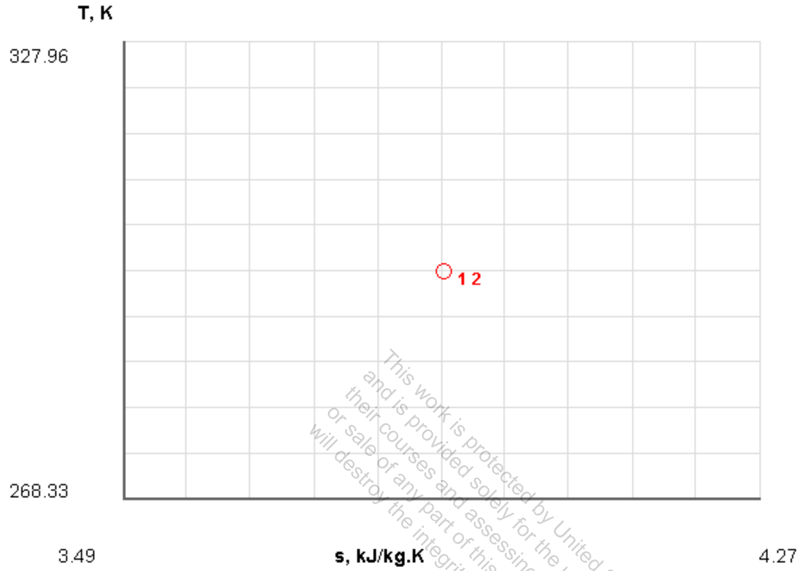
4-4-1 [OBN] An irrigation pump takes water at 25°C from a lake and discharges it through a nozzle located 20 m above the surface of the lake water with a velocity of 10 m/s. The exit area of the nozzle is 50 cm2. Assuming adiabatic and reversible flow through the system, determine the power input in kW. (b) ***What-if scenario:*** How would the answer change if the exit velocity was doubled?

SOLUTION



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

The specific heat $c = 4.184 \ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$;

Let state-1 represents the inlet state and state-2 the exit state.

State-1 (given p_1, T_1)

State-2 (given $p_2 = p_1,\ T_2 = T_1,\ \dot{m}_2 = \dot{m}_1,\ A_2, V_2$):

$$\dot{m}_2 = \rho V_2 A_2 = 997(10)(0.005) = 49.8 \ \frac{\text{kg}}{\text{s}};$$

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

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}(j_1 - j_2) + \cancel{\dot{Q}}^{0} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(\cancel{c(T_1 - T_2)}^{0} + \cancel{v(p_1 - p_2)}^{0} + \frac{V_1^2 - V_2^2}{2000} + \frac{g(z_1 - z_2)}{1000} \right);$$

$$\Rightarrow \dot{W}_P = \dot{m}\left(\frac{V_2^2 - V_1^2}{2000} + \frac{g(z_2 - z_1)}{1000} \right);$$

$$\Rightarrow \dot{W}_P = (49.8)\left(\frac{(10^2 - 0^2)}{2000} + \frac{9.81(20-0)}{1000} \right);$$

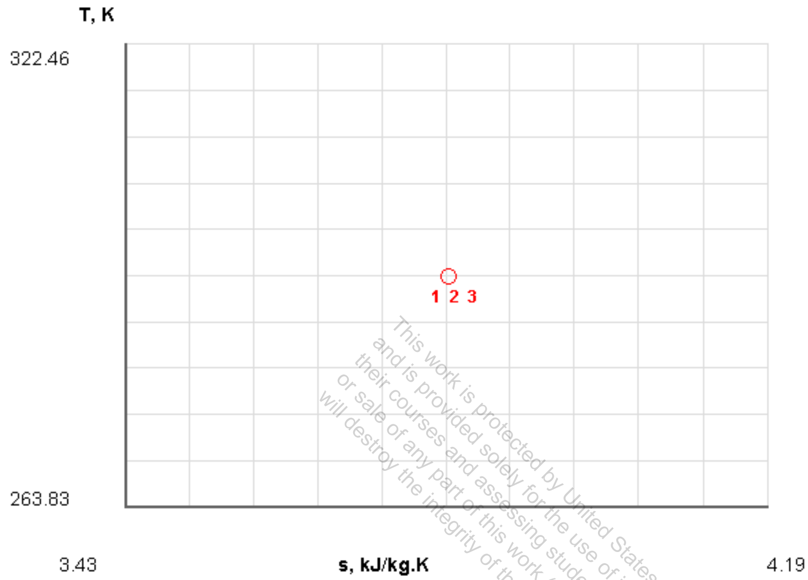
$$\Rightarrow \dot{W}_P = 12.26 \text{ kW}$$

TEST Solution and What-if Scenario:

Launch the SL single-flow 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.

4-4-2 [OBG] A water cannon sprays 50 L/min of liquid water at a velocity of 100 m/s horizontally out from a nozzle. It is driven by a pump that receives the water from a tank at 20oC, 100 kPa. There is no change in elevation between the surface of the water in the tank and the nozzle exit. Assuming adiabatic and reversible flow throughout the system, determine (a) the nozzle exit area, (b) the power input to the pump, and (c) the pressure at the pump exit.

SOLUTION



Use the steady state SL model for water.

The specific heat $c = 4.184\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$;

State-1 (given $T_1,\ \dot{V}_1,\ V_1$):

$$\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{0.000833}{0.001} = 0.833\ \frac{\text{kg}}{\text{s}};$$

State-2 (given $p_2 = p_1,\ T_2 = T_1,\ \dot{m}_2 = \dot{m}_1$)

State-3 (given $T_3 = T_1,\ \dot{m}_3 = \dot{m}_1$)

(a) $A_1 = \dfrac{v_1 \dot{m}_1}{V_1} = \dfrac{(0.001)(0.833)}{100} = 8.33\times 10^{-6} = 8.33\ \text{mm}^2$

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

$$\frac{d\cancel{E}^{\,0}}{\cancel{dt}} = \dot{m}\left(j_2 - j_3\right) + \cancel{\dot{Q}}^{\,0} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(\cancel{c\left(T_2 - T_3\right)}^{\,0} + v\left(p_2 - p_3\right) + \cancel{\frac{V_2^{\,2} - V_3^{\,2}}{2000}}^{\,0} + \cancel{\frac{g\left(z_2 - z_3\right)}{1000}}^{\,0} \right);$$

$$\Rightarrow \dot{W}_P = \dot{m}\left(v\left(p_3 - p_2\right)\right);$$

$$\Rightarrow \dot{W}_P = (0.83)\left((0.001)(5100 - 100)\right);$$

$$\Rightarrow \dot{W}_P = 4.15 \text{ kW}$$

(c) The energy balance for the steady flow nozzle can be expressed as

$$\frac{d\cancel{E}^{\,0}}{\cancel{dt}} = \dot{m}\left(j_3 - j_1\right) + \cancel{\dot{Q}}^{\,0} - \cancel{\dot{W}_{\text{ext}}}^{\,0};$$

$$\Rightarrow 0 = \dot{m}\left(\cancel{c\left(T_3 - T_1\right)}^{\,0} + v\left(p_3 - p_1\right) + \frac{V_3^{\,2} - V_1^{\,2}}{2000} + \cancel{\frac{g\left(z_1 - z_2\right)}{1000}}^{\,0} \right);$$

$$\Rightarrow 0 = (0.83)\left((0.001)\left(p_3 - 100\right) + \frac{-(100)^2}{2000} \right);$$

$$\Rightarrow p_3 = 5100 \text{ kPa}$$

TEST Solution:

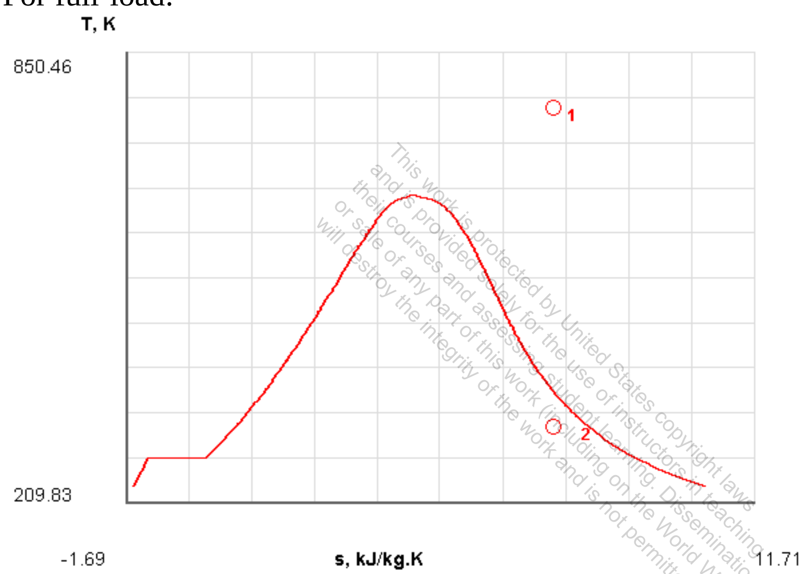
Launch the SL single-flow TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

4-4-3 [OBI] To operate a steam turbine in part-load power output, a throttling valve is used as shown in the figure below, which reduces the pressure of steam before it enters the turbine. The state of steam in the supply line remain fixed at 2 MPa, 500°C, and the turbine exhaust pressure remains fixed at 10 kPa. Assuming the turbine to be adiabatic and reversible, determine (a) the full-load specific work output in kJ/kg, (b) the pressure the steam must be throttled to for 75% of full-load output, and (c) the rate of entropy generation in the systems and their immediate surroundings.

SOLUTION

Treat this as two separate problems, the first asking for the full-load and the second for 75% of full load.

For full-load:



State-1 (given p_1, T_1):

$$h_1 = 3467.6 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.4316 \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

State-2 (given $p_2, s_2 = s_1$):

$$s_f = 0.6493 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}; \quad s_g = 8.1502 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{7.4316 - 0.6493}{8.1502 - 0.6493} = 0.904;$$

$$h_f = 191.83 \ \frac{\text{kJ}}{\text{kg}}; \quad h_g = 2584.7 \ \frac{\text{kJ}}{\text{kg}};$$

$$h_2 = h_f + x_2 h_{fg} = 191.83 + (0.904)(2584.7 - 191.83) = 2355 \ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy equation

$$\frac{d\cancel{E}^{0}}{\cancel{d}t} = \dot{m}\left(j_1 - j_2\right) + \cancel{\dot{Q}}^{0} - \dot{W}_T;$$

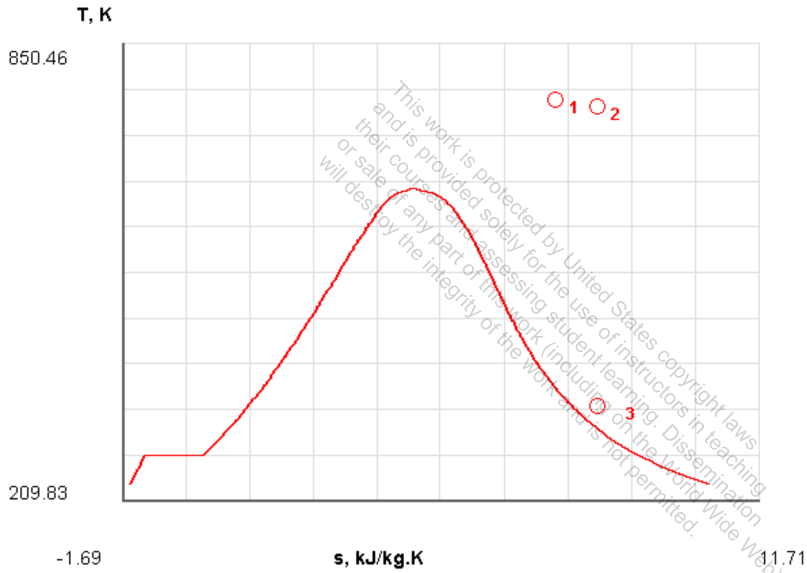
$$\Rightarrow \dot{W}_T = \dot{m}\left(j_1 - j_2\right);$$

$$\Rightarrow w_T = h_1 - h_2;$$

$$\Rightarrow w_T = 3467.6 - 2355;$$

$$\Rightarrow w_T = 1112.6\ \frac{\text{kJ}}{\text{kg}}$$

For 75% of full-load:



State-1 (given p_1, T_1):

$$h_1 = 3467.6\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.4316\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $h_2 = h_1$)

State-3 (given $p_3, s_3 = s_2$)

From the energy equation

$$h_2 - h_3 = w_T;$$

$$w_T = 0.75 w_{T,\text{orig}};$$

$$\Rightarrow h_2 - h_3 = 0.75 w_{T,\text{orig}};$$

$$\Rightarrow h_2 - h_3 = (0.75)(1112.6);$$

$$\Rightarrow h_2 - h_3 = 834.45;$$

Now state-3's specific enthalpy can be found.

$$h_3 = h_2 - 834.45;$$

$$\Rightarrow h_3 = 3467.6 - 834.45;$$

$$\Rightarrow h_3 = 2633.15;$$

Now state-3's specific entropy can be found, providing state-2's as well.

$$h_{g@10\text{kPa}} = 2584.7 \ \frac{\text{kJ}}{\text{kg}} \ \therefore \text{ superheated vapor}$$

$$s_3 = s_2 = 8.2904 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(b) From specific enthalpy and entropy, pressure of state-2 can be found as

$$p_2 = 305.9 \text{ kPa}$$

(c) Taking the composite system as a single system,

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}(s_1 - s_4) + \cancel{\frac{\dot{Q}}{T_B}}^{0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}(s_4 - s_1);$$

$$\Rightarrow s_{\text{gen,univ}} = 1.090 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

TEST Solution:

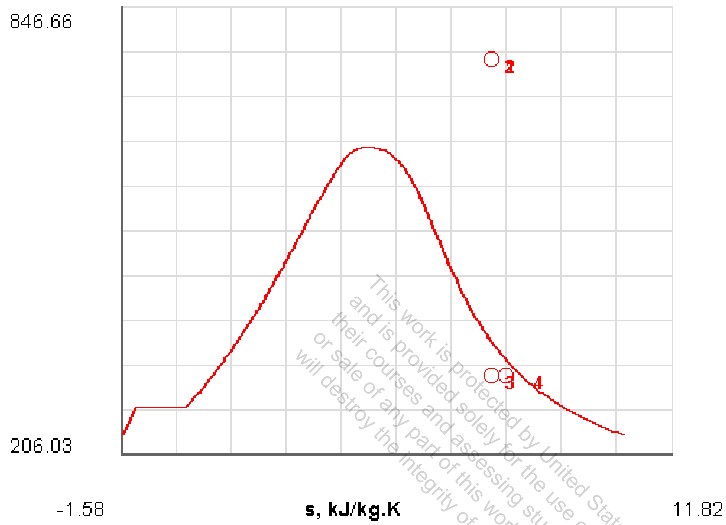
Launch the PC single-flow TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

4-4-4 [OBL] Repeat the above problem assuming the turbine to have an adiabatic efficiency of 90%.

SOLUTION

Treat this as two separate problems, the first asking for the full-load and the second for 75% of full load.

For full-load:



State-1 (given p_1, T_1):

$$h_1 = 3467.6 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.4316 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2, s_2 = s_1$):

$$s_f = 0.6493 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_g = 8.1502 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{7.4316 - 0.6493}{8.1502 - 0.6493} = 0.904;$$

$$h_f = 191.83 \ \frac{\text{kJ}}{\text{kg}}; \quad h_g = 2584.7 \ \frac{\text{kJ}}{\text{kg}};$$

$$h_2 = h_f + x_2 h_{fg} = 191.83 + (0.904)(2584.7 - 191.83) = 2355 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_2, h_3 = h_1 - (0.9)(h_1 - h_2) = 2466.6 \ \frac{\text{kJ}}{\text{kg}}$):

(d) From the energy equation

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}\left(j_1 - j_3\right) + \cancel{\dot{Q}}^{0} - \dot{W}_T;$$

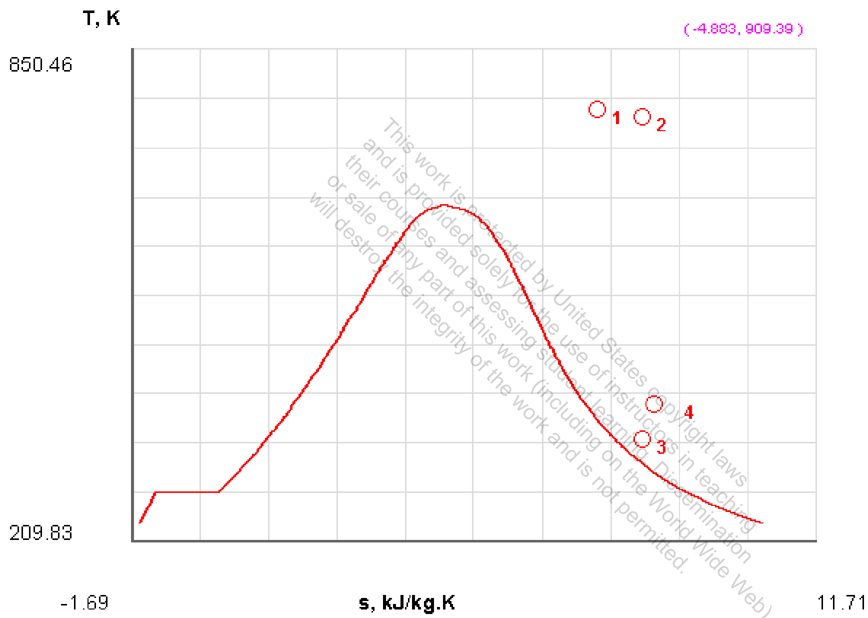
$$\Rightarrow \dot{W}_T = \dot{m}\left(j_1 - j_2\right);$$

$$\Rightarrow w_T = h_1 - h_3;$$

$$\Rightarrow w_T = 3467.6 - 2466.6;$$

$$\Rightarrow w_T = 1001 \ \frac{\text{kJ}}{\text{kg}}$$

For 75% of full-load:



State-1 (given p_1, T_1):

$$h_1 = 3467.6 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.4316 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $h_2 = h_1$)

State-4 (given p_4)

From the energy equation

$$h_2 - h_4 = 0.75 w_{T,\text{orig}} = 750.7$$

$$\Rightarrow h_4 = h_2 - 750.7 = h_1 - 750.7 = 2716$$

$$\Rightarrow h_2 - h_3 = 0.75 w_{T,\text{orig}};$$
$$\Rightarrow h_2 - h_3 = (0.75)(1112.6);$$
$$\Rightarrow h_2 - h_3 = 834.45;$$
$$s_4 = 8.522 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_4$)

$$h_3 = h_2 - (h_2 - h_4)/(0.9) = 2633 \ \frac{\text{kJ}}{\text{kg}}$$
$$\Rightarrow s_3 = 8.2904 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(e) From specific enthalpy and entropy $(s_2 = s_3)$, pressure of state-2 can be found as

$p_2 =$ 305.9 kPa

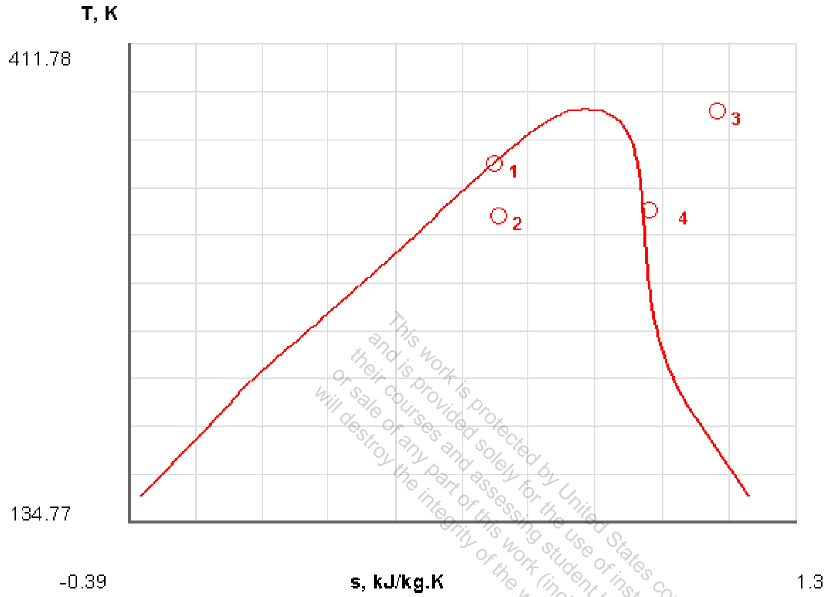
(f) $$\frac{d\cancel{S}}{\cancel{dt}}^{0} = \dot{m}(s_1 - s_2) + \frac{\cancel{\dot{Q}}}{\cancel{T_B}}^{0} + \dot{S}_{\text{gen,univ}};$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}(s_2 - s_1);$$
$$\Rightarrow s_{\text{gen,univ}} = 8.2904 - 7.4316;$$
$$\Rightarrow s_{\text{gen,univ}} = 0.8588 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

TEST Solution:

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

4-4-5 [OBZ] An insulated mixing chamber receives 2 kg/s R-134a at 1 MPa, 100°C in a line (state-3). Another line brings 1 kg/s of R-134a as saturated liquid at 70°C (state-1), which is throttled to a pressure of 1 MPa (state-2) before it enters the mixing chamber. At the exit (state-3) the pressure is 1 MPa. Determine (a) the temperature at the exit, (b) the entropy generated by the valve, (c) the entropy generated by the mixing chamber, and (d) the entropy generated in the system's universe.

SOLUTION



Let's consider the throttling device:

State-1 (given T_1, x_1, m_1):

$$h_1 = 155.66 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.5352 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2,\ h_2 = h_1,\ \dot{m}_2 = \dot{m}_1$):

$$T_2 = 312.5\ \text{K}; \quad s_2 = 0.5457 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Now let's solve for the mixing chamber:

State-3 (given $p_3,\ T_3,\ \dot{m}_3$):

$$h_3 = 334.36 \ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = 1.10 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-4 (given $p_4,\ \dot{m}_4 = \dot{m}_2 + \dot{m}_3$)

Using the energy equation we have

$$\dot{m}_2 j_2 + \dot{m}_3 j_3 = \dot{m}_4 j_4;$$

$$\Rightarrow \dot{m}_2(h_2) + \dot{m}_3(h_3) = (\dot{m}_2 + \dot{m}_3) h_4;$$

$$\Rightarrow h_4 = \frac{155.6 + (2)(334.4)}{3};$$

$$\Rightarrow h_4 = 274.8 \ \frac{\text{kJ}}{\text{kg}};$$

$$\therefore s_4 = 0.927 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \qquad T_4 = 316.3 \text{ K};$$

(a) $T_4 = 316.3 \text{ K} = 43.2^{\circ}\text{C}$

(b) Using the entropy equation we have

$$\cancelto{0}{\frac{dS}{dt}} = \dot{m}_1 s_1 - \dot{m}_2 s_2 + \cancelto{0}{\frac{\dot{Q}}{T_B}} + \dot{S}_{\text{gen}};$$

$$\Rightarrow \dot{S}_{\text{gen,valve}} = \dot{m}(s_2 - s_1);$$

$$\Rightarrow \dot{S}_{\text{gen,valve}} = (0.546 - 0.535);$$

$$\Rightarrow \dot{S}_{\text{gen,valve}} = 0.011 \ \frac{\text{kW}}{\text{K}}$$

(c) Using the entropy equation we have

$$\cancelto{0}{\frac{dS}{dt}} = \dot{m}_2 s_2 + \dot{m}_3 s_3 - \dot{m}_4 s_4 + \cancelto{0}{\frac{\dot{Q}}{T_B}} + \dot{S}_{\text{gen,mixing}};$$

$$\Rightarrow \dot{S}_{\text{gen,mixing}} = \dot{m}_4 s_4 - \dot{m}_2 s_2 - \dot{m}_3 s_3;$$

$$\Rightarrow \dot{S}_{\text{gen,mixing}} = (3)(0.927) - 0.546 - (2)(1.10);$$

$$\Rightarrow \dot{S}_{\text{gen,mixing}} = 0.035 \ \frac{\text{kW}}{\text{K}}$$

(d) The entropy generated in the system's universe

$$\dot{S}_{\text{gen,univ}} = \dot{S}_{\text{gen,valve}} + \dot{S}_{\text{gen,mixing}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.035 + 0.011;$$

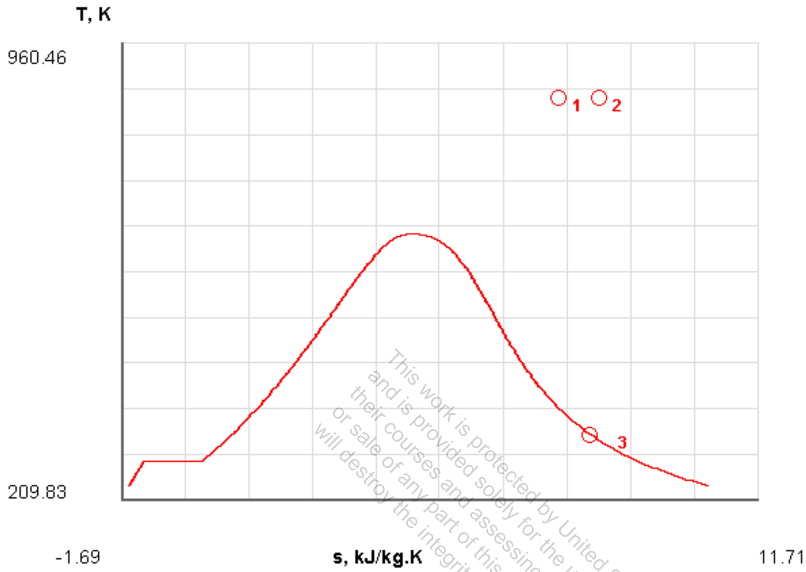
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.046 \ \frac{\text{kW}}{\text{K}}$$

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.

4-4-6 [OBK] An adiabatic steam turbine receives steam from two boilers. One flow is 5 kg/s at 3 MPa, 600oC, and the other flow is 5 kg/s at 0.5 MPa, 600°C. The exit flow is at 10 kPa with a quality of 100%. Neglecting any changes in ke, determine (a) the total power output in MW, (b) the rate of entropy generation in the turbine. (c) ***What-if scenario:*** How would the answers change if the turbine worked in a reversible manner?

SOLUTION



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

$$h_1 = 3682.3\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 7.5\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 3701.6\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 8.35\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3,\ x_3,\ \dot{m}_3 = \dot{m}_1 + \dot{m}_2$):

$$h_3 = 2584.6\ \frac{\text{kJ}}{\text{kg}};\qquad s_3 = 8.15\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) From the energy balance equation, we have

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

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

$$\Rightarrow \dot{W}_T = (5)(3682.3) + (5)(3701.6) - (10)(2584.6);$$

$$\Rightarrow \dot{W}_T = 11.07\ \text{MW}$$

(b) Using the entropy equation we have

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

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (10)(8.15) - (5)(7.5) - (5)(8.35);$$

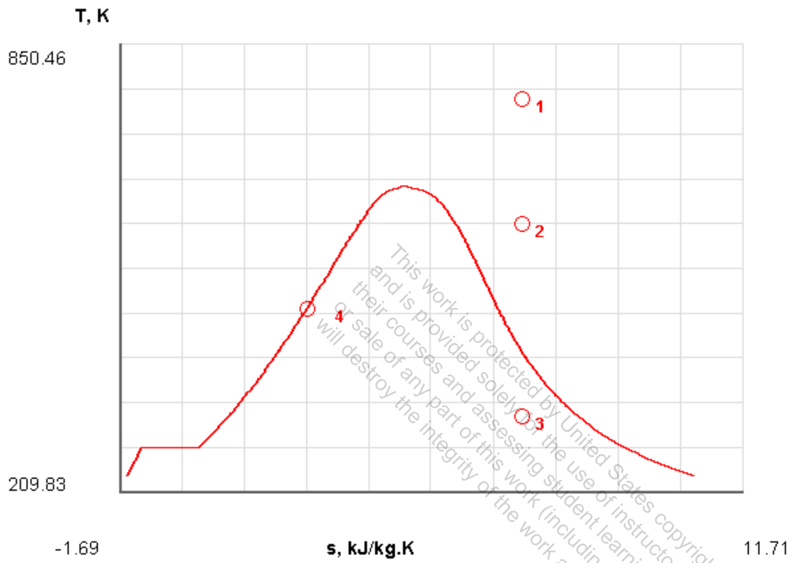
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 2.2\ \frac{\text{kW}}{\text{K}}$$

TEST Solution and What-if Scenario:

Launch the PC mixing multi-flow 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.

4-4-7 [OBP] Steam is bled from a turbine to supply 2 MW of process heat in a chemical plant at 200 deg-C as shown in the schematic so that state 4 is saturated liquid water at 200 deg-C. At the turbine inlet (state-1) steam is at 5 MPa, 500 deg-C and at the turbine exit the pressure is 10 kPa. Determine (a) the quality of steam at the turbine exit, (b) the bleed pressure in MPa (assume no frictional losses), (c) the bleed rate, and (d) the mass flow rate at the turbine inlet if the power output is 2 MW. (e) ***What-if Scenario:*** What would the mass flow rate at state-1 be if the process heating demand went down to 1 MW?

SOLUTION



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

$$h_1 = 3433.7\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 6.9757\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_4,\ s_2 = s_1$):

$$T_2 = 320.7°\text{C};\qquad h_2 = 3081.1\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3,\ s_3 = s_1,\ \dot{m}_3 = \dot{m}_1 - \dot{m}_2$):

$$T_3 = 45.8°\text{C};\qquad h_3 = 2210.0\ \frac{\text{kJ}}{\text{kg}};\qquad s_f = 0.6493\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad s_{fg} = 7.5\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-4 (given $T_4,\ x_4,\ \dot{m}_4 = \dot{m}_2$):

$$p_4 = 1.553\ \text{MPa};\qquad h_4 = 852.5\ \frac{\text{kJ}}{\text{kg}};$$

(a) To find the quality of steam at the turbine exit

$$x_3 = \frac{s_3 - s_f}{s_{fg}};$$

$$\Rightarrow x_3 = \frac{6.9757 - 0.6493}{7.5};$$

$$\Rightarrow x_3 = 0.84$$

(b) $p_2 = p_4 = 1.553 \text{ MPa}$

(c) From an energy balance of the process heat

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}_2 h_2 - \dot{m}_4 h_4 + \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0};$$

$$\Rightarrow \dot{m}_2 = -\frac{\dot{Q}}{h_2 - h_4};$$

$$\Rightarrow \dot{m}_2 = -\frac{-2000}{3081.1 - 852.5};$$

$$\Rightarrow \dot{m}_2 = 0.897 \ \frac{\text{kg}}{\text{s}}$$

(d) From an energy balance of the turbine

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3 + \cancel{\dot{Q}}^{0} - \dot{W}_T;$$

$$\Rightarrow 0 = \dot{m}_1 h_1 - \dot{m}_2 h_2 - (\dot{m}_1 - \dot{m}_2) h_3 - \dot{W}_T;$$

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

$$\Rightarrow \dot{m}_1 = \frac{2000 + (0.897)(3081.1 - 2210.0)}{3433.7 - 2210.0};$$

$$\Rightarrow \dot{m}_1 = 2.27 \ \frac{\text{kg}}{\text{s}}$$

TEST Solution and What-if Scenario:

Launch the PC single-flow 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.