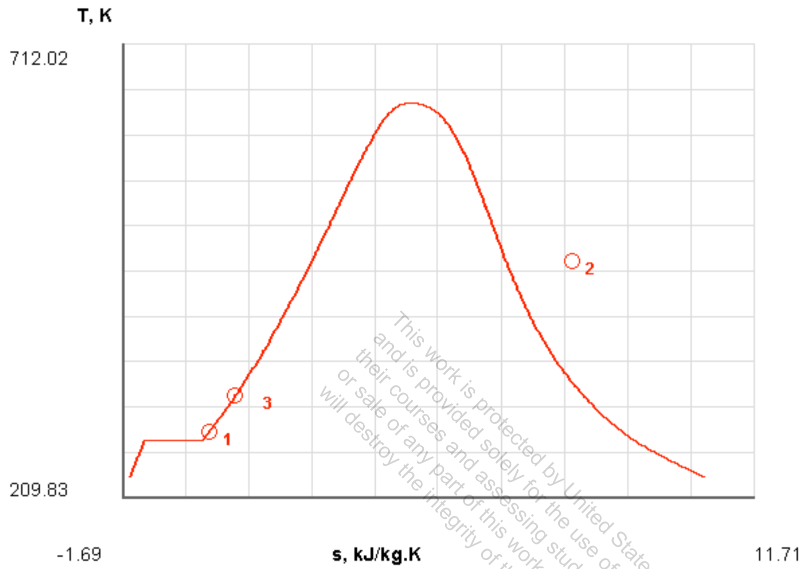
4-2-1 [OOY] Liquid water at 100 kPa and 10°C is heated by mixing it with an unknown amount of steam at 100 kPa and 200°C. Liquid water enters the chamber at 1 kg/s and the chamber loses heat at a rate of 500 kJ/min with the ambient conditions at 25°C. If the mixture leaves at 100 kPa and 50°C, determine (a) the mass flow rate of steam, and (b) the rate of entropy generation in the system and its immediate surroundings.

SOLUTION



State-1 (given p_1, T_1, $\dot{m}_1$):

$$h_1 = 42.01 \ \frac{\text{kJ}}{\text{kg}}; \qquad s_1 = 0.1510 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 2875.3 \ \frac{\text{kJ}}{\text{kg}}; \qquad s_2 = 7.8343 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given p_3, T_3):

$$h_3 = 209.33 \ \frac{\text{kJ}}{\text{kg}}; \qquad s_3 = 0.7038 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The energy balance for the steady flow system can be expressed as

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}_1 j_1 + \dot{m}_2 j_2 - \dot{m}_3 j_3 + \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0};$$

$$\Rightarrow \dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3 - \dot{Q}; \quad \text{(Since } \dot{W} = 0 \text{ and } \dot{m}_1 + \dot{m}_2 = \dot{m}_3\text{)}$$

$$\Rightarrow \dot{m}_1(h_1 + \mathrm{ke}_1) + \dot{m}_2(h_2 + \mathrm{ke}_2) = \dot{m}_1 + \dot{m}_2(h_3 + \mathrm{ke}_3) - \dot{Q};$$

$$\Rightarrow \dot{m}_1(h_1 - h_3) = \dot{m}_2(h_3 - h_2) - \dot{Q};$$

$$\Rightarrow \dot{m}_2 = \frac{\dot{m}_1\left(h_1 - h_3\right) + \dot{Q}}{h_2 - h_3};$$

$$\Rightarrow \dot{m}_2 = \frac{(1.0)(42.01 - 209.33) + (-8.333)}{(209.33 - 2875.3)};$$

$$\Rightarrow \dot{m}_2 = 0.066 \ \frac{\mathrm{kg}}{\mathrm{s}}$$

(b) The entropy equation, applied to the overall adiabatic system produces

$$\frac{d\cancel{S}^{\,0}}{\cancel{d}t} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \frac{\dot{Q}}{T_B} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_1 s_1 - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (1.066)(0.7038) - (0.066)(7.8343) - (1)(0.1510) - \frac{-8.33}{298};$$

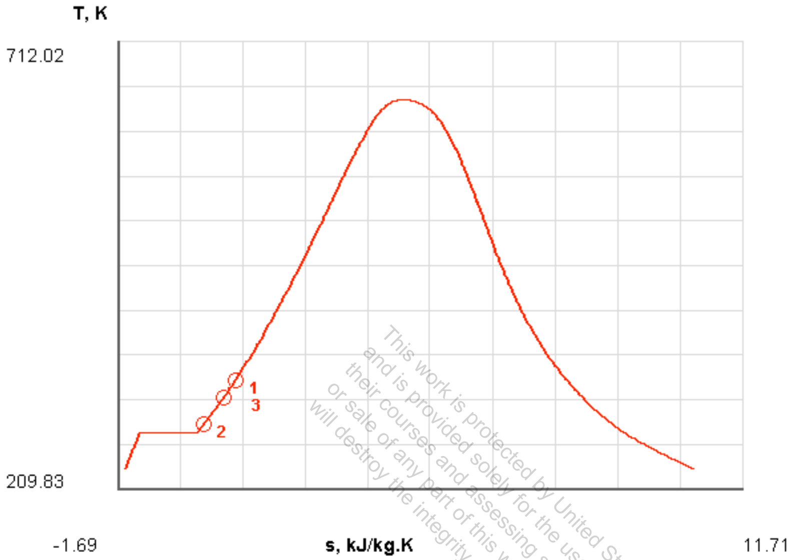
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.111 \ \frac{\mathrm{kW}}{\mathrm{K}}$$

TEST Solution:

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

4-2-2 [OOJ] Consider an ordinary shower where hot water at 60°C is mixed with cold water at 10°C. Steady stream of warm water at 40°C is desired. The hot water enters at 1 kg/s. Assume the heat losses from the mixing chamber to be negligible and the mixing to take place at a pressure of 140 kPa. Determine the mass flow rate of cold water.

SOLUTION



Use the steady state SL model for water, with two inlets and one exit.

Let state-1 and state-2 represent the inlet states and state-3 the exit state.

State-1 (given p_1, T_1)

State-2 (given p_2, T_2)

State-3 (given p_3, T_3)

The energy balance for the steady flow system can be expressed as

$\dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3$; (Since $\dot{Q} \cong 0$, $\dot{W} = 0$ and $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$)

$$\Rightarrow \dot{m}_1(h_1 + \text{ke}_1) + \dot{m}_2(h_2 + \text{ke}_2) = \dot{m}_1 + \dot{m}_2(h_3 + \text{ke}_3);$$

$$\Rightarrow \dot{m}_1(h_1 - h_2) = \dot{m}_2(h_3 - h_2);$$

$$\Rightarrow \dot{m}_1 c(T_1 - T_3) = \dot{m}_2 c(T_3 - T_2);$$

$$\Rightarrow \dot{m}_2 = \dot{m}_1 \frac{T_1 - T_3}{T_3 - T_2};$$

$$\Rightarrow \dot{m}_2 = 1.0\left(\frac{60-40}{40-10}\right);$$

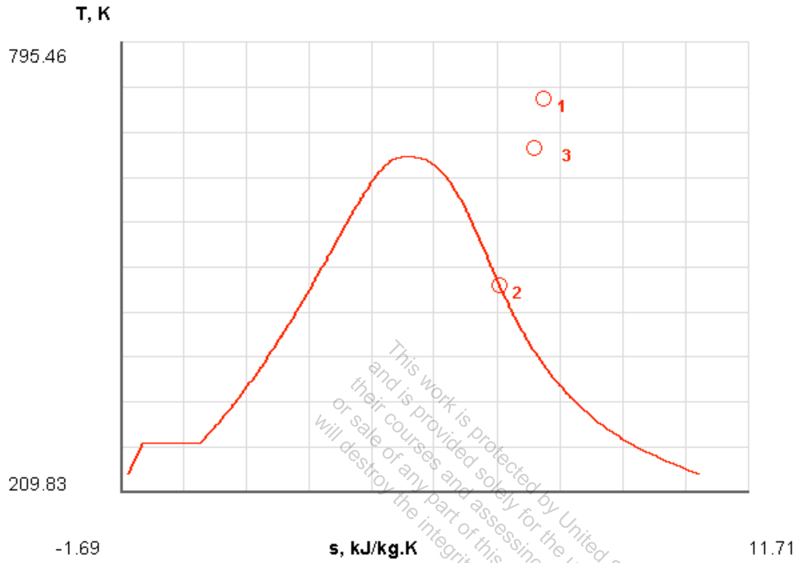
$$\Rightarrow \dot{m}_2 = 0.66\ \frac{\text{kg}}{\text{s}}$$

TEST Solution:

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

4-2-3 [OOF] Superheated steam with a state of 450°C, 1.8 MPa flows into an adiabatic mixing chamber at a rate of 0.3 kg/s. A second stream of dry, saturated water vapor at 1.8 MPa enters the chamber at a rate of 0.1 kg/s. There is no pressure loss in the system and the exit pressure is also 1.8 MPa. Determine (a) the mass flow rate ($\dot{m}_3$), (b) temperature (T_3) of the exit flow and (c) the entropy generation rate ($\dot{S}_{gen}$) during mixing.

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 and state-2 for the two inlets, state-3 for the actual exit.

State-1 (given p_1, T_1, $\dot{m}_1$):

$$h_1 = 3360.3 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.331 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_1$, x_2, $\dot{m}_2$):

$$T_2 = 207.14\,^\circ\text{C}; \quad h_2 = 2797.13 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 6.379 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_1$)

(a) $\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 0.3 + 0.1 = 0.4 \ \frac{\text{kg}}{\text{s}}$

(b) The energy balance for the steady flow system can be expressed as

$$\dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3; \quad (\text{Since } \dot{Q} \cong 0,\ \dot{W} = 0 \text{ and } \dot{m}_1 + \dot{m}_2 = \dot{m}_3)$$

$$\Rightarrow \dot{m}_1(h_1 + \text{ke}_1) + \dot{m}_2(h_2 + \text{ke}_2) = \dot{m}_3(h_3 + \text{ke}_3);$$

$$\Rightarrow \dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3;$$

$$\Rightarrow h_3 = \frac{\dot{m}_1 h_1 + \dot{m}_2 h_2}{\dot{m}_3};$$

$$\Rightarrow h_3 = \frac{1008.1 + 279.7}{0.4};$$

$$\Rightarrow h_3 = 3219.5\ \frac{\text{kJ}}{\text{kg}};$$

$$\therefore s_3 = 7.13\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad T_3 = 385.7^{\circ}\text{C}$$

(c) The entropy equation, applied to the overall adiabatic system produces

$$\cancel{\frac{dS}{dt}}^{\,0} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \cancel{\frac{\dot{Q}}{T_B}}^{\,0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_1 s_1;$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (0.4)(7.13) - (0.1)(6.379) - (0.3)(7.331);$$

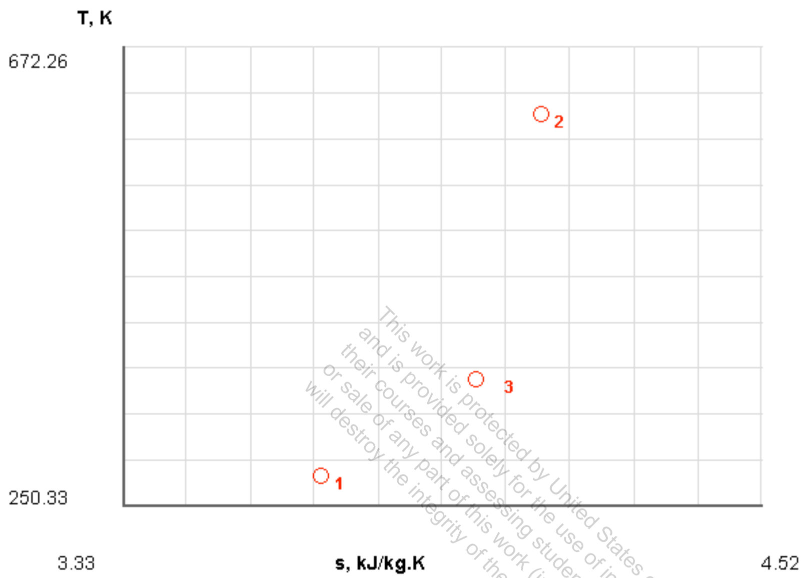
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.0148\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

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

4-2-4 [OOD] Argon gas flows steadily through a mixer nozzle device. At the first inlet, argon enters at 200 kPa, 5°C, 0.01 kg/s. At the second inlet, argon enters at 338°C, 200 kPa, 0.008 kg/s. At the exit, argon leaves at 94°C and 100 kPa. A stirrer transfers work into the device at a rate of 0.005 kW, the heat transfer rate leaving the device is 0.007 kW. Determine (a) velocity (V_3) of argon at exit, and (b) the entropy generation rate ($\dot{S}_{gen}$) during mixing.

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 and state-2 for the two inlets, state-3 for the actual exit.

State-1 (given $p_1, T_1, \dot{m}_1$)

State-2 (given $p_2, T_2, \dot{m}_2$)

State-3 (given p_3, T_3):

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 0.01 + 0.008 = 0.018 \ \frac{\text{kg}}{\text{s}};$$

(a) The energy balance for the steady flow system can be expressed as

$$\dot{m}_1(h_1 + \text{ke}_1) + \dot{m}_2(h_2 + \text{ke}_2) + \dot{Q} - \dot{W}_{\text{ext}} = \dot{m}_3(h_3 + \text{ke}_3);$$

$$\Rightarrow \dot{m}_1 h_1 + \dot{m}_2 h_2 + \dot{Q} - \dot{W}_{\text{ext}} = \dot{m}_3 h_3 + \text{ke}_3;$$

$$\Rightarrow \left(\frac{1}{2000}\right)\dot{m}_3 V_3^{\,2} = \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3 + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \left(\frac{1}{2000}\right)\dot{m}_3 V_3^{\,2} = -0.104 + 1.303 - 0.646 - 0.007 + 0.005;$$

$$\Rightarrow \left(\frac{1}{2000}\right)\dot{m}_3 V_3^{\,2} = 0.551 \text{ kW};$$

$$\Rightarrow V_3 = \sqrt{\frac{(2000)(0.551)}{(0.018)}};$$

$$\Rightarrow V_3 = 247.4 \frac{\text{m}}{\text{s}}$$

(b) The entropy equation, Eq. (2.13), applied to the overall adiabatic system produces

$$\frac{d\cancel{S}^{\,0}}{\cancel{dt}} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \frac{\dot{Q}}{T_B} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}_1 (s_3 - s_1) + \dot{m}_2 (s_3 - s_2) - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}_1 \left(c_p \ln\left(\frac{T_3}{T_1}\right) - R \ln\left(\frac{P_3}{P_1}\right)\right) + \dot{m}_2 \left(c_p \ln\left(\frac{T_3}{T_2}\right) - R \ln\left(\frac{P_3}{P_2}\right)\right) - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.01\left(0.5203 \ln\left(\frac{367}{278}\right) - 0.2081 \ln\left(\frac{100}{200}\right)\right) + 0.008\left(0.5203 \ln\left(\frac{367}{611}\right) - 0.2081 \ln\left(\frac{100}{200}\right)\right) - \left(\frac{-0.007}{298}\right);$$

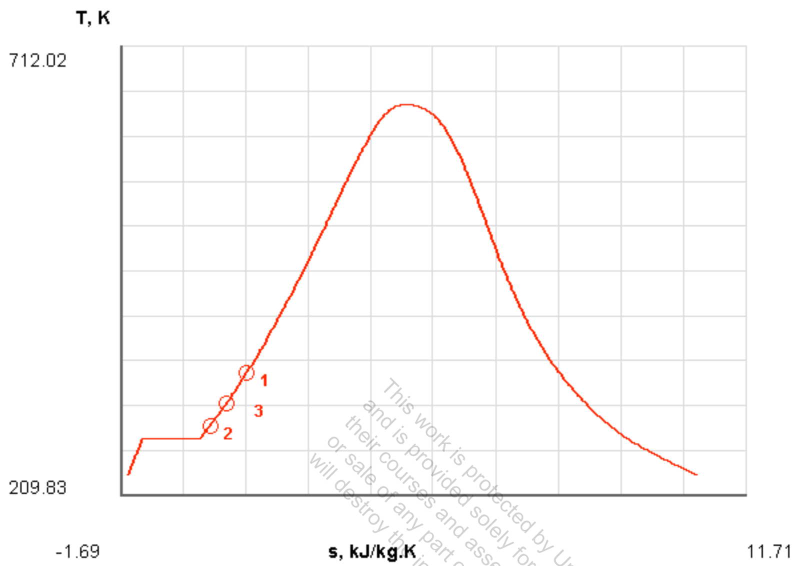
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.0019 \frac{\text{kW}}{\text{K}}$$

TEST Solution:

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

4-2-5 [OBR] A hot water stream at 75°C enters a mixing chamber with a mass flow rate of 1 kg/s where it is mixed with a stream of cold water at 15°C. If it is desired that the mixture leaves the chamber at 40°C, determine (a) the mass flow rate of cold water stream, and (b) the entropy generation rate during mixing. Assume all streams are at a pressure of 300 kPa.

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 and state-2 for the two inlets, state-3 for the actual exit.

State-1 (given $p_1,\ T_1,\ \dot{m}_1$):

$$h_1 = 314.19\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 1.0155\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 63.29\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 0.2244\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_1,\ T_3$):

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2;$$

$$h_3 = 167.86\ \frac{\text{kJ}}{\text{kg}};\qquad s_3 = 0.5724\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The energy balance for the steady flow system can be expressed as

$$\dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3;\qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W} = 0 \text{ and } \dot{m}_1 + \dot{m}_2 = \dot{m}_3)$$

$$\Rightarrow \dot{m}_1(h_1 + \mathrm{ke}_1) + \dot{m}_2(h_2 + \mathrm{ke}_2) = \dot{m}_3(h_3 + \mathrm{ke}_3);$$

$$\Rightarrow \dot{m}_1 h_1 + \dot{m}_2 h_2 = \left(\dot{m}_1 + \dot{m}_2\right) h_3;$$

$$\Rightarrow \dot{m}_2 = \frac{\dot{m}_1\left(h_3 - h_1\right)}{h_2 - h_3};$$

$$\Rightarrow \dot{m}_2 = \frac{167.86 - 314.19}{63.29 - 167.86};$$

$$\Rightarrow \dot{m}_2 = 1.39\ \frac{\mathrm{kg}}{\mathrm{s}}$$

(b) The entropy equation, applied to the overall adiabatic system produces

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \cancel{\frac{\dot{Q}}{T_B}}^{0} + \dot{S}_{\mathrm{gen,univ}};$$

$$\Rightarrow \dot{S}_{\mathrm{gen,univ}} = \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_1 s_1;$$

$$\Rightarrow \dot{S}_{\mathrm{gen,univ}} = (2.39)(0.5724) - (1.39)(0.2244) - (1)(1.0155);$$

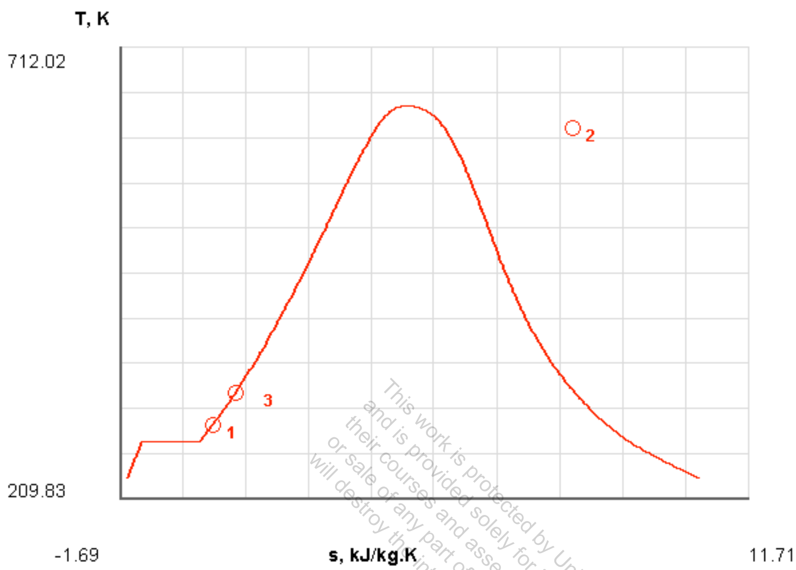
$$\Rightarrow \dot{S}_{\mathrm{gen,univ}} = 0.0406\ \frac{\mathrm{kW}}{\mathrm{K}}$$

TEST Solution:

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

4-2-6 [OOM] Liquid water at 250 kPa and 20°C is heated in a chamber by mixing with superheated steam at 250 kPa and 350°C. Cold water enters the chamber at a rate of 2 kg/s. If the mixture leaves the chamber at 55°C, determine (a) the mass flow rate of superheated steam, and (b) the entropy generation rate during mixing?

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 and state-2 for the two inlets, state-3 for the actual exit.

State-1 (given $p_1,\ T_1$):

$$h_1 = 84.20\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 0.296\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 3173.13\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 7.952\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_1,\ T_3, \dot{m}_3 = \dot{m}_1 + \dot{m}_2$):

$$h_3 = 230.46\ \frac{\text{kJ}}{\text{kg}};\qquad s_3 = 0.7679\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The energy balance for the steady flow system can be expressed as

$$\dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3;\qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W} = 0 \text{ and } \dot{m}_1 + \dot{m}_2 = \dot{m}_3)$$

$$\Rightarrow \dot{m}_1(h_1 + \text{ke}_1) + \dot{m}_2(h_2 + \text{ke}_2) = \dot{m}_1 + \dot{m}_2(h_3 + \text{ke}_3);$$

$$\Rightarrow \dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_1 + \dot{m}_2 h_3;$$

$$\Rightarrow \dot{m}_2 = \frac{h_1 - h_3}{h_3 - h_2}\dot{m}_1;$$

$$\Rightarrow \dot{m}_2 = \frac{84.20 - 230.46}{230.46 - 3173.13}(2);$$

$$\Rightarrow \dot{m}_2 = 0.099\ \frac{\text{kg}}{\text{s}}$$

(b) The entropy equation, applied to the overall adiabatic system produces

$$\cancel{\frac{dS}{dt}}^{\,0} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \cancel{\frac{\dot{Q}}{T_B}}^{\,0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_1 s_1;$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (2.099)(0.7679) - (0.099)(7.952) - (2)(0.296);$$

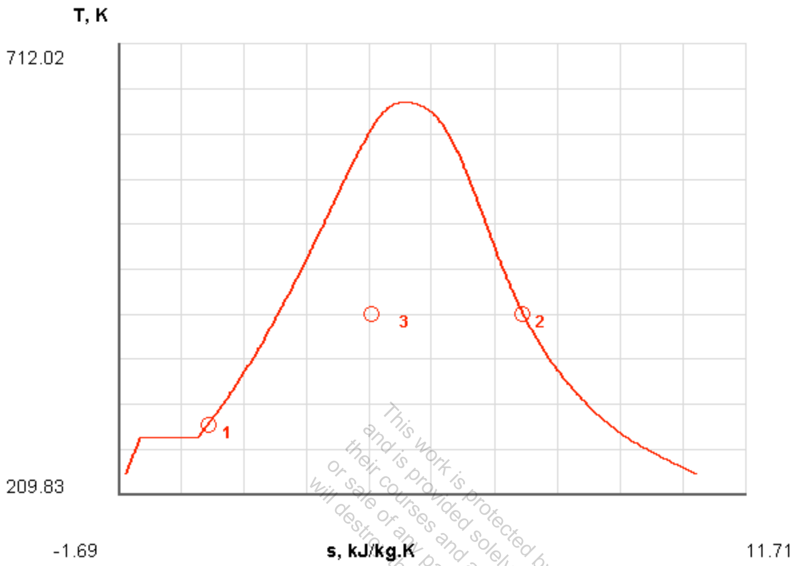
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.23\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

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

4-2-7 [OOW] Water at 350 kPa and 15°C is heated in a chamber by mixing with saturated water vapor at 350 kPa. Both streams enter the mixing chamber at a mass flow rate of 1 kg/s. Determine (a) temperature, (b) quality of exiting stream, and (c) the entropy generation rate during mixing.

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 and state-2 for the two inlets, state-3 for the actual exit.

State-1 (given p_1, T_1,):

$$h_1 = 62.982 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.2245 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_1$, x_2):

$$T_2 = 138.8^\circ\text{C}; \quad h_2 = 2732 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 6.9 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_1$, $\dot{m}_3 = \dot{m}_1 + \dot{m}_2$):

$$h_f = 584.26 \ \frac{\text{kJ}}{\text{kg}}; \quad h_{fg} = 2147.7 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 1.7274 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_{fg} = 5.2128 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $T_2 = 138.8^\circ\text{C}$

(b) The energy balance for the steady flow system can be expressed as

$$\dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3; \quad (\text{Since } \dot{Q} \cong 0,\ \dot{W} = 0 \text{ and } \dot{m}_1 + \dot{m}_2 = \dot{m}_3)$$

$$\Rightarrow \dot{m}_1(h_1 + \text{ke}_1) + \dot{m}_2(h_2 + \text{ke}_2) = \dot{m}_1 + \dot{m}_2(h_3 + \text{ke}_3);$$

$$\Rightarrow h_1 + h_2 = 2h_3;$$

$$\Rightarrow h_3 = \frac{h_1 + h_2}{2};$$

$$\Rightarrow h_3 = \frac{62.982 + 2732}{2};$$

$$\Rightarrow h_3 = 1397.49\ \frac{\text{kJ}}{\text{kg}};$$

$$x_3 = \frac{h_3 - h_f}{h_{fg}} = \frac{1397.49 - 584.26}{2147.7} = 0.3787$$

(c) $$s_3 = s_f + xs_{fg} = 1.7274 + (0.3787)(5.2128) = 3.7015\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

The entropy equation, applied to the overall adiabatic system produces

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \cancel{\frac{\dot{Q}}{T_B}}^{0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 2s_3 - s_2 - s_1;$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (2)(3.7015) - 0.2245 - 6.9405;$$

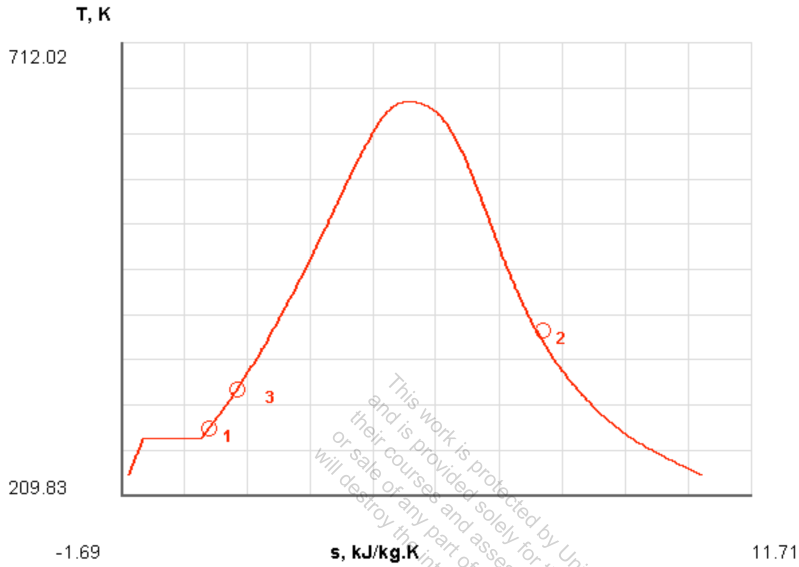
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.238\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

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

4-2-8 [OBB] Water at 150 kPa and 12°C is heated in a mixing chamber at a rate of 3 kg/s where it is mixed with steam entering at 150 kPa 120°C. The mixture leaves the chamber at 150 kPa and 55°C. Heat is lost to the surrounding air at a rate of 3 kW. (a) Determine the entropy generation rate during mixing. (b) Draw an entropy flow diagram for the chamber.

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 and state-2 for the two inlets, state-3 for the actual exit.

State-1 (given $p_1,\ T_1$):

$$h_1 = 50.55\ \frac{\text{kJ}}{\text{kg}}; \qquad s_1 = 0.181\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 2711.2\ \frac{\text{kJ}}{\text{kg}}; \qquad s_2 = 7.27\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_1,\ T_3,\ \dot{m}_3 = \dot{m}_1 + \dot{m}_2$):

$$h_3 = 230.37\ \frac{\text{kJ}}{\text{kg}}; \qquad s_3 = 0.768\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

The energy balance for the steady flow system can be expressed as

$$\dot{m}_1 j_1 + \dot{m}_2 j_2 = \dot{m}_3 j_3; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W} = 0 \text{ and } \dot{m}_1 + \dot{m}_2 = \dot{m}_3)$$

$$\Rightarrow \dot{m}_1(h_1) + \dot{m}_2(h_2) = (\dot{m}_1 + \dot{m}_2)h_3;$$

$$\Rightarrow \dot{m}_1(h_1 - h_3) = \dot{m}_2(h_3 - h_2);$$

$$\Rightarrow \dot{m}_2 = \frac{\dot{m}_1(h_1 - h_3)}{(h_3 - h_2)};$$

$$\Rightarrow \dot{m}_2 = \frac{3(50.55 - 230.37)}{230.37 - 2711.2};$$

$$\Rightarrow \dot{m}_2 = 0.217\ \frac{\text{kg}}{\text{s}};$$

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 3.217\ \frac{\text{kg}}{\text{s}};$$

(a) The entropy equation, applied to the overall adiabatic system produces

$$\cancel{\frac{dS}{dt}}^{\,0} = \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \cancel{\frac{\dot{Q}}{T_B}}^{\,0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_1 s_1;$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (3.217)(0.768) - (0.217)(7.27) - (3)(0.181);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.35\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

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