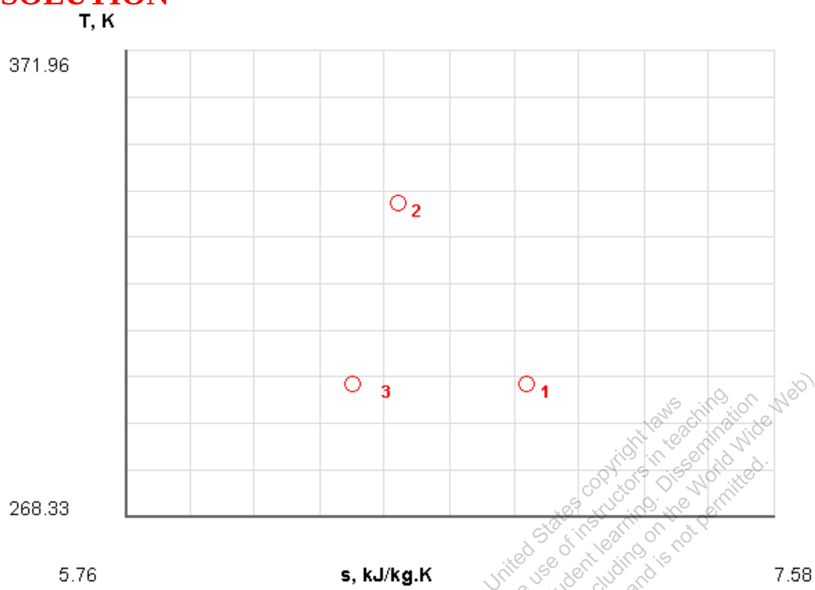
$$\Rightarrow S_{\text{gen,univ}} = 0.564 \; \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the PG open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-3 [OHW] A 3 m^3 tank initially contains air at 100 kPa and 25^{o}C. The tank is connected to a supply line at 550 kPa and 25^{o}C. The valve is opened, and air is allowed to enter the tank until the pressure in the tank reaches the line pressure, at which point the valve is closed. A thermometer placed in the tank indicates that the air temperature at the final state is 65^{o}C. Treating air as a perfect gas, determine (a) the mass of air that has entered the tank, (b) the heat transfer and (c) the entropy generated.

SOLUTION



Given:

$$c_v = 0.71651 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$R = 0.287 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

State-1 (given $p_1, T_1, \cancel{V}_1$):

$$u_1(p_1, T_1) = -85.565 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1(p_1, T_1) = 6.88669 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)(3)}{(0.287)(298)} = 3.5078 \,\text{kg};$$

State-2 (given $p_2 = p_3, T_2, \cancel{V}_2 = \cancel{V}_1$):

$$u_2(p_2, T_2) = -56.905 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2(p_2, T_2) = 6.52378 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$m_2 = \frac{p_2 \cancel{V}_2}{RT_2} = \frac{(550)(3)}{(0.287)(338)} = 17.0096 \,\text{kg};$$

State-3 (given p_3, T_3, inlet):

$$s_3\left(p_3, T_3\right) = 6.39745 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) From the conservation of mass

$$\Delta m = m_2 - m_1 = m_3;$$

$$\Rightarrow m_3 = 17.0096 - 3.5078;$$

$$\Rightarrow m_3 = 13.5 \text{ kg}$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow m_2 e_2 - m_1 e_1 = m_i j_i + Q;$$

$$j_i = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (-85.565) + (550)(0.15557);$$

$$\Rightarrow j_3 = 0;$$

$$m_2 e_2 - m_1 e_1 = \cancel{m_i j_i}^{0} + Q;$$

$$\Rightarrow Q = m_2 e_2 - m_1 e_1;$$

$$e = \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0} + u;$$

$$\Rightarrow e = u;$$

(b) $Q = m_2 u_2 - m_1 u_1;$

$$\Rightarrow Q = (17.0096)(-56.905) - (3.5078)(-85.565);$$

$$\Rightarrow Q = -667.8 \text{ kJ}$$

(c) From the entropy balance equation

$$S_{\text{gen,univ}} = \Delta S - \left(m_i s_i - m_e s_e\right) - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = \left(m_f s_f - m_b m_b\right) - \left(m_i s_i - \cancel{m_e s_e}^{0}\right) - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = (17.0096)(6.52378) - (3.5078)(6.88669) - (13.5)(6.39745) - \left(\frac{-667.8}{298}\right);$$

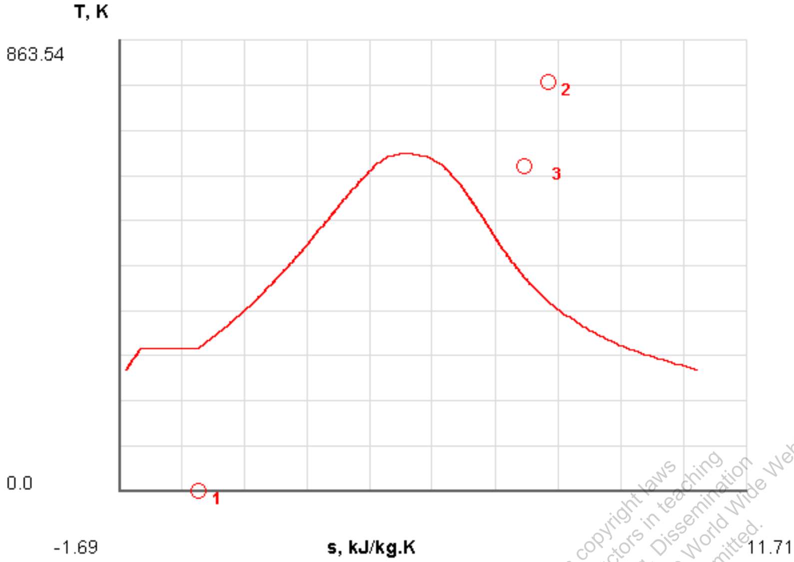
$$\Rightarrow S_{\text{gen,univ}} = 2.685\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the PG open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-4 [OHM] An insulated rigid tank is initially evacuated. It is then connected through a valve to a supply line that carries steam at 2 MPa and 350°C. The valve is then opened, and steam is allowed to flow slowly into the tank until the pressure reaches 2 MPa, at which point the valve is closed. Determine the final temperature of the steam in the tank.

SOLUTION



State-1 (given p_1)

State-2 (given $p_2, m_2 = m_3$)

State-3 (given p_3, T_3, inlet):

$$v_3 = 0.13857 \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 2859.8 \ \frac{\text{kJ}}{\text{kg}};$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{\,0} + \cancel{Q}^{\,0} - \cancel{W_{\text{ext}}}^{\,0};$$

$$\Rightarrow m_2 e_2 - m_1 e_1 = m_i j_i;$$

$$j_i = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{ke}^{\,0} + \cancel{pe}^{\,0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (2859.8) + (2000)(0.13857);$$

$$\Rightarrow j_3 = 3136.94 \ \frac{\text{kJ}}{\text{kg}};$$

$$e = \cancel{ke}^0 + \cancel{pe}^0 + u;$$
$$\Rightarrow e = u;$$

$$m_2 u_2 - \cancel{m_1 u_1}^0 = m_i j_i;$$
$$\Rightarrow u_2 = j_3 = 3136.94 \ \frac{\text{kJ}}{\text{kg}};$$

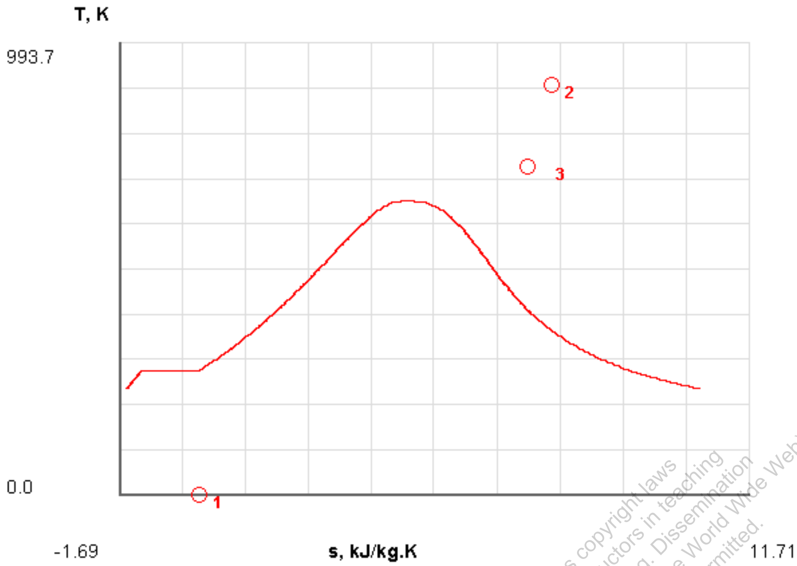
$$T_2\left(p_2, u_2\right) = 511.9°\text{C}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-5 [OHJ] A completely evacuated, insulated, rigid tank with a volume of 8 m^3 is filled from a steam line transporting steam at 450°C and 3.5 MPa. Determine (a) the temperature of steam in the tank when its pressure reaches 3.5 MPa. Also find (b) the mass of the steam that flows into the tank.

SOLUTION



State-1 (given $p_1, \cancel{V}_1$)

State-2 (given $p_2, \cancel{V}_2 = \cancel{V}_1, m_2 = m_3$)

State-3 (given p_3, T_3, inlet):

$$v_3 = 0.09196 \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 3015.27 \ \frac{\text{kJ}}{\text{kg}};$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + \cancel{Q}^{0} - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow m_2 e_2 - m_1 e_1 = m_i j_i;$$

$$j_i = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{ke}^{0} + \cancel{pe}^{0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (3015.27) + (3500)(0.09196);$$

$$\Rightarrow j_3 = 3337.13 \ \frac{\text{kJ}}{\text{kg}};$$

$$e = \cancel{ke}^{0} + \cancel{pe}^{0} + u;$$

$$\Rightarrow e = u;$$

$$m_2 u_2 - \cancel{m_1 u_1}^{0} = m_i j_i;$$

$$\Rightarrow u_2 = j_3 = 3337.13 \ \frac{\mathrm{kJ}}{\mathrm{kg}};$$

(a) $T_2\left(p_2, u_2\right) = 630.2°\mathrm{C}$

$$v_2\left(p_2, u_2\right) = 0.11739 \ \frac{\mathrm{m}^3}{\mathrm{kg}};$$

(b) $m_2 = \dfrac{\cancel{V_2}}{v_2};$

$$\Rightarrow m_2 = \frac{8}{0.11739};$$

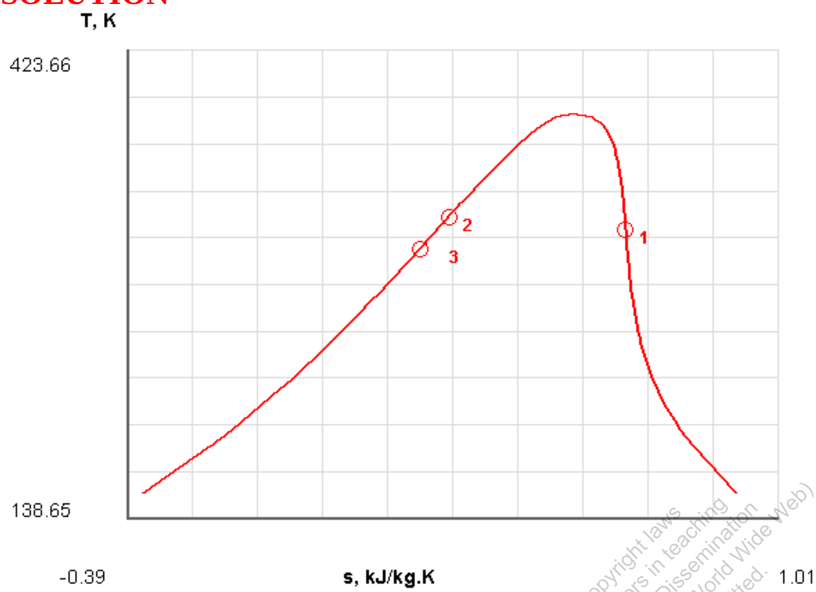
$$\Rightarrow m_2 = 68.15 \ \mathrm{kg}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-6 [ONR] A 0.2 m^3 tank initially contains R-12 at 1 MPa and x = 1. The tank is charged to 1.2 MPa, x = 0 from a supply line that carries R-12 at 1.5 MPa and 30^{o}C. Determine (a) the final temperature and (b) the heat transfer.

SOLUTION



State-1 (given $p_1, x_1, \cancel{V}_1$):

$$T_{\text{sat@1MPa}} = 41.626°\text{C};$$

$$u_1 = u_g = 186.311 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\cancel{V}_1}{v_{g@1\text{MPa}}} = \frac{0.2}{0.01745} = 11.46276 \ \text{kg};$$

State-2 (given $p_2, x_2, \cancel{V}_2 = \cancel{V}_1$):

$$u_2 = u_f = 82.445 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 = \frac{\cancel{V}_2}{v_{f@1.2\text{MPa}}} = \frac{0.2}{8.2\times10^{-4}} = 242.74767 \ \text{kg};$$

(a) $T_{\text{sat@1.2MPa}} = 49.300°\text{C}$

State-3 (given p_3, T_3, inlet):

Subcooled liquid

$$v_3 = v_{f@30°\text{C}} = 7.7\times10^{-4} \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = u_{f@30°\text{C}} = 64.02 \ \frac{\text{kJ}}{\text{kg}};$$

From the conservation of mass

$$\Delta m = m_2 - m_1 = m_3;$$
$$\Rightarrow m_3 = 242.74767 - 11.46276;$$
$$\Rightarrow m_3 = 231.28491 \text{ kg};$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + Q - \cancel{W_{\text{ext}}}^{0};$$
$$\Rightarrow m_2 e_2 - m_1 e_1 = m_i j_i + Q;$$

$$j_i = j_3;$$
$$\Rightarrow j_3 = h_3 + \cancel{ke}^{0} + \cancel{pe}^{0};$$
$$\Rightarrow j_3 = u_3 + p_3 v_3;$$
$$\Rightarrow j_3 = (64.01344) + (1500)(7.7 \times 10^{-4});$$
$$\Rightarrow j_3 = 65.17 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 e_2 - m_1 e_1 = m_3 j_3 + Q;$$
$$\Rightarrow Q = m_2 e_2 - m_1 e_1 - m_3 j_3;$$

$$e = \cancel{ke}^{0} + \cancel{pe}^{0} + u;$$
$$\Rightarrow e = u;$$

(b) $Q = m_2 u_2 - m_1 u_1 - m_3 j_3;$

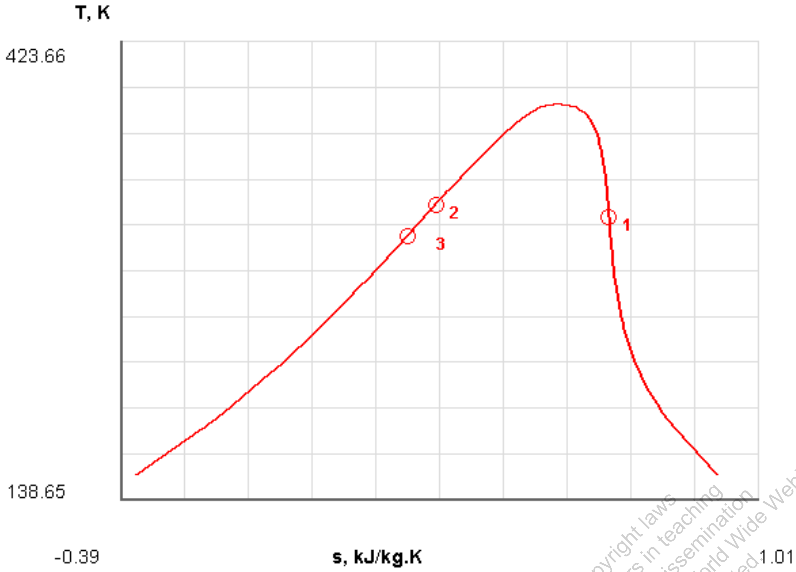
$$\Rightarrow Q = (242.74767)(82.445) - (11.46276)(186.311) - (231.28491)(65.17);$$
$$\Rightarrow Q = 2804.9 \text{ kJ}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-7 [ONO] In the charging process described above, determine (a) the change of entropy of refrigerant in the tank and (b) the entropy generation by the device and its surroundings. Assume the surrounding temperature to be 50°C.

SOLUTION



State-1 (given $p_1, x_1, \cancel{V}_1$):

$$u_1 = u_g = 186.311\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = s_g = 0.68204\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_{g@1\text{MPa}}} = \frac{0.2}{0.01745} = 11.46276\ \text{kg};$$

State-2 (given $p_2, x_2, \cancel{V}_2 = \cancel{V}_1$):

$$T_{\text{sat@1.2MPa}} = 49.300°\text{C};$$

$$u_2 = u_f = 82.445\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = s_f = 0.30146\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_2 = \frac{\cancel{V}_2}{v_{f@1.2\text{MPa}}} = \frac{0.2}{8.2\times10^{-4}} = 242.74767\ \text{kg};$$

State-3 (given p_3, T_3, T_B, inlet):

Subcooled liquid

$$v_3 = v_{f@30°\text{C}} = 7.7\times10^{-4}\ \frac{\text{m}^3}{\text{kg}};\quad u_3 = u_{f@30°\text{C}} = 64.02\ \frac{\text{kJ}}{\text{kg}};\quad s_3 = s_{f@30°\text{C}} = 0.2399\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

From the conservation of mass

$$\Delta m = m_2 - m_1 = m_3;$$

$$\Rightarrow m_3 = 242.74767 - 11.46276;$$
$$\Rightarrow m_3 = 231.28491\,\text{kg};$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{\,0} + Q - \cancel{W_{\text{ext}}}^{\,0};$$
$$\Rightarrow m_2 e_2 - m_1 e_1 = m_i j_i + Q;$$

$$j_i = j_3;$$
$$\Rightarrow j_3 = h_3 + \cancel{\text{ke}}^{\,0} + \cancel{\text{pe}}^{\,0};$$
$$\Rightarrow j_3 = u_3 + p_3 v_3;$$
$$\Rightarrow j_3 = (64.01344) + (1500)\left(7.7 \times 10^{-4}\right);$$
$$\Rightarrow j_3 = 65.17\ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 e_2 - m_1 e_1 = m_3 j_3 + Q;$$
$$\Rightarrow Q = m_2 e_2 - m_1 e_1 - m_3 j_3;$$

$$e = \cancel{\text{ke}}^{\,0} + \cancel{\text{pe}}^{\,0} + u;$$
$$\Rightarrow e = u;$$

$$Q = m_2 u_2 - m_1 u_1 - m_3 j_3;$$
$$\Rightarrow Q = (242.74767)(82.445) - (11.46276)(186.311) - (231.28491)(65.17);$$
$$\Rightarrow Q = 2804.9\ \text{kJ};$$

(a) Looking at the entropy change in the tank

$$\Delta S = m_2 s_2 - m_1 s_1;$$
$$\Rightarrow \Delta S = (242.74767)(0.30146) - (11.46276)(0.68204);$$
$$\Rightarrow \Delta S = 65.36\ \frac{\text{kJ}}{\text{K}}$$

(b) From the entropy balance equation

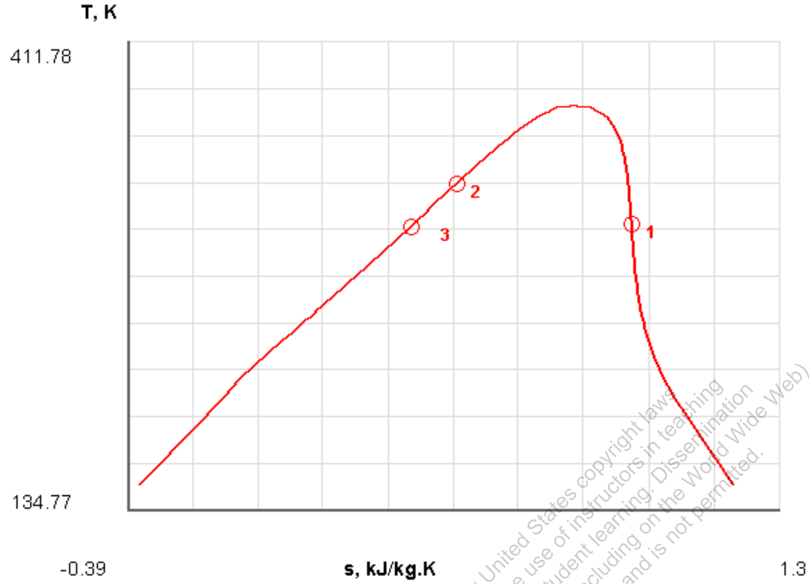
$$S_{\text{gen,univ}} = \Delta S - \left(m_i s_i - \cancel{m_e s_e}^{\,0}\right) - \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = 65.36 - (231.28491)(0.2399) - \frac{2803.8928}{323};$$
$$\Rightarrow S_{\text{gen,univ}} = 1.19\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-8 [ONB] A 0.5 m^3 rigid tank initially contains refrigerant-134a at 0.8 MPa and 100 percent quality. The tank is connected by a valve to a supply line that carries refrigerant-134a at 1.5 MPa and 30°C. Then the valve is opened and the refrigerant is allowed to enter the tank. The valve is closed when it is observed that the tank contains saturated liquid at 1.5 MPa. Determine (a) the heat transfer and (b) mass of refrigerant that has entered the tank.

SOLUTION



State-1 (given $p_1, x_1, \cancel{V}_1$):

$$u_1 = u_g = 246.152 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = s_g = 0.91584 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_{g@0.8\text{MPa}}} = \frac{0.2}{0.02575} = 19.419 \text{ kg};$$

State-2 (given $p_2, x_2, \cancel{V}_2 = \cancel{V}_1$):

$$u_2 = u_f = 129.711 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = s_f = 0.46388 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_2 = \frac{\cancel{V}_2}{v_{f@15\,\text{MPa}}} = \frac{0.2}{9.3\times10^{-4}} = 538.191 \text{ kg};$$

State-3 (given p_3, T_3, inlet):
Subcooled liquid

$$v_3 = v_{f@30°\text{C}} = 8.4\times10^{-4} \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = u_{f@30°\text{C}} = 92.16 \ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = s_{f@30°\text{C}} = 0.3446 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

From the energy balance equation

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow m_2 e_2 - m_1 e_1 = m_i j_i + Q;$$

$$j_i = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (92.16) + (1500)\left(8.4 \times 10^{-4}\right);$$

$$\Rightarrow j_3 = 93.42 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 e_2 - m_1 e_1 = m_3 j_3 + Q;$$

$$\Rightarrow Q = m_2 e_2 - m_1 e_1 - m_3 j_3;$$

$$e = \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0} + u;$$

$$\Rightarrow e = u;$$

(a) $Q = m_2 u_2 - m_1 u_1 - m_3 j_3;$

$$\Rightarrow Q = (538.191)(129.711) - (19.419)(246.152) - (518.772)(93.42);$$

$$\Rightarrow Q = 16565.6 \text{ kJ}$$

(b) From the conservation of mass

$$\Delta m = m_2 - m_1 = m_3;$$

$$\Rightarrow m_3 = 538.191 - 19.419;$$

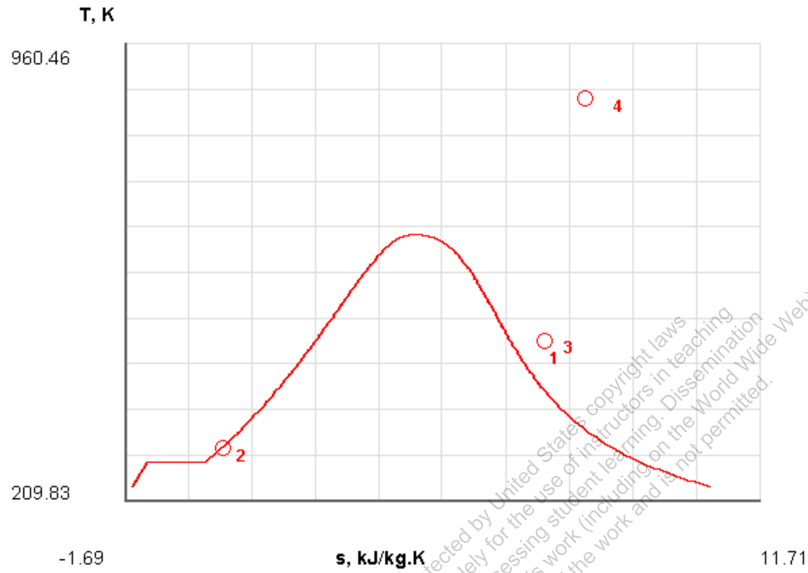
$$\Rightarrow m_3 = 518.772 \text{ kg}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-9 [ONA] A piston-cylinder device initially contains 0.1 m^3 of steam at 200°C. The force on the piston is such that it maintains a constant pressure of 400 kPa inside. Due to heat rejection to the ambient air, the temperature of the steam drops down to 25°C. To restore the steam temperature to its original value, superheated steam from a supply line at 1 MPa, 600°C is introduced through a valve into the cylinder as shown in the accompanying figure. Neglecting any heat transfer during this charging process, determine (a) the heat transfer during the cooling process and (b) the mass of steam introduced.

SOLUTION



State-1 (given $p_1, T_1, \cancel{V}_1$):

$$v_1 = 0.5342 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2646.81 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.1}{0.5342} = 0.1872 \text{ kg};$$

State-2 (given $p_2 = p_1, T_2, m_2 = m_1$):

Subcooled liquid

$$v_2 = v_{f@25°\text{C}} = 0.001 \ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = u_{f@25°\text{C}} = 104.88 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_1, T_3 = T_1, m_3 = m_2 + m_4$):

$v_3 = v_1;$

$u_3 = u_1;$

State-4 (given p_4, T_4, inlet):

$$v_4 = 0.4011\ \frac{\text{m}^3}{\text{kg}}; \quad u_4 = 3296.74\ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation for the cooling process

$$\Delta E = Q - W_{\text{ext}};$$

$$\Rightarrow m_2 u_2 - m_1 u_1 = Q - m_1 p_1 (v_2 - v_1);$$

$$\Rightarrow m_2 (u_2 - u_1) = Q - m_1 p_1 (v_2 - v_1);$$

$$\Rightarrow Q = m_2 (u_2 - u_1) + m_1 p_1 (v_2 - v_1);$$

$$\Rightarrow Q = (0.1872)(104.88 - 2646.81) + (0.1872)(400)(0.001 - 0.5342);$$

$$\Rightarrow Q = -516.45\ \text{kJ}$$

The energy balance equation for the open process reduces to:

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{0} + \cancel{Q}^{0} - W_{\text{ext}};$$

$$\Rightarrow m_3 e_3 - m_2 e_2 = m_i j_i - p_1 (m_3 v_3 - m_2 v_2);$$

$$j_i = j_4;$$

$$\Rightarrow j_4 = h_4 + \cancel{ke}^{0} + \cancel{pe}^{0};$$

$$\Rightarrow j_4 = u_4 + p_4 v_4;$$

$$\Rightarrow j_4 = (3296.74) + (1000)(0.4011);$$

$$\Rightarrow j_4 = 3697.84\ \frac{\text{kJ}}{\text{kg}};$$

$$m_3 e_3 - m_2 e_2 = m_4 j_4 - p_1 (m_3 v_3 - m_2 v_2);$$

$$\Rightarrow (m_2 + m_4) e_3 - m_2 e_2 = m_4 j_4 - p_1 \left[(m_2 + m_4) v_3 - m_2 v_2 \right];$$

$$\Rightarrow m_2 e_3 + m_4 e_3 - m_2 e_2 = m_4 j_4 - m_2 p_1 v_3 - m_4 p_1 v_3 + m_2 p_1 v_2;$$

$$\Rightarrow m_4 e_3 - m_4 j_4 + m_4 p_1 v_3 = m_2 e_2 - m_2 e_3 - m_2 p_1 v_3 + m_2 p_1 v_2;$$

$$\Rightarrow m_4 (e_3 - j_4 + p_1 v_3) = m_2 \left[e_2 - e_3 - (p_1 (v_3 - v_2)) \right];$$

$$\Rightarrow m_4 = \frac{m_2 \left[e_2 - e_3 - p_1 (v_3 - v_2) \right]}{(e_3 - j_4 + p_1 v_3)};$$

$$e = \cancel{ke}^{0} + \cancel{pe}^{0} + u;$$

$$\Rightarrow e = u;$$

(b) $m_4 = \dfrac{m_2\left[u_2 - u_3 - p_1\left(v_3 - v_2\right)\right]}{\left(u_3 - j_4 + p_1 v_3\right)};$

$$\Rightarrow m_4 = \frac{(0.1872)\left[(104.88 - 2646.81) - (400)(0.5342 - 0.001)\right]}{\left[2646.81 - 3697.84 + (400)(0.5342)\right]};$$

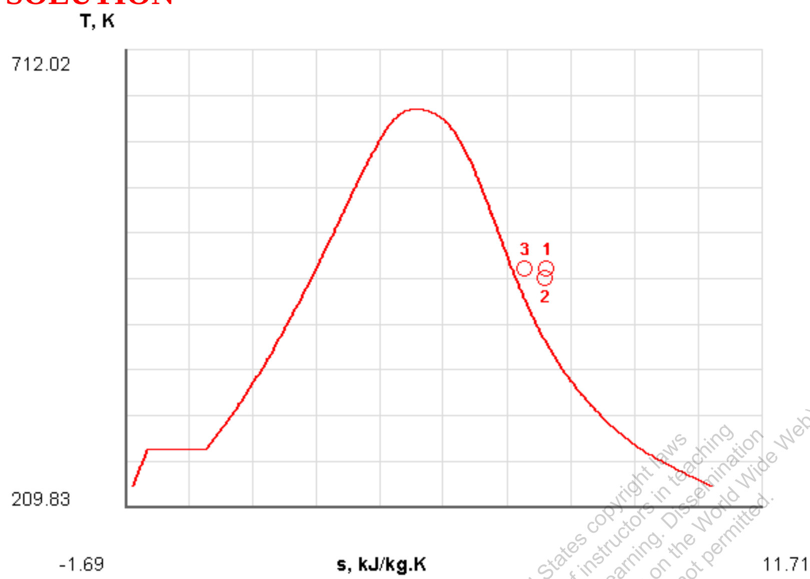
$$\Rightarrow m_4 = 0.616 \text{ kg}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

xx**5-4-10** [ONS] An insulated piston-cylinder device initially contains 0.01 m^3 of steam at 200°C. The force on the piston is such that it maintains a constant pressure of 400 kPa inside. A valve is then opened and steam at 1 MPa, 200°C is allowed to enter the cylinder until the volume inside increases to 0.04 m^3. Determine (a) the final temperature of the steam and (b) the amount of mass transfer.

SOLUTION



State-1 (given $p_1, T_1, \mathcal{V}_1$):

$$v_1 = 0.5342\ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2646.81\ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\mathcal{V}_1}{v_1} = \frac{0.01}{0.5342} = 0.01872\ \text{kg};$$

State-2 (given $p_2, \mathcal{V}_2, m_2 = m_1 + m_3$)

State-3 (given p_3, T_3, inlet):

$$v_3 = 0.2060\ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 2621.88\ \frac{\text{kJ}}{\text{kg}};$$

From the conservation of mass

$$m_3 = m_2 - m_1 = \frac{\mathcal{V}_2}{v_2} - m_1;$$

The energy balance equation for the open process reduces to:

$$\Delta E = m_i j_i - \cancel{m_e j_e}^{\,0} + \cancel{Q}^{\,0} - W_{\text{ext}};$$

$$\Rightarrow m_2u_2 - m_1u_1 = m_3h_3 - p_1\left(\cancel{V}_2 - \cancel{V}_1\right);$$
$$\Rightarrow \left(m_1 + m_3\right)u_2 - m_1u_1 = m_3h_3 - p_1\left(\cancel{V}_2 - \cancel{V}_1\right);$$
$$\Rightarrow m_3 = \frac{m_1\left(u_2 - u_1\right) + p_1\left(\cancel{V}_2 - \cancel{V}_1\right)}{\left(h_2 - u_2\right)};$$

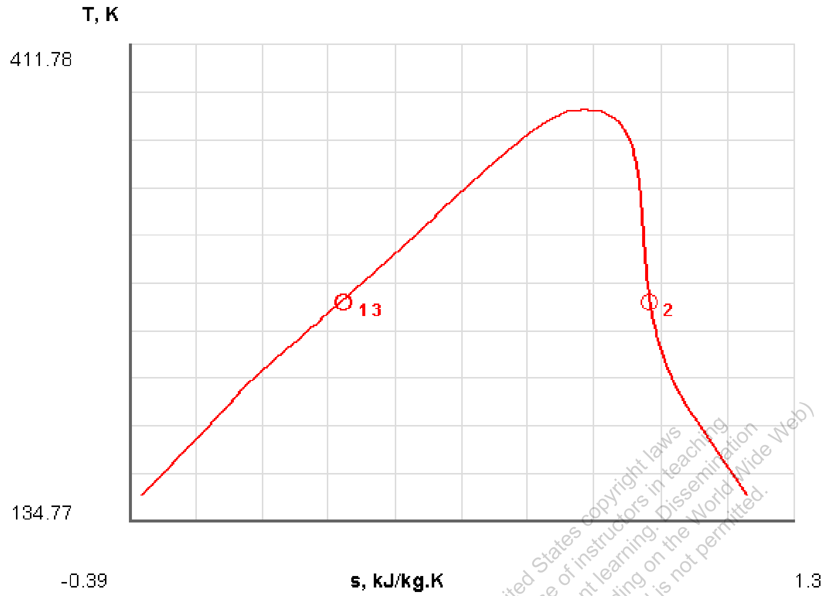
By guessing T_2, we can evaluate State-2 completely and obtain m_3 from the mass and energy equation. The correct solution $T_2 = 188.5^{\circ}\mathrm{C}$ will yield the same value, 0.018 kg.

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-11 [ONE] An insulated piston-cylinder device initially contains 0.2 m^3 of R-134a, half (by volume) of which is in the vapor phase. The mass of the piston maintains a constant pressure of 200 kPa inside. A valve is then opened and all the liquid refrigerant is allowed to escape. Determine (a) the mass of liquid refrigerant in the beginning, (b) the mass withdrawn and (c) the entropy generated during the process.

SOLUTION



State-1 (given $p_1, y_1, \cancel{V}_1$):

$$y_1 = \frac{\cancel{V}_{g,1}}{\cancel{V}_1}; \qquad \Rightarrow 0.5 = \frac{\cancel{V}_{g,1}}{0.2}; \qquad \Rightarrow \cancel{V}_{g,1} = 0.1 \text{ m}^3;$$

$$\cancel{V}_{f,1} = \cancel{V}_1 - \cancel{V}_{g,1} = 0.1 \text{ m}^3;$$

$$m_{g,1} = \frac{\cancel{V}_{g,1}}{v_{g@200\text{kPa}}} = \frac{0.1}{0.1001} = 1 \text{ kg};$$

$$m_{f,1} = \frac{\cancel{V}_{f,1}}{v_{f@200\text{kPa}}} = \frac{0.1}{7.55\times10^{-4}} = 132.45 \text{ kg};$$

$$x_1 = \frac{m_{g,1}}{m_{f,1} + m_{g,1}} = \frac{1}{132.45+1} = 0.00749;$$

$$s_1 = s_f + x_1 s_{fg} = (0.1481) + (0.00749)(0.93296 - 0.15049) = 0.15396 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2, x_2, \cancel{V}_2 = \cancel{V}_1$):

$$s_2 = s_g = 0.93296 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given p_3, x_3, outlet):

$$s_3 = s_f = 0.15049\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a,b) There remains a constant pressure, and the mixture is saturated through the process therefore temperature remains constant. This means there is no change in quality, so the amount of liquid refrigerant that leaves is the initial 132.45 kg.

(c) $$\Delta S = \cancel{m_i s_i}^{\,0} - m_e s_e + \cancel{\frac{Q}{T_B}}^{\,0} + S_{\text{gen,univ}};$$

$$\Rightarrow m_2 s_2 - m_1 s_1 = -m_e s_e + S_{\text{gen,univ}};$$

$$\Rightarrow (1)(0.93296) - (133.45)(0.15396) = -(132.35)(0.15049) + S_{\text{gen,univ}};$$

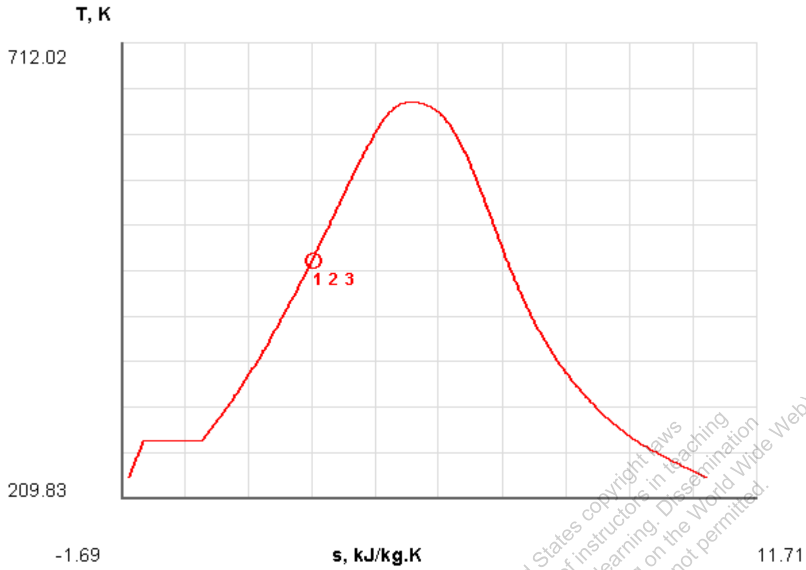
$$\Rightarrow S_{\text{gen,univ}} \cong 0\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-12 [ONH] A 0.5 m^3 tank initially contains saturated liquid water at 200°C. A valve in the bottom of the tank is opened and half the liquid is drained. Heat is transferred from a source at 300°C to maintain constant temperature inside the tank. Determine (a) the heat transfer. (b) What-if scenario: What would the heat transfer be if the 0.5 m^3 tank initially contained saturated liquid water at 100°C?

SOLUTION



State-1 (given $T_1, x_1, \cancel{V}_1$):

$$p_1 = p_{\text{sat@200°C}} = 1554 \text{ kPa};$$

$$v_1 = v_{f@200°\text{C}} = 0.001157 \frac{\text{m}^3}{\text{kg}}; \quad u_1 = u_{f@200°\text{C}} = 850.65 \frac{\text{kJ}}{\text{kg}}; \quad s_1 = s_{f@200°\text{C}} = 2.3309 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.5}{0.001157} = 432.15 \text{ kg};$$

State-2 (given $T_2 = T_1, \cancel{V}_2 = \cancel{V}_1, m_2 = 0.5 m_1$):

$$v_2 = \frac{\cancel{V}_2}{m_2} = \frac{0.5}{216.075} = 0.00231 \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.00231 - 0.00116}{0.1274 - 0.00116} = 0.0091;$$

$$p_2 = p_{\text{sat@200°C}} = 1554 \text{ kPa};$$

$$u_2 = u_f + x_2 u_{fg} = 850.65 + (0.0091)(2595.22 - 850.65) = 866.52 \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_f + x_2 s_{fg} = 2.3309 + (0.0091)(6.4323 - 2.3309) = 2.3682 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $T_3 = T_1, T_B, x_1, m_3 = 0.5m_1$):

$p_3 = p_{\text{sat@200°C}} = 1554$ kPa;

$v_3 = v_{f@200°C} = 0.001157\ \frac{\text{m}^3}{\text{kg}};\quad u_3 = u_{f@200°C} = 850.65\ \frac{\text{kJ}}{\text{kg}};\quad s_3 = s_{f@200°C} = 2.3309\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

From the energy balance equation

$$\Delta E = \cancel{m_i j_i}^{0} - m_e j_e + Q - \cancel{W_{\text{ext}}}^{0};$$
$$\Rightarrow m_2 e_2 - m_1 e_1 = -m_e j_e + Q;$$

$$j_e = j_3;$$
$$\Rightarrow j_3 = h_3 + \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0};$$
$$\Rightarrow j_3 = u_3 + p_3 v_3;$$
$$\Rightarrow j_3 = (850.65) + (1554)(0.001157);$$
$$\Rightarrow j_3 = 852.45\ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 e_2 - m_1 e_1 = -m_3 j_3 + Q;$$
$$\Rightarrow Q = m_2 e_2 - m_1 e_1 + m_3 j_3;$$

$$e = \cancel{\text{ke}}^{0} + \cancel{\text{pe}}^{0} + u;$$
$$\Rightarrow e = u;$$

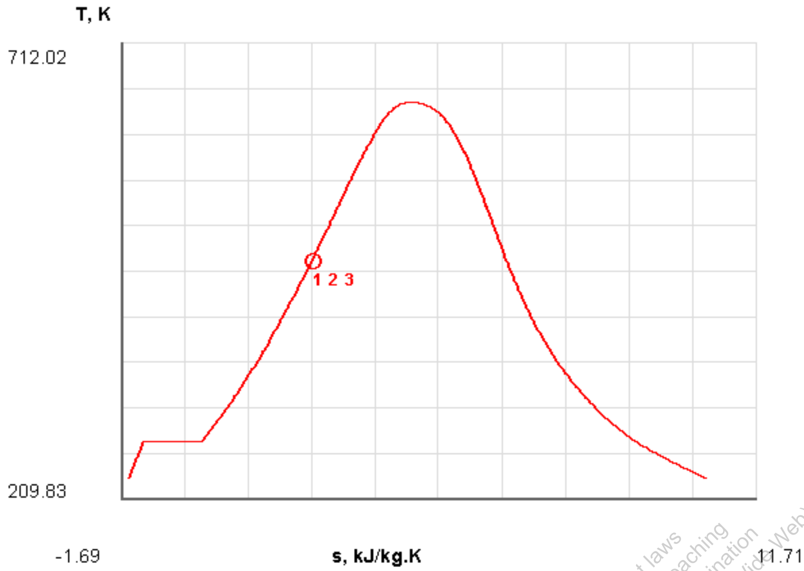
(a) $Q = m_2 u_2 - m_1 u_1 + m_3 j_3;$
$$\Rightarrow Q = (216.075)(866.52) - (432.15)(850.65) + (216.075)(852.45);$$
$$\Rightarrow Q = 3818\ \text{kJ}$$

TEST Solution and What-if Scenario:

Launch the PC open process system TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-4-13 [ONN] In the problem described above, determine the entropy generated in the system's universe during the discharge.

SOLUTION



State-1 (given $T_1, x_1, \cancel{V}_1$):

$$p_1 = p_{\text{sat}@200°\text{C}} = 1554 \text{ kPa};$$

$$v_1 = v_{f@200°\text{C}} = 0.001157 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = u_{f@200°\text{C}} = 850.65 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = s_{f@200°\text{C}} = 2.3309 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.5}{0.001157} = 432.15 \text{ kg};$$

State-2 (given $T_2 = T_1, \cancel{V}_2 = \cancel{V}_1, m_2 = 0.5 m_1$):

$$v_2 = \frac{\cancel{V}_2}{m_2} = \frac{0.5}{216.075} = 0.00231 \ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.00231 - 0.00116}{0.1274 - 0.00116} = 0.0091;$$

$$p_2 = p_{\text{sat}@200°\text{C}} = 1554 \text{ kPa};$$

$$u_2 = u_f + x_2 u_{fg} = 850.65 + (0.0091)(2595.22 - 850.65) = 866.52 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_f + x_2 s_{fg} = 2.3309 + (0.0091)(6.4323 - 2.3309) = 2.3682 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $T_3 = T_1, T_B, x_1, m_3 = 0.5 m_1$):

$$p_3 = p_{\text{sat@200°C}} = 1554 \text{ kPa};$$

$$v_3 = v_{f\,@200°\text{C}} = 0.001157 \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = u_{f\,@200°\text{C}} = 850.65 \ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = s_{f\,@200°\text{C}} = 2.3309 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

From the energy balance equation

$$\Delta E = \cancel{m_i j_i}^{0} - m_e j_e + Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow m_2 e_2 - m_1 e_1 = -m_e j_e + Q;$$

$$j_e = j_3;$$

$$\Rightarrow j_3 = h_3 + \cancel{ke}^{0} + \cancel{pe}^{0};$$

$$\Rightarrow j_3 = u_3 + p_3 v_3;$$

$$\Rightarrow j_3 = (850.65) + (1554)(0.001157);$$

$$\Rightarrow j_3 = 852.45 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 e_2 - m_1 e_1 = -m_3 j_3 + Q;$$

$$\Rightarrow Q = m_2 e_2 - m_1 e_1 + m_3 j_3;$$

$$e = \cancel{ke}^{0} + \cancel{pe}^{0} + u;$$

$$\Rightarrow e = u;$$

$$Q = m_2 u_2 - m_1 u_1 + m_3 j_3;$$

$$\Rightarrow Q = (216.075)(866.52) - (432.15)(850.65) + (216.075)(852.45);$$

$$\Rightarrow Q = 3818 \text{ kJ};$$

Looking at the entropy change in the tank

$$\Delta S = m_2 s_2 - m_1 s_1;$$

$$\Rightarrow \Delta S = (216.075)(2.3682) - (432.15)(2.3309);$$

$$\Rightarrow \Delta S = -495.59 \ \frac{\text{kJ}}{\text{K}};$$

From the entropy balance equation

$$S_{\text{gen,univ}} = \Delta S - \left(\cancel{m_i s_i}^{0} - m_e s_e\right) - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = -495.45 + (216.075)(2.3309) - \frac{3818}{573};$$

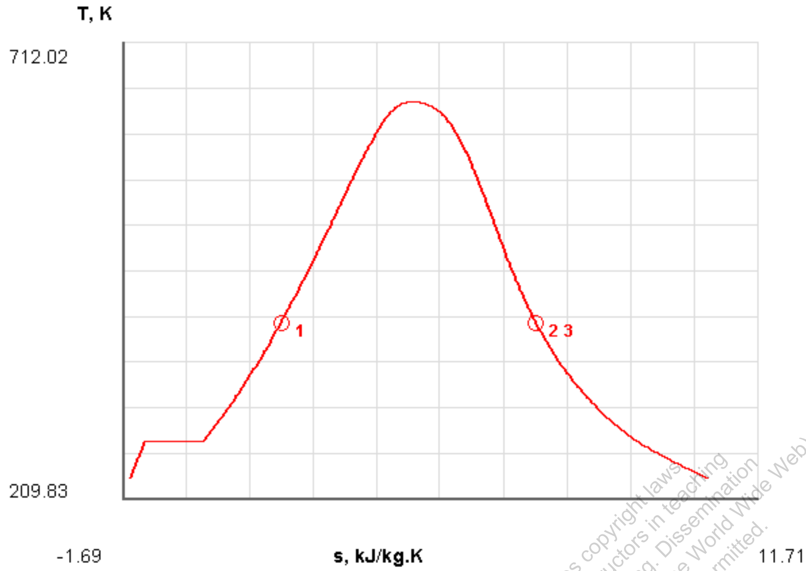
$$\Rightarrow S_{\text{gen,univ}} = 1.54 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the PC open process system TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net

5-4-14 [ONI] A 0.2 ft^3 pressure cooker has an operating pressure of 40 psia. Initially, 50% of the volume is filled with vapor and the rest with liquid water. Determine (a) the heat transfer necessary to vaporize all the water in the cooker. (b) What-if scenario: What would the heat transfer be if initially 20% of the volume were filled with vapor?

SOLUTION



State-1 (given $p_1, y_1, \cancel{V}_1$):

$$x_1 = 0.00163$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = 2.649 \text{ kg};$$

$$u_1 = 552.2 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = p_1, x_2 = 1, \cancel{V}_2 = \cancel{V}_1$):

$$m_2 = \frac{\cancel{V}_2}{v_2} = 0.008631 \text{ kg};$$

$$u_2 = u_g = 2541 \ \frac{\text{kJ}}{\text{kg}};$$

From the energy balance equation

$$\Delta U = \cancel{m_i j_i}^{0} - m_e j_e + Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow Q = m_3 j_3 + m_2 e_2 - m_1 e_1;$$

$$\Rightarrow Q = (m_2 - m_1) h_3 + m_2 u_2 - m_1 u_1 = 5745 \text{ kJ} = 5445 \text{ Btu};$$

TEST Solution and What-if Scenario:

Launch the PC open process system TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.