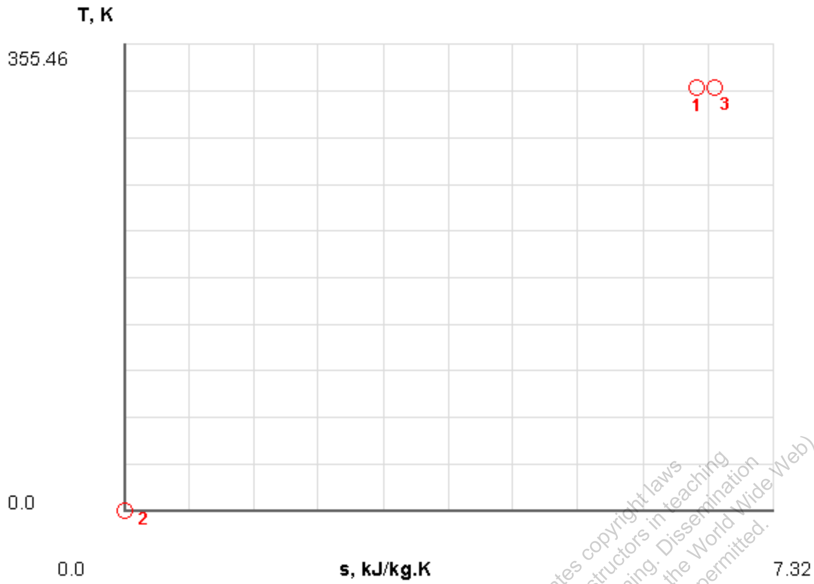
5-2-1 [OAJ] An insulated rigid tank is divided into two equal parts by a membrane. At the beginning, one part contains 3 kg of nitrogen at 500 kPa and 50°C, and the other part is completely evacuated. The membrane is punctured and the gas expands into the entire tank. Determine the final (a) temperature and (b) pressure. Use the PG model.

SOLUTION



State-1 (given p_1, T_1, m_1):

$$V_1 = \frac{mRT_1}{p_1} = \frac{(3)(0.296)(323)}{(500)} = 0.573 \text{ m}^3;$$

State-2 (given p_2, T_2)

State-3 (given $m_3 = m_1, V_3 = V_2 + V_1$)

The energy balance for the system can be expressed as

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = \cancel{Q}^{0} - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow U_f = U_b;$$

$$\Rightarrow mu_3 = m_1 u_1 + \cancel{m_2}^{0} u_2;$$

$$\Rightarrow u_3 = u_1;$$

(a) $\cancel{\Delta u}^{0} = c_v \left(T_3 - T_1\right);$

$$\Rightarrow T_3 = T_1 = 50^\circ\text{C}$$

(b) From the relation

$$\frac{p_1 \cancel{V_1}}{T_1} = \frac{p_3 \cancel{V_3}}{T_3};$$

$$\Rightarrow p_3 = \frac{p_1 \cancel{V_1} T_3}{T_1 \cancel{V_3}};$$

$$\Rightarrow p_3 = \frac{(500)(0.573)(323)}{(323)(1.147)};$$

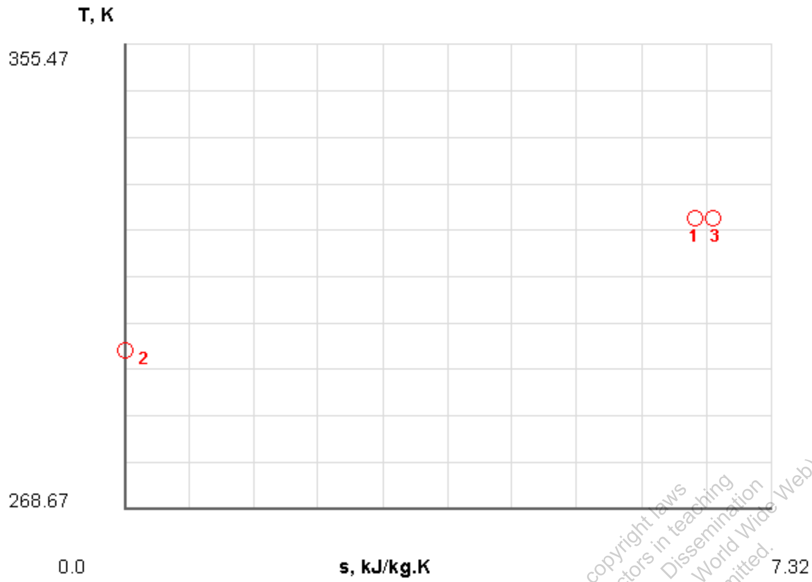
$$\Rightarrow p_3 = 250 \text{ kPa}$$

TEST Solution:

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

5-2-2 [OAW] In the above problem, (a) determine the entropy generated during the expansion process. (b) ***What-if scenario:*** How would the answer change if the temperature of nitrogen was 100°C?

SOLUTION



Given:

$$c_p = 1.039\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.297\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 (given p_1, T_1, m_1):

$$\cancel{V}_1 = \frac{mRT_1}{p_1} = \frac{(3)(0.296)(323)}{(500)} = 0.573\ \text{m}^3;$$

State-2 (given p_2, T_2)

State-3 (given $m_3 = m_1, \cancel{V}_3 = \cancel{V}_2 + \cancel{V}_1$)

The energy balance for the system can be expressed as

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = \cancel{Q}^{0} - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow U_f = U_b;$$

$$\Rightarrow mu_3 = m_1u_1 + \cancel{m_2}^{0}u_2;$$

$$\Rightarrow u_3 = u_1;$$

$$\cancel{\Delta u}^{0} = c_v\left(T_3 - T_1\right);$$

$$\Rightarrow T_3 = T_1 = 50^{\circ}\text{C};$$

From the relation

$$\frac{p_1\cancel{V_1}}{T_1} = \frac{p_3\cancel{V_3}}{T_3};$$

$$\Rightarrow p_3 = \frac{p_1\cancel{V_1}T_3}{T_1\cancel{V_3}};$$

$$\Rightarrow p_3 = \frac{(500)(0.573)(323)}{(323)(1.147)};$$

$$\Rightarrow p_3 = 250 \text{ kPa};$$

The change in entropy

$$\Delta S = m\left(s_2 - s_1\right);$$

$$\Rightarrow \Delta S = m\left(c_p \ln\cancel{\frac{T_2}{T_1}}^{0} - R\ln\frac{p_2}{p_1}\right);$$

$$\Rightarrow \Delta S = (3)\left[-(0.297)\ln\frac{(250)}{(500)}\right];$$

$$\Rightarrow \Delta S = 0.620\ \frac{\text{kJ}}{\text{K}};$$

(a) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^{0};$$

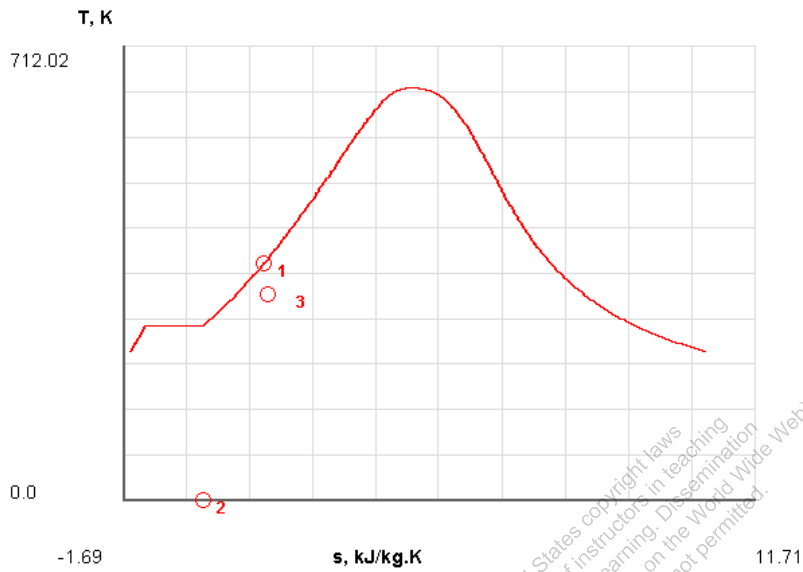
$$\Rightarrow S_{\text{gen,univ}} = 0.620\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution and What-if Scenario:

Launch the IG non-uniform mixing system closed process 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.

5-2-3 [OHR] An insulated rigid tank of volume 1 m^3 is separated into two chambers by a membrane. One chamber contains 1 kg of saturated liquid water at 100 kPa while the other chamber is completely evacuated. The membrane is punctured and water expands to occupy the entire tank. Determine the final (a) temperature and (b) pressure. (c) Determine the entropy generation in the tank's universe. Use the PC model.

SOLUTION



State-1 (given p_1, x_1, m_1):

$T_1 = 99.63°\text{C};$

$$u_2 = 417.34 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 1.3025 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given p_2, m_2):

$$u_2 = 0 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $\cancel{V}_3$, $m_3 = m_1 + m_2$):

$$v_3 = \frac{\cancel{V}_3}{m_3} = 1 \ \frac{\text{m}^3}{\text{kg}};$$

The energy balance equation provides

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = \cancel{Q}^0 - \cancel{W_{\text{ext}}}^0;$$

$$\Rightarrow 0 = m_3 u_3 - \left(m_1 u_1 + \cancel{m_2 u_2}^{0}\right);$$

$$\Rightarrow \cancel{m_3} u_3 = \cancel{m_1} u_1;$$

$$\Rightarrow u_3 = u_1 = 417.34\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 1.38349\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $T_3\left(v_3, u_3\right) = T_3\left(1, 417.34\right);$

$$\Rightarrow T_3 = 51.7°\text{C}$$

(b) $p_3\left(v_3, u_3\right) = p_3\left(1, 417.34\right);$

$$\Rightarrow p_3 = 13.4\ \text{kPa}$$

(c) Applying the entropy balance equation

$$S_{\text{gen,univ}} = m\Delta s - \cancel{\frac{Q}{T_B}}^{0};$$

$$\Rightarrow S_{\text{gen,univ}} = m\left(s_3 - \left(s_1 + \cancel{s_2}^{0}\right)\right);$$

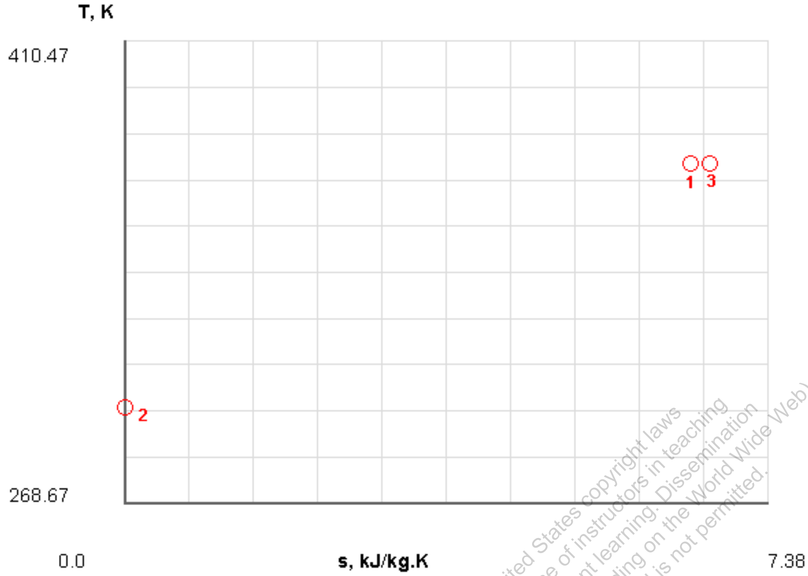
$$\Rightarrow S_{\text{gen,univ}} = (1)(1.38349 - 1.3025);$$

$$\Rightarrow S_{\text{gen,univ}} = 0.08\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:
Launch the PC non-uniform mixing system closed process TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-2-4 [OHO] A rigid, well insulated tank consists of two compartments, each having a volume of 1.5 m^3, separated by a valve. Initially, one of the compartments is evacuated and the other contains nitrogen gas at 700 kPa and 100^{o}C. The valve is opened and the nitrogen expands to fill the total volume, eventually achieving an equilibrium state. Determine the final (a) temperature and (b) pressure. Also determine (c) the entropy generated. Use the IG model.

SOLUTION



Given:

$$c_p = 1.039 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.297 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$m = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(700)(1.5)}{(0.296)(373)} = 9.51 \text{ kg};$$

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

State-3 (given $m_3 = m_1, \cancel{V}_3 = \cancel{V}_1 + \cancel{V}_2$)

The energy balance for the system can be expressed as

$$\Delta U + \cancel{\Delta \text{KE}}^{\,0} + \cancel{\Delta \text{PE}}^{\,0} = \cancel{Q}^{\,0} - \cancel{W_{\text{ext}}}^{\,0};$$

$$\Rightarrow U_f = U_b;$$
$$\Rightarrow mu_3 = m_1 u_1 + \cancel{m_2}^0 u_2;$$
$$\Rightarrow u_3 = u_1;$$

(a) $\cancel{\Delta u}^0 = c_v\left(T_3 - T_1\right);$

$$\Rightarrow T_3 = T_1 = 100^\circ\text{C}$$

(b) From the relation

$$\frac{p_1 \cancel{V_1}}{T_1} = \frac{p_3 \cancel{V_3}}{T_3};$$
$$\Rightarrow p_3 = \frac{p_1 \cancel{V_1} T_3}{T_1 \cancel{V_3}};$$
$$\Rightarrow p_3 = \frac{(700)(1.5)(373)}{(373)(3)};$$
$$\Rightarrow p_3 = 350\text{ kPa}$$

The change in entropy

$$\Delta S = m\left(s_2 - s_1\right);$$
$$\Rightarrow \Delta S = m\left(\cancel{\int_{T_1}^{T_2} c_p \frac{dT}{T}}^0 - R\ln\frac{p_2}{p_1}\right);$$
$$\Rightarrow \Delta S = (9.51)\left[-(0.297)\ln\frac{(350)}{(700)}\right];$$
$$\Rightarrow \Delta S = 1.958\ \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

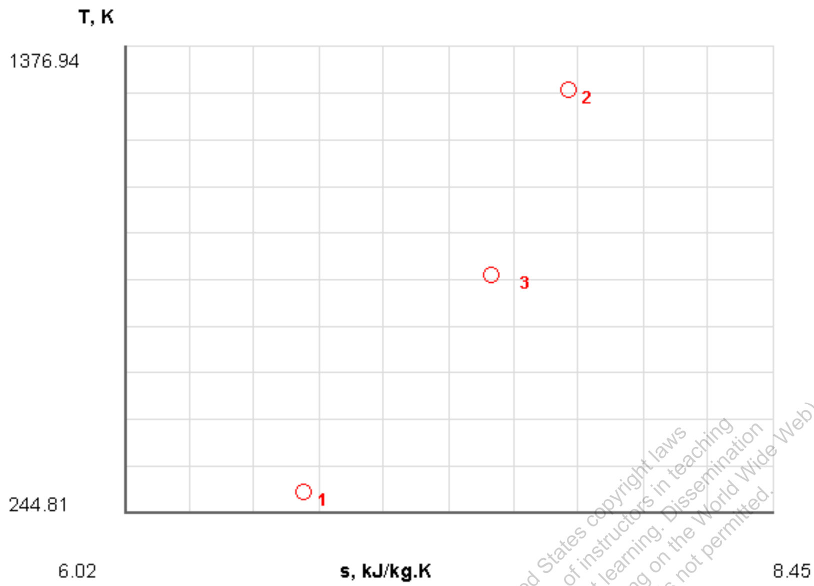
$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^0;$$
$$\Rightarrow S_{\text{gen,univ}} = 1.958\,\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the IG non-uniform mixing system closed process TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-2-5 [OHN] An insulated cylinder is divided into two parts of 1 m^3 each by a membrane. Side A has air at 200 kPa, 25°C, and side B has air at 1 MPa, 1000°C. The membrane is punctured so air comes to a uniform temperature. Determine (a) final pressure and temperature, (b) the entropy generated in this process. Use the PG model (c) ***What-if scenario:*** How would the answers change if the IG model was used?

SOLUTION



Given:

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

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

$$s_1 = 6.687 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(200)(1)}{(0.287)(298)} = 2.338 \text{ kg};$$

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

$$s_2 = 7.682 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_2 = \frac{p_2 V_2}{RT_2} = \frac{(1000)(1)}{(0.287)(1273)} = 2.737 \text{ kg};$$

State-3 (given $m_3 = m_1 + m_2, \cancel{V}_3 = \cancel{V}_1 + \cancel{V}_2$):

$$s_3 = 7.392 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $p_3 = \dfrac{p_2 + p_1}{2} = \dfrac{200 + 1000}{2} = 600 \text{ kPa}$

(b) $T_3 = \dfrac{p_3 \cancel{V}_3}{R m_3} = \dfrac{(600)(2)}{(0.287)(5.075)} = 823.87 \text{ K} = 550.87°\text{C}$

The change in entropy

$$\Delta S = m_3 s_3 - (m_2 s_2 + m_1 s_1);$$

$$\Rightarrow \Delta S = (5.075)(7.392) - (2.737)(7.682) - (2.338)(6.687);$$

$$\Rightarrow \Delta S = 0.854 \ \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^{0};$$

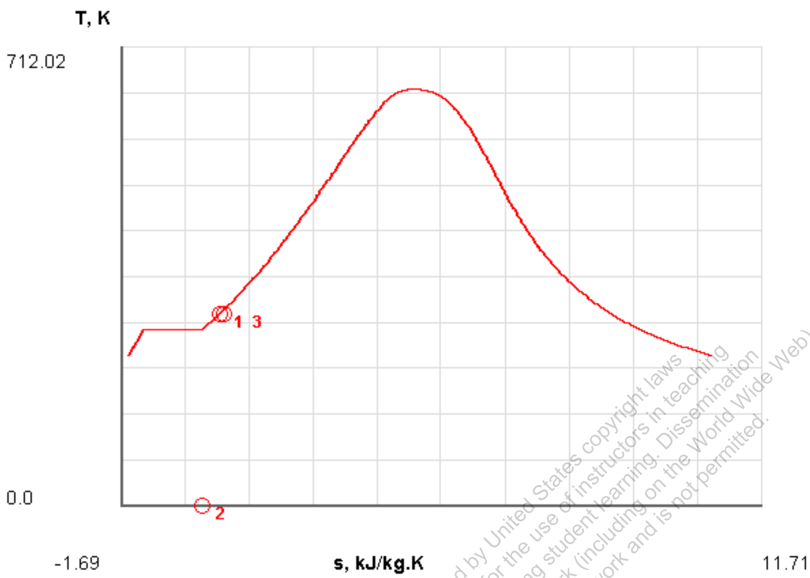
$$\Rightarrow S_{\text{gen,univ}} = 0.854 \frac{\text{kJ}}{\text{K}}$$

TEST Solution and What-if Scenario:

Launch the PG non-uniform mixing system closed process 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.

5-2-6 [OHA] A rigid tank has two compartments, one 500 times larger than the other. The smaller part contains 2 kg of compressed liquid water at 1 MPa and 25°C, while the other part is completely evacuated. The partition is now removed, and the water expands to fill the entire tank. Heat transfer with the atmosphere at 25°C is allowed, and, as a result, the final temperature after mixing is 25°C. Determine the final (a) pressure and (b) quality of the mixture. Also find (b) the entropy change of water, and (d) the entropy generation during the process.

SOLUTION



State-1 (given p_1, T_1, v_1, m_1):

$$u_1 = 104.88 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.3673 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\cancel{V}_1 = m_1 v_1 = (2)(0.001) = 0.002 \ \text{m}^3;$$

State-2 (given $p_2, \cancel{V}_2 = \cancel{V}_1 \times 500$):

$$\cancel{V}_2 = (500)\times(0.002) = 1 \ \text{m}^3;$$

State-3 (given $T_3, m_3 = m_1 + m_2, \cancel{V}_3 = \cancel{V}_1 + \cancel{V}_2$):

$$v_3 = \frac{\cancel{V}_3}{m_3} = \frac{1.002}{2} = 0.501 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_f = 104.88 \ \frac{\text{kJ}}{\text{kg}}; \quad u_g = 2409.81 \ \frac{\text{kJ}}{\text{kg}};$$

$$v_f = 0.001 \ \frac{\text{m}^3}{\text{kg}}; \quad v_g = 43.513 \ \frac{\text{m}^3}{\text{kg}};$$

$$s_f = 0.3673 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_g = 8.5584 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_3 = p_{\text{sat@25°C}} = 3.16 \text{ kPa}$

(b) $x_3 = \dfrac{v_3 - v_f}{v_{fg}} = \dfrac{0.501 - 0.001}{43.512} = 0.01149 = 1.15\%$

$$u_3 = u_f + x_3 u_{fg} = 104.88 + (0.01149)(2304.93) = 131.36 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = s_f + x_3 s_{fg} = 0.3673 + (0.01149)(8.1911) = 0.4614 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow Q = \Delta U;$$

$$\Rightarrow Q = m(u_3 - u_1);$$

$$\Rightarrow Q = (2)(131.36 - 104.88);$$

$$\Rightarrow Q = 52.96 \text{ kJ};$$

(c) The change in entropy

$$\Delta S = m(s_3 - s_1);$$

$$\Rightarrow \Delta S = (2)(0.4614 - 0.3673);$$

$$\Rightarrow \Delta S = 0.1882 \ \frac{\text{kJ}}{\text{K}}$$

(d) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = 0.1882 - \frac{52.96}{298};$$

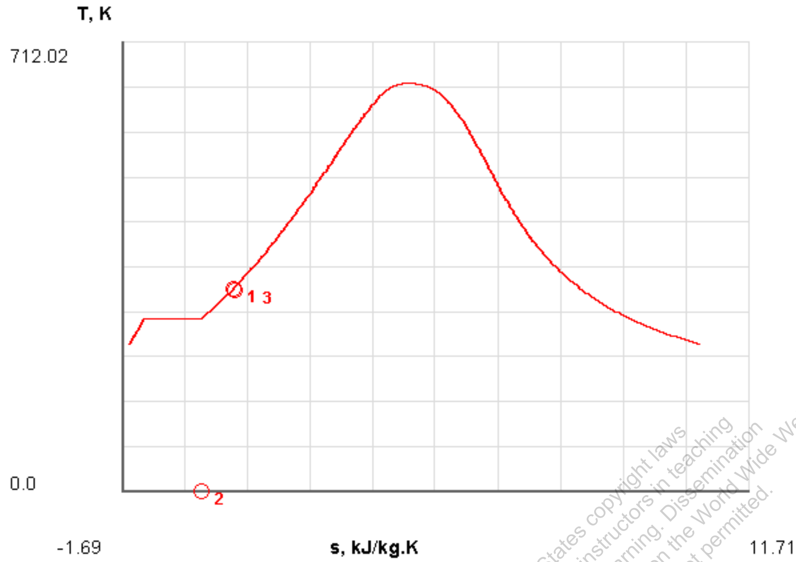
$$\Rightarrow S_{\text{gen,univ}} = 0.0105 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-7 [OHB] An insulated rigid tank has two compartments, one 100 times larger than the other. The smaller part contains 2 kg of compressed liquid water at 400 kPa and 50^{o}C, while the other part is completely evacuated. The partition is now removed, and the water expands to fill the entire tank. Determine (a) the final pressure, (b) temperature, (b) the entropy change of water, and (d) the entropy generation during the process.

SOLUTION



State-1 (given p_1, T_1, m_1):

$$v_1 = 0.00101\ \frac{\text{m}^3}{\text{kg}};\quad u_1 = 209.32\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 0.7038\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\mathcal{V}_1 = m_1 v_1 = (2)(0.00101) = 0.00202\ \text{m}^3;$$

State-2 (given $p_2, \mathcal{V}_2 = 100\times\mathcal{V}_1$):

$$\mathcal{V}_2 = (100)(0.00202) = 0.202\ \text{m}^3;$$

State-3 (given $m_3 = m_1 + m_2, \mathcal{V}_3 = \mathcal{V}_1 + \mathcal{V}_2$):

$$v_3 = \frac{\mathcal{V}_3}{m_3} = \frac{0.20402}{2} = 0.10221\ \frac{\text{m}^3}{\text{kg}};$$

From the energy equation

$$\Delta U + \Delta KE + \Delta PE = \cancel{Q}^0 - \cancel{W_{\text{ext}}}^0;$$

$$\Rightarrow m_3u_3 - \left(m_1u_1 + \cancel{m_2u_2}^{\,0}\right) = 0;$$

$$\Rightarrow \cancel{m_3}u_3 = \cancel{m_1}u_1;$$

$$\Rightarrow u_3 = u_1;$$

$$\Rightarrow u_3 = 209.32\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 0.7072\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_3(v_3, u_3) = p_3(0.10221, 209.32);$

$$\Rightarrow p_3 = 10.2\ \text{kPa}$$

(b) $T_3(v_3, u_3) = T_3(0.10221, 209.32);$

$$\Rightarrow T_3 = 46.2°\text{C}$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^{\,0};$$

$$\Rightarrow S_{\text{gen,univ}} = m\Delta s;$$

$$\Rightarrow S_{\text{gen,univ}} = m\left(s_3 - \left(s_1 + \cancel{s_2}^{\,0}\right)\right);$$

$$\Rightarrow S_{\text{gen,univ}} = (2)(0.7072 - 0.7038);$$

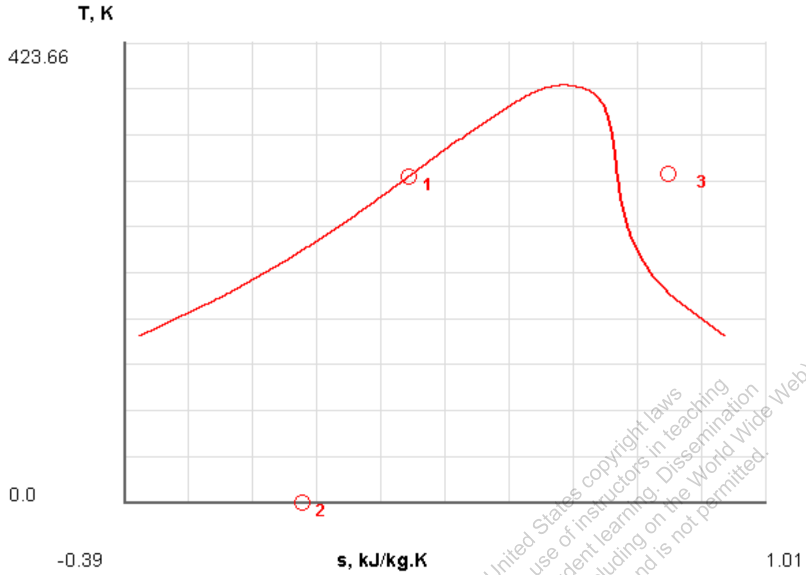
$$\Rightarrow S_{\text{gen,univ}} = 0.0068\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-8 [OHS] A tank whose volume is unknown is divided into two parts by a partition. One side contains 0.02 m^3 of saturated liquid R-12 at 0.7 MPa, while the other side is evacuated. The partition is now removed, and R-12 fills up the entire volume. If the final state is 200 kPa, 30^o C. Determine (a) the volume of the tank, (b) the heat transfer. (c) ***What-if scenario:*** How would the answer in part (a) change if the final state was 300kPa and 30^oC.

SOLUTION



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

$$v_1 = 0.00077 \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 61.75 \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{(0.02)}{(0.00077)} = 25.97 \text{ kg};$$

State-2 (given p_2)

State-3 (given $p_3, T_3, m_3 = m_1$)

$$v_3 = 0.10023 \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 188.54 \frac{\text{kJ}}{\text{kg}};$$

(a) $\cancel{V}_3 = m_3 v_3 = (25.97)(0.10023) = 2.603 \text{ m}^3$

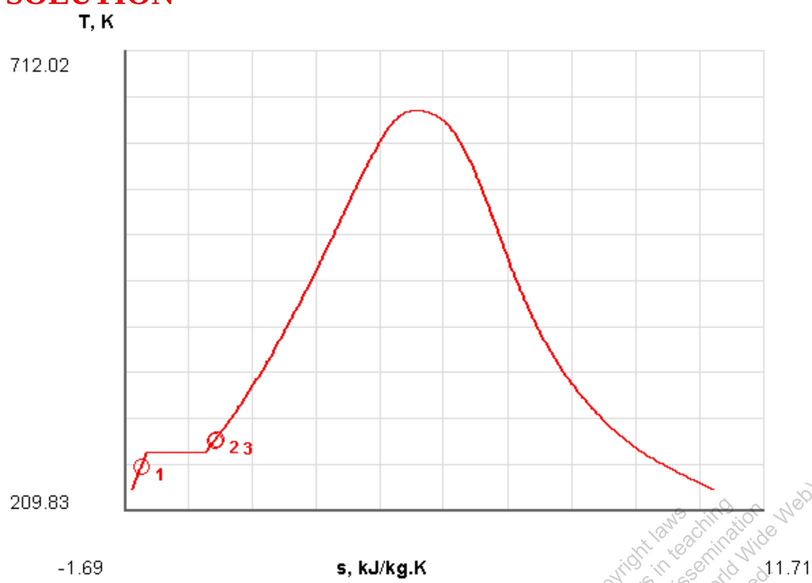
(b) $\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \cancel{W_{ext}}^0;$

$$\Rightarrow Q = m(u_3 - u_1);$$
$$\Rightarrow Q = (25.97)(188.54 - 61.75);$$
$$\Rightarrow Q = 3292.73 \text{ kJ}$$

TEST Solution and What-if Scenario:
Launch the PC non-uniform mixing system closed process 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.

5-2-9 [OHH] Four ice cubes (3 cm * 2 cm * 1 cm) at -15^{o}C are added to an insulated glass of cola at 15^{o}C. The volume of cola is 1.5 L. Determine (a) the equilibrium temperature, (b) and the total entropy change for this process.

SOLUTION



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

$$v_1 = 0.00109 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = -364.14 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = -1.338 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$m_1 = \frac{\mathcal{V}_1}{v_1} = \frac{(0.000024)}{(0.00109)} = 0.022 \text{ kg};$$

State-2 (given $p_2, T_2, \mathcal{V}_2$):

$$v_2 = 0.0010 \ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = 62.99 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 0.2244 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$m_2 = \frac{\mathcal{V}_2}{v_2} = \frac{(0.0015)}{(0.0010)} = 1.5 \text{ kg};$$

State-3 (given p_3, $m_3 = m_1 + m_2$)

From the energy equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = \cancel{Q}^{0} - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow m_3u_3 - \left(m_1u_1 + m_2u_2\right) = 0;$$

$$\Rightarrow u_3 = \frac{m_1u_1 + m_2u_2}{m_3};$$

$$\Rightarrow u_3 = \frac{(0.022)(-364.14) + (1.5)(62.99)}{1.522};$$

$$\Rightarrow u_3 = 56.82 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 0.2028 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

(a) $T_3 = 13.52°C$

(b) From the entropy equation

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^{0};$$

$$\Rightarrow S_{\text{gen,univ}} = m_3s_3 - \left(m_1s_1 + m_2s_2\right);$$

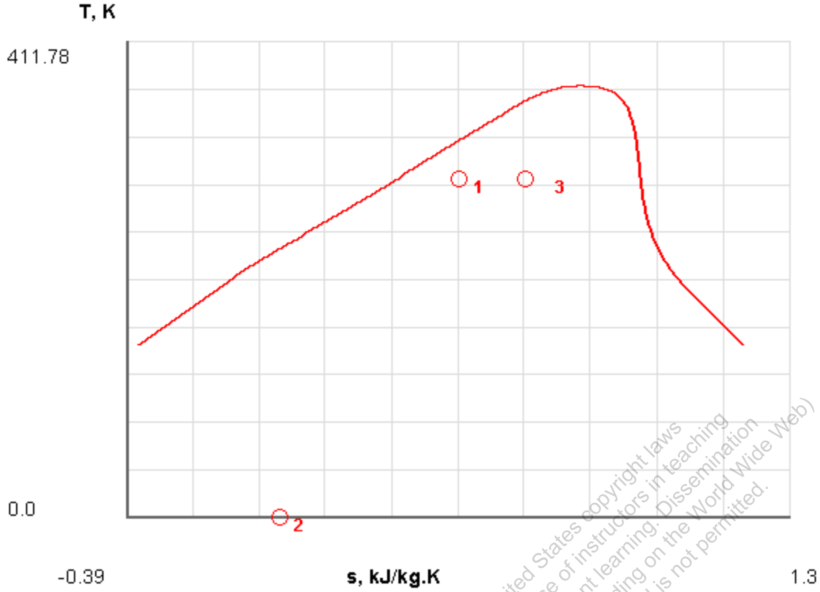
$$\Rightarrow S_{\text{gen,univ}} = (1.522)(0.2028) - \left[(0.022)(-1.338) + (1.5)(0.2244)\right];$$

$$\Rightarrow S_{\text{gen,univ}} = 0.0015 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:
Launch the PC non-uniform mixing system closed process TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-2-10 [OHK] Two tanks are connected by a valve and line. The volumes are both 1 m^3 with R-134a at 21° C, quality 25% in tank A and tank B is evacuated. The valve is opened and saturated vapor flows from A to B until the pressure became equal. The process occurs slowly enough that all temperatures stay at 21°C during the process. Determine (a) the entropy generated, and (b) the total heat transfer.

SOLUTION



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

$$v_1 = 0.00936 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 119.76 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.4562 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{(1)}{(0.00936)} = 106.83 \text{ kg};$$

State-2 (given $p_2, \cancel{V}_2$)

State-3 (given $T_3, m_3 = m_1, \cancel{V}_3 = \cancel{V}_1 + \cancel{V}_2$):

$$v_3 = \frac{\cancel{V}_3}{m_3} = \frac{2}{106.83} = 0.01872 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_3 = 163.96 \ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = 0.625 \ \frac{\text{kJ}}{\text{kg}};$$

The change in entropy

$$\Delta S = m(s_3 - s_1);$$

$$\Rightarrow \Delta S = (106.83)(0.625 - 0.4562);$$

$$\Rightarrow \Delta S = 18.03 \frac{\text{kJ}}{\text{K}};$$

(a) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = 18.03 - \frac{4721}{298};$$

$$\Rightarrow S_{\text{gen,univ}} = 2.18 \frac{\text{kJ}}{\text{K}}$$

(b) From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow Q = m(u_3 - u_1);$$

$$\Rightarrow Q = (106.83)(163.96 - 119.76);$$

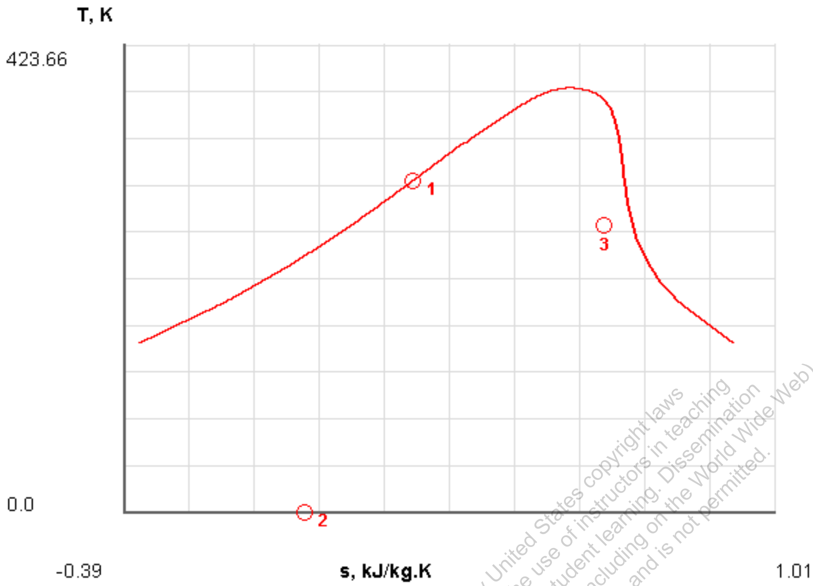
$$\Rightarrow Q = 4721 \text{ kJ}$$

TEST Solution:

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

5-2-11 [OHE] A tank whose volume is unknown is divided into two parts by a partition. One side contains 0.02 m^3 of saturated liquid R-12 at 0.7 MPa, while the other side is evacuated. The partition is now removed and R-12 fills up the entire volume. If the final state is 200 kPa, quality 90%, determine (a) the volume of the tank, (b) the heat transfer, and (c) the entropy generated. The atmospheric temperature is 30^{o}C. (d) ***What-if scenario:*** How would the answer in part (b) change if the final pressure was 300 kPa?

SOLUTION



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

$$v_1 = 0.00077\ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 61.75\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.232\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\mathcal{V}_1}{v_1} = \frac{(0.02)}{(0.00077)} = 25.97\ \text{kg};$$

State-2 (given p_2)

State-3 (given $p_3, x_3, m_3 = m_1 + m_2$):

$$v_3 = 0.0752\ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 151.26\ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = 0.643\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $\mathcal{V}_3 = v_3 m_3 = (0.0752)(25.97) = 1.95\ \text{m}^3$

(b) From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow Q = m(u_3 - u_1);$$
$$\Rightarrow Q = (25.97)(151.26 - 61.75);$$
$$\Rightarrow Q = 2324.56 \text{ kJ}$$

The change in entropy

$$\Delta S = m(s_3 - s_1);$$
$$\Rightarrow \Delta S = (25.97)\left(0.643 - 0.232\right);$$
$$\Rightarrow \Delta S = 10.67 \frac{\text{kJ}}{\text{K}};$$

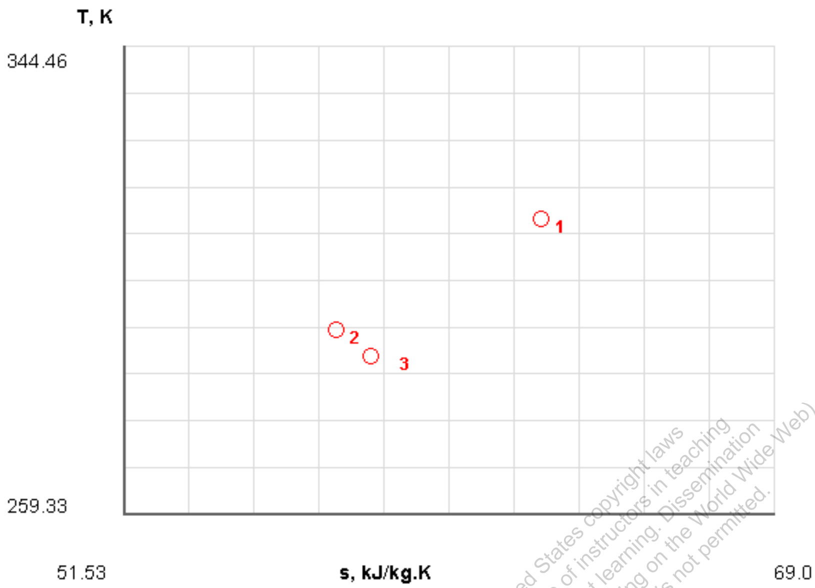
(c) The entropy equation, applied over the system's universe, produces

$$\Rightarrow S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = 10.67 - \frac{2324.56}{303};$$
$$\Rightarrow S_{\text{gen,univ}} = 3 \frac{\text{kJ}}{\text{K}}$$

TEST Solution and What-if Scenario:
Launch the PC non-uniform mixing system closed process 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.

5-2-12 [OHI] Two tanks are connected Part A tank is having 0.5 m^3 containing hydrogen at 40°C, 200 kPa is connected to Part B tank having 1 m^3 rigid tank containing hydrogen at 20°C, 600 kPa. The valve is opened and the system is allowed to reach thermal equilibrium with the surroundings at 15°C. Determine (a) the final pressure, (b) heat transfer, and (c) the entropy generated during the mixing process. Use the PG model.

SOLUTION



Given

$$R = 4.115\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$m_1 = \frac{p_1\mathcal{V}_1}{RT_1} = \frac{(200)(0.5)}{(4.115)(313)} = 0.0776\ \text{kg};$$

$$u_1 = -1074.73\ \frac{\text{kJ}}{\text{kg}}; \qquad s_1 = 62.59\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2, T_2, \mathcal{V}_2$):

$$m_2 = \frac{p_2\mathcal{V}_2}{RT_2} = \frac{(600)(1)}{(4.115)(293)} = 0.497\ \text{kg};$$

$$u_2 = -1277.93\ \frac{\text{kJ}}{\text{kg}}; \qquad s_2 = 57.13\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $T_3, m_3 = m_1 + m_2, \mathcal{V}_3 = \mathcal{V}_1 + \mathcal{V}_2$):

$$u_3 = -1328.73\ \frac{\text{kJ}}{\text{kg}}; \qquad s_3 = 58.02\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_3 = \frac{m_3 R T_3}{\cancel{V}_3} = \frac{(0.575)(4.115)(288)}{1.5} = 454.48\ \text{kPa}$

(b) From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow Q = m_3 u_3 - \left(m_1 u_1 + m_2 u_2\right);$$

$$\Rightarrow Q = (0.5746)(-1328.73) - \left[(0.0776)(-1074.73) + (0.497)(-1277.93)\right];$$

$$\Rightarrow Q = -44.96\ \text{kJ}$$

The change in entropy

$$\Delta S = m_3 s_3 - \left(m_1 s_1 + m_2 s_2\right);$$

$$\Rightarrow \Delta S = 0.110\ \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = 0.11 - \frac{-44.96}{288};$$

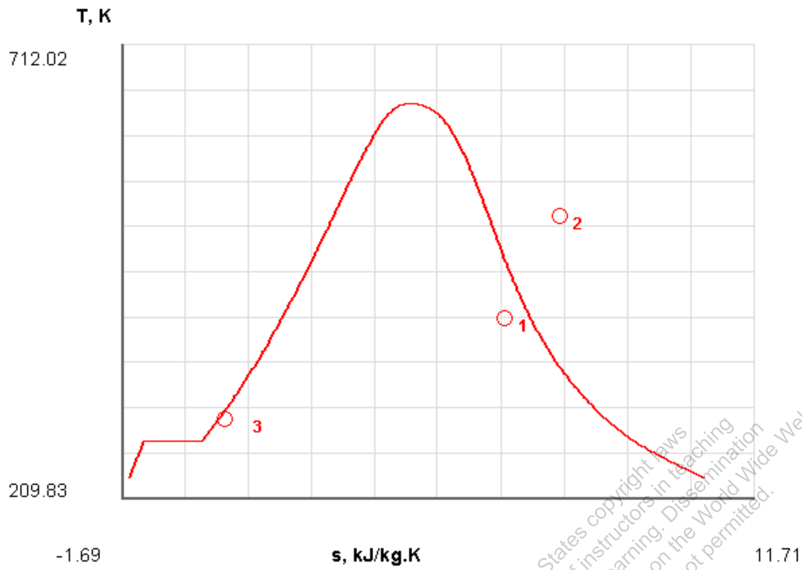
$$\Rightarrow S_{\text{gen,univ}} = 0.266\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-13 [OHL] Two rigid tanks are connected by a valve. Tank A contains 0.4 m^3 of water at 330 kPa and 90 percent quality. Tank B contains 0.5 m^3 of water at 250 kPa and 250^{o}C. The valve is now opened, and the two tanks eventually come to equilibrium while exchanging heat with the surroundings at 25^{o}C. Determine (a) the final pressure, (b) heat transfer and (c) the entropy generation during the process.

SOLUTION



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

$$v_1 = 0.4952\ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2349.65\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.434\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{(0.4)}{(0.4952)} = 0.807\ \text{kg};$$

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

$$v_2 = 0.957\ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = 2729.93\ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 7.602\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_2 = \frac{\cancel{V}_2}{v_2} = \frac{(0.5)}{(0.957)} = 0.522\ \text{kg};$$

State-3 (given $T_3, m_3 = m_1 + m_2, \cancel{V}_3 = \cancel{V}_1 + \cancel{V}_2$):

$$v_3 = 0.676\ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 140.84\ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = 0.495\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_3 = 3.15\ \text{kPa}$

(b) From the energy balance equation

$$\Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} = Q - \cancel{W_{ext}}^{0};$$

$$\Rightarrow Q = m_3 u_3 - (m_1 u_1 + m_2 u_2);$$

$$\Rightarrow Q = (1.329)(140.84) - [(0.807)(2349.65) + (0.522)(2729.93)];$$

$$\Rightarrow Q = -3134 \text{ kJ}$$

The change in entropy

$$\Delta S = m_3 s_3 - (m_1 s_1 + m_2 s_2);$$

$$\Rightarrow \Delta S = (1.329)(0.495) - [(0.807)(6.434) - (0.522)(7.602)];$$

$$\Rightarrow \Delta S = -8.502 \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = -8.502 - \frac{-3134}{298};$$

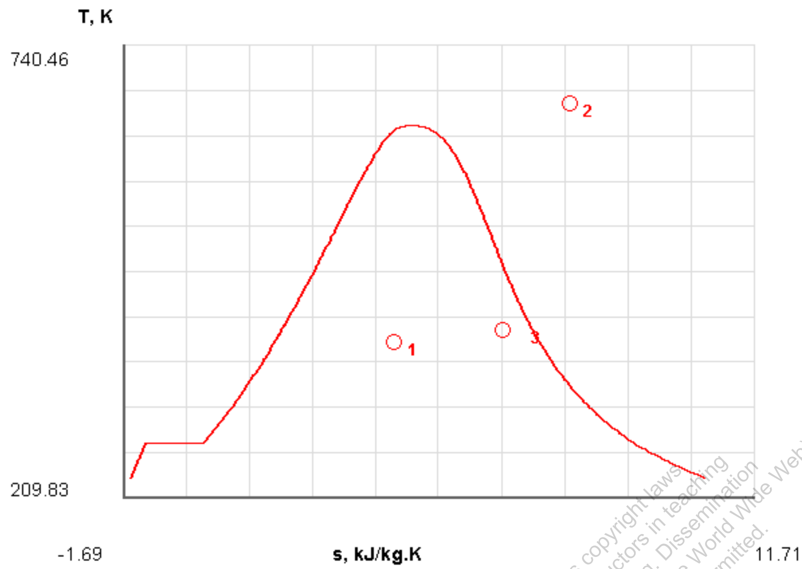
$$\Rightarrow S_{\text{gen,univ}} = 2.014 \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-14 [OHG] Two insulated tanks are connected, both containing H_2O. Tank-A is at 200 kPa, v = 0.4 m^3/kg, V = 1 m^3 and tank B contains 3.5 kg at 0.5 MPa, 400^{o}C. The valve is now opened and the two come to a uniform state. Find (a) the final pressure, (b) temperature and (c) the entropy generated by the mixing process.

SOLUTION



State-1 (given $p_1, v_1, \cancel{V}_1$):

$$v_f = 0.001061 \ \frac{\text{m}^3}{\text{kg}}; \quad v_g = 0.8857 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_f = 504.49 \ \frac{\text{kJ}}{\text{kg}}; \quad u_g = 2529.5 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 1.5301 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_g = 7.1271 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.4 - 0.001061}{0.884639} = 0.451;$$

$$u_1 = u_f + x_1 u_{fg} = 504.49 + (0.451)(2025.01) = 1417.77 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_f + x_1 s_{fg} = 1.5301 + (0.451)(5.597) = 4.054 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{(1)}{(0.4)} = 2.5 \text{ kg};$$

State-2 (given p_2, T_2, m_2):

$$v_2 = 0.6173 \ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = 2963.17 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 7.793 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$\cancel{V}_2 = m_2 v_2 = (3.5)(0.6173) = 2.16 \text{ m}^3;$

State-3 (given $m_3 = m_1 + m_2, \cancel{V}_3 = \cancel{V}_1 + \cancel{V}_2$):

$v_3 = 0.526 \ \dfrac{\text{m}^3}{\text{kg}};$

From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = \cancel{Q}^o - \cancel{W_{\text{ext}}}^0;$$

$$\Rightarrow m_3 u_3 - (m_1 u_1 + m_2 u_2) = 0;$$

$$\Rightarrow u_3 = \frac{(m_1 u_1 + m_2 u_2)}{m_3};$$

$$\Rightarrow u_3 = \frac{(2.5)(1417.77) + (3.5)(2963.17)}{6};$$

$$\Rightarrow u_3 = 2318 \ \frac{\text{kJ}}{\text{kg}};$$

Knowing two independent properties of state-3:

(a) $p_3 = 305.9 \text{ kPa};$

(b) $T_3 = 134.2°\text{C}$

$s_3 = 6.377 \dfrac{\text{kJ}}{\text{kg} \cdot \text{K}};$

The change in entropy

$$\Delta S = m_3 s_3 - (m_1 s_1 + m_2 s_2);$$

$$\Rightarrow \Delta S = (6)(6.377) - [(2.5)(4.054) - (3.5)(7.793)];$$

$$\Rightarrow \Delta S = 0.8515 \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^0;$$

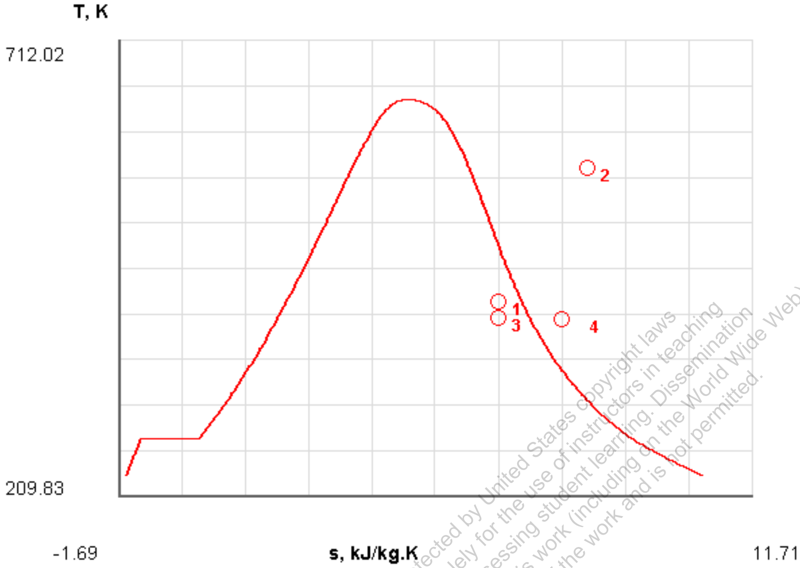
$$\Rightarrow S_{\text{gen,univ}} = 0.8515 \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-15 [OHZ] Two rigid tanks are connected by a valve as shown in the accompanying figure. Tank A is insulated and contains 0.1 m^3 of steam at 500 kPa and 90% quality. Tank B is uninsulated and contains 2 kg of steam at 100 kPa and 300°C. The valve is now opened, and steam flows from tank A to tank B. As the pressure in tank A drops to 300 kPa, the valve is closed. During the process 500 kJ of heat is transferred from tank B to the surroundings at 25°C. Assuming the steam in tank A to have undergone a reversible adiabatic process (isentropic), determine (a) the final temperature in each tank, (b) final pressure in tank B, and (c) the entropy generated in the system's universe.

SOLUTION



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

$$v_1 = 0.3385 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2369 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.325 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\mathcal{V}_1}{v_1} = \frac{(0.1)}{(0.3385)} = 0.295 \text{ kg};$$

State-2 (given p_2, T_2, m_2):

$$v_2 = 2.639 \ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = 2810 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 8.215 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\mathcal{V}_2 = m_2 v_2 = (2)(2.639) = 5.278 \text{ m}^3;$$

State-3 (given $p_3, s_3 = s_1, \mathcal{V}_3 = \mathcal{V}_1$):

$$v_3 = 0.531 \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 2296 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_3 = \frac{\mathcal{V}_3}{v_3} = \frac{(0.1)}{(0.531)} = 0.188 \text{ kg};$$

State-4 (given $m_4 = m_1 + m_2 - m_3, \cancel{V_4} = \cancel{V_2}$):

$m_4 = 2.107$ kg;

$\Rightarrow v_4 = 2.504 \ \dfrac{\text{m}^3}{\text{kg}}$

From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \cancel{W_{\text{ext}}}^0;$$

$$\Rightarrow (m_4 u_4 + m_3 u_3) - (m_1 u_1 + m_2 u_2) = Q;$$

$$\Rightarrow u_4 = 2557 \ \frac{\text{kJ}}{\text{kg}}$$

Knowing two independent properties of state-4:

$s_4 = 7.664 \ \dfrac{\text{kJ}}{\text{kg} \cdot \text{K}};$

(a) $T_4 = 132.07^{\circ}\text{C}$

(b)

$p_4 = 74.06$ kPa

The change in entropy

$$\Delta S = (m_4 s_4 + m_3 s_3) - (m_1 s_1 + m_2 s_2);$$

$$\Rightarrow \Delta S = 17.33 - 18.29;$$

$$\Rightarrow \Delta S = -0.965 \ \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = -0.965 - \frac{-500}{298};$$

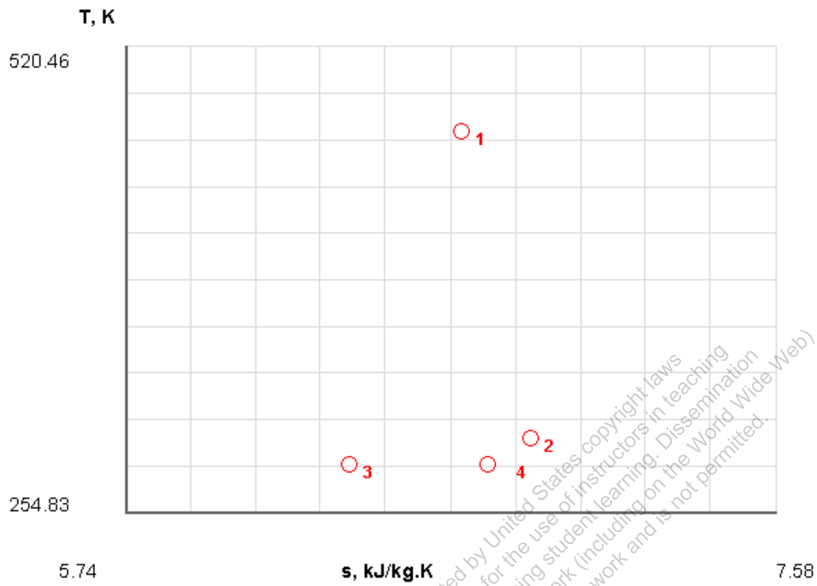
$$\Rightarrow S_{\text{gen,univ}} = 0.712 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-16 [OHX] Two rigid tanks are connected by a valve. Tank A contains 1 m^3 of air at 1 MPa, 200^{o}C. Tank B contains 3 m^3 of air at 100 kPa, 25^{o}C. The valve is now opened, and air flows from tank A to tank B. Before the two gases comes to mechanical equilibrium, the valve is closed. After a sufficient time, air in both tanks comes to thermal equilibrium with the surroundings at 10 ^{o}C. The pressure in tank A is measured as 500 kPa. Using the PG model for air, determine (a) the final pressure in tank B, (b) the heat transfer, and (c) the entropy generated in the system's universe.

SOLUTION



Given:

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

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

$$m_1 = \frac{p_1\cancel{V}_1}{RT_1} = \frac{(1000)(1)}{(0.287)(473)} = 7.36 \text{ kg};$$

$$u_1 = 39.82 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.689 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$m_2 = \frac{p_2\cancel{V}_2}{RT_2} = \frac{(100)(3)}{(0.287)(298)} = 3.50 \text{ kg};$$

$$u_2 = -85.56 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 6.886 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3, T_3, \cancel{V}_3 = \cancel{V}_1$):

$$m_3 = \frac{p_3 \cancel{V}_3}{RT_3} = \frac{(500)(1)}{(0.287)(283)} = 6.15 \text{ kg};$$

$$u_3 = -96.31 \frac{\text{kJ}}{\text{kg}}; \quad s_3 = 6.373 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-4 (given $T_4, m_4 = m_1 + m_2 - m_3, \cancel{V}_4 = \cancel{V}_2$):

$$m_4 = 4.71 \text{ kg};$$

$$u_4 = -96.31 \frac{\text{kJ}}{\text{kg}}; \quad s_4 = 6.764 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $$p_4 = \frac{m_4 RT_4}{\cancel{V}_4} = \frac{(4.71)(0.287)(283)}{(3)} = 127.51 \text{ kPa}$$

(b) From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$

$$\Rightarrow Q = (m_4 u_4 + m_3 u_3) - (m_1 u_1 + m_2 u_2);$$

$$\Rightarrow Q = -1045.92 + 6.38;$$

$$\Rightarrow Q = -1039.5 \text{ kJ}$$

The change in entropy

$$\Delta S = (m_4 s_4 + m_3 s_3) - (m_1 s_1 + m_2 s_2);$$

$$\Rightarrow \Delta S = 71.05 - 73.33;$$

$$\Rightarrow \Delta S = -2.28 \frac{\text{kJ}}{\text{K}};$$

The amount of entropy transfer into the atmosphere

$$\frac{Q}{T_B} = \frac{-1039.5}{283} = -3.67 \frac{\text{kJ}}{\text{K}};$$

(c) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = -2.28 - \frac{-1039.5}{283};$$

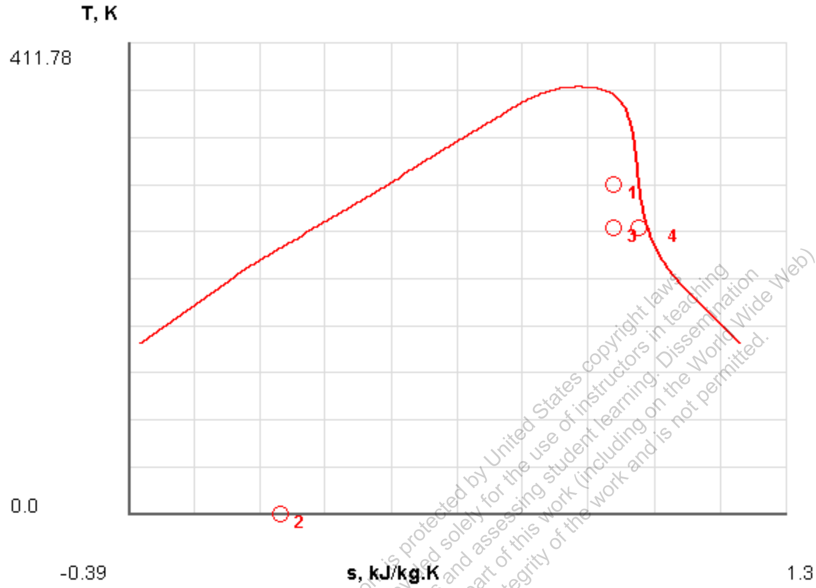
$$\Rightarrow S_{\text{gen,univ}} = 1.39 \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-2-17 [OHP] An insulated tank containing 0.5 m^3 of R-134a at 500 kPa and 90% quality is connected to an initially evacuated insulated piston-cylinder device as shown in the accompanying figure. The force balance on the piston is such that a pressure of 200 kPa is required to lift the piston. Now the valve is opened slightly and part of the refrigerant flows to the cylinder, pushing the piston up. The process ends when the pressure in the tank drops to 120 kPa. Assuming that the refrigerant in the tank undergoes an isentropic (reversible and adiabatic) process, determine the final quality in the (a) tank and (b) cylinder. Also calculate (c) the boundary work, and (d) the entropy generated during the process.

SOLUTION



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

$$v_1 = 0.0368 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 221.24 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.856 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{(0.5)}{(0.0368)} = 13.55 \text{ kg};$$

State-2 (given $p_2, \cancel{V}_2$)

State-3 (given $p_3, s_3 = s_1, \cancel{V}_3 = \cancel{V}_1$):

$$v_3 = 0.1463 \ \frac{\text{m}^3}{\text{kg}}; \quad u_3 = 196.39 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_3 = \frac{\cancel{V}_3}{v_3} = \frac{(0.5)}{(0.1463)} = 3.41 \text{ kg};$$

(a) $x_3 = \dfrac{s_3 - s_f}{s_{fg}} = \dfrac{(0.856)-(0.0879)}{(0.847)} = 0.906$

State-4 (given $p_4, m_4 = m_1 + m_2 - m_3, \cancel{V_4}$):

$m_4 = 10.14$ kg;

$v_4 = 0.1556\ \dfrac{\text{m}^3}{\text{kg}}$;

$u_4 = 210.95\ \dfrac{\text{kJ}}{\text{kg}}$; $\quad s_4 = 0.920\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$;

(b) $x_4 = \dfrac{v_4 - v_f}{v_{fg}} = \dfrac{(0.1556)-(0.000732)}{(0.1606)} = 0.964$

(c) From the energy balance equation

$$\Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} = \cancel{Q}^{0} - W_{\text{ext}};$$

$$\Rightarrow W_{\text{ext}} = \left(m_1u_1 + m_2u_2\right) - \left(m_4u_4 + m_3u_3\right);$$

$$\Rightarrow W_{\text{ext}} = 2997.80 - 2808.72;$$

$$\Rightarrow W_{\text{ext}} = 189.07 \text{ kJ}$$

The change in entropy

$$\Delta S = \left(m_4s_4 + m_3s_3\right) - \left(m_1s_1 + m_2s_2\right);$$

$$\Rightarrow \Delta S = 12.24 - 11.59;$$

$$\Rightarrow \Delta S = 0.641\,\frac{\text{kJ}}{\text{K}};$$

(d) The entropy equation, applied over the system's universe, produces

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^{0};$$

$$\Rightarrow S_{\text{gen,univ}} = 0.641\,\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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