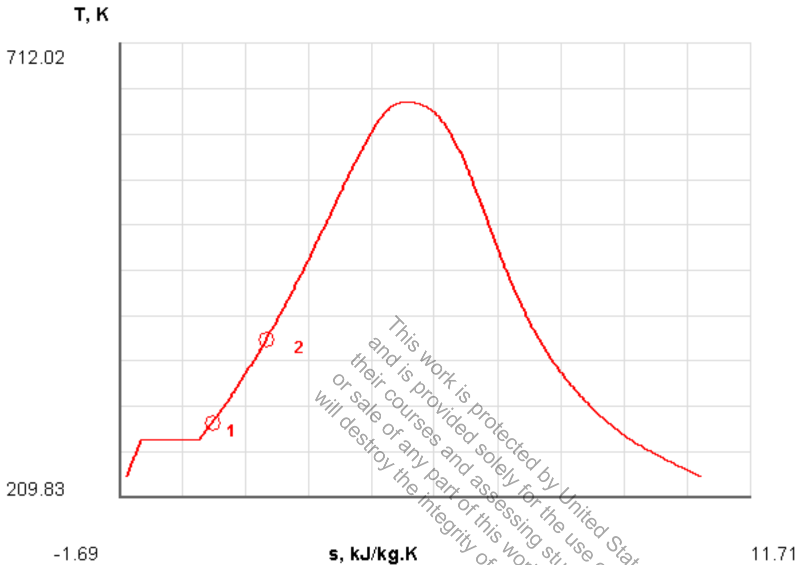
4-1-1 [JP] An insulated electric water heater operates at steady state at a constant pressure of 150 kPa, supplying hot water at a flow rate of 0.5 kg/s. If the inlet temperature is 20°C and the exit temperature is maximized without creating any vapor, determine (a) the electrical power consumption, (b) the temperature of the water leaving the heater, (c) the volume flow rate in L/min at the inlet, and (d) the volume flow rate in L/min at the exit. Use the PC model for water.

SOLUTION



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

State-1 (given p_1, T_1):

$$h_1 = 84.11 \ \frac{\text{kJ}}{\text{kg}}; \qquad v_1 = 0.0010 \ \frac{\text{m}^3}{\text{kg}};$$

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

$$T_2 = T_{\text{sat}} = 111.34^{\text{o}}\text{C};$$

$$h_2 = h_f = 467.00 \ \frac{\text{kJ}}{\text{kg}};$$

$$v_2 = 0.00105 \ \frac{\text{m}^3}{\text{kg}};$$

(a) From the energy balance equation, we have

$$\dot{W}_{\text{el}} = \dot{m}(j_1 - j_2);$$

$$\Rightarrow \dot{W}_{\text{el}} = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \ \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{\text{el}} = 0.5(84.11 - 467.00);$$

$$\Rightarrow \dot{W}_{\text{el}} = -191.44 \text{ kW} \therefore \dot{W}_{\text{el,in}} = 191.44 \text{ kW}$$

(b) $T_2 = 111.34^{\circ}\mathrm{C}$

(c) $\dot{V}_1 = \dot{m}v_1; \quad \Rightarrow \dot{V}_1 = (0.5)(0.0010); \quad \Rightarrow \dot{V}_1 = 5\times10^{-4}\ \frac{\mathrm{m^3}}{\mathrm{s}}; \quad \Rightarrow \dot{V}_1 = 30.06\ \frac{\mathrm{L}}{\mathrm{min}}$

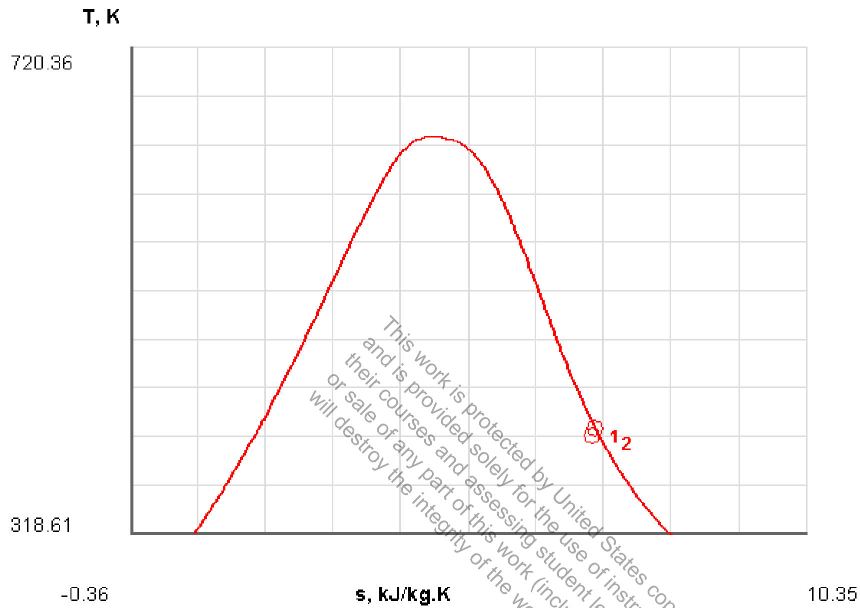
(d) $\dot{V}_2 = \dot{m}v_2; \quad \Rightarrow \dot{V}_2 = (0.5)0.00105; \quad \Rightarrow \dot{V}_2 = 5.3\times10^{-4}\ \frac{\mathrm{m^3}}{\mathrm{s}}; \quad \Rightarrow \dot{V}_2 = 31.59\ \frac{\mathrm{L}}{\mathrm{min}}$

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.

4-1-2 [JU] A steam heating system for a building 175 m high is supplied from a boiler 20 m below ground level. Dry, saturated steam is supplied from the boiler at 300 kPa, which reaches the top of the building at 250 kPa. Heal losses from the supply line to the surroundings is 50 kJ/kg. Determine (a) the quality of steam at the 175 m elevation. Neglect any change in ke. (b) ***What-if scenario:*** How would the answer change if the change in pe was neglected in the analysis?

SOLUTION



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

State-1 (given p_1, x_1, z_1):

$$h_1 = 2724.9 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given p_2, z_2):

$$T_{\text{sat}} = 127.41^{\circ}\text{C}; \quad h_f = 535.35 \ \frac{\text{kJ}}{\text{kg}}; \quad h_{fg} = 2181.2 \ \frac{\text{kJ}}{\text{kg}};$$

From the energy balance equation on the steady turbine, we have

$$-\dot{Q} = \dot{m}\left(j_1 - j_2\right);$$

$$\Rightarrow -\dot{Q} = \dot{m}(h_1 - h_2 + \frac{g(z_1\text{-}z_2)}{1000}); \quad (\text{since } \dot{W}_{\text{ext}} \cong 0, \text{and } \Delta\text{ke} \cong 0)$$

$$\Rightarrow 50 = \left(2724.9 - h_2 + \frac{9.8(-20-175)}{1000}\right);$$

$$\Rightarrow h_2 = 2672.98 \ \frac{\text{kJ}}{\text{kg}};$$

(a) Quality of steam at exit, is

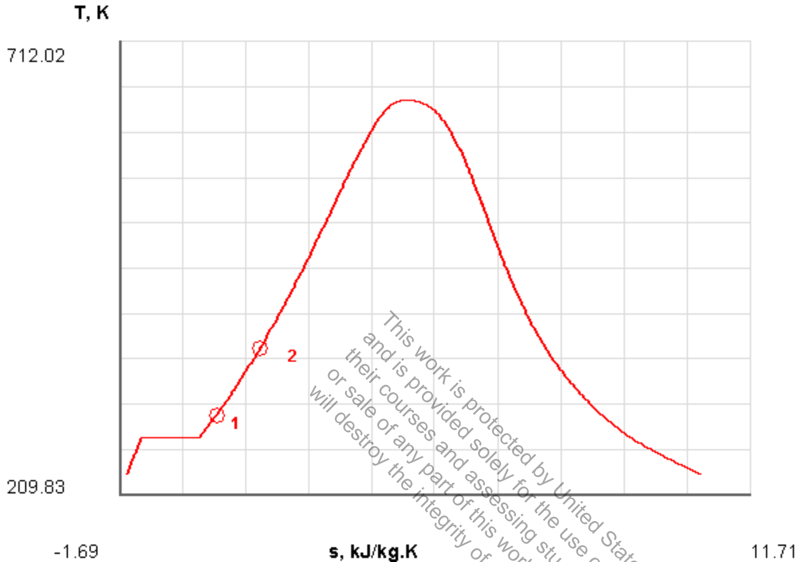
$$h_f + x_2 h_{fg} = h_2; \qquad \Rightarrow x_2 = \frac{h_2 - h_f}{h_{fg}}; \qquad \Rightarrow x_2 = \frac{2672.98 - 535.35}{2181.2}; \qquad \Rightarrow x_2 = 98\%$$

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.

4-1-3 [JX] Water flows steadily into a well-insulated electrical water heater (see Anim. 4-1-1) with a mass flow rate of 1 kg/s at 100 kPa and 25°C. Determine (a) the electrical power consumption if the water becomes saturated (liquid) at the exit. Assume no pressure loss, neglect changes in ke and pe, and use the SL model (use c_v = 4.184 kJ/kg-K for water). (b)***What-if Scenario:*** What would the power consumption be if the PC model were used instead?

SOLUTION



Given:

$$c_p = c_v = c = 4.184 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

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

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

State-2 (given $p_2 = p_1, x_2, \dot{m}_2 = \dot{m}_1$):

$T_{\text{sat@100kPa}} = 100°\text{C};$

(a) From the energy balance equation, we have

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

$$\Rightarrow \dot{W}_{el} = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{ and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{el} = \dot{m}\left[c\left(T_1 - T_2\right) + v\cancel{\left(p_1 - p_2\right)}^{0}\right];$$

$$\Rightarrow \dot{W}_{el} = (1)(4.184)(25 - 100);$$

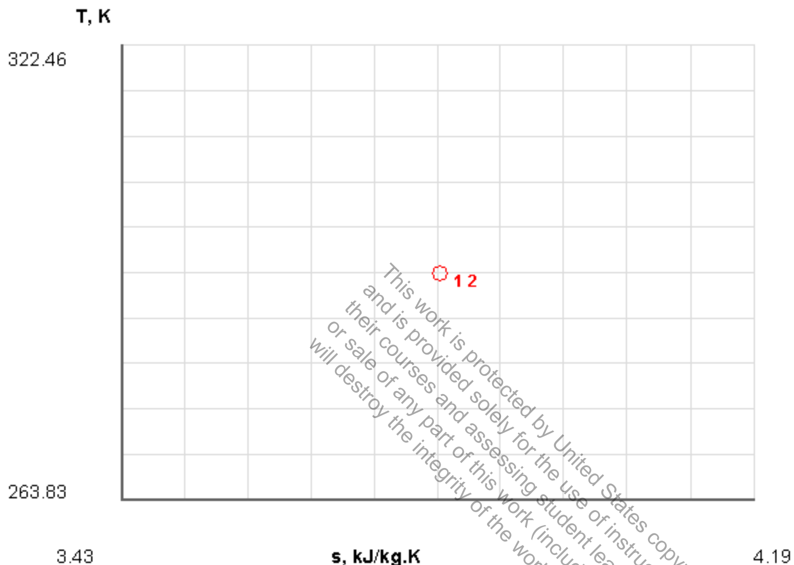
$$\Rightarrow \dot{W}_{el} = -313.8 \text{ kW} \therefore \dot{W}_{el,in} = 313.8 \text{ kW}$$

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.

4-1-4 [JD] Water flows steadily down an insulated vertical pipe (of constant diameter). The following conditions are given at the inlet and exit. Inlet (state-1): *T1* = 20 oC, *V1* = 10 m/s, *z1* = 10 m; Exit (state-2): *T<sub2</sub2* = 20 oC, *p<sub2</sub2* = 100 kPa, *z<sub2</sub2* = 0 m. Determine (a) the velocity at the exit (m/s), (b) the pressure at the inlet (in kPa). Use the SL model for water. Do not neglect ke and pe. ***What-if Scenario:*** What would be the answer in part c if the change in potential energy was neglected?

SOLUTION



Given:

$$c_p = c_v = c = 4.184\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_1 = v_2 = 0.001\frac{\text{m}^3}{\text{kg}};$$

$$\rho_1 = \rho_2 = 997\frac{\text{kg}}{\text{m}^3};$$

$$A_1 = A_2;$$

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

State-1 (given T_1, V_1, z_1)

State-2 (given $T_2, z_2, \dot{m}_2 = \dot{m}_1$)

(a) From the mass balance equation, we have

$$\frac{d\cancel{m}^{0}}{\cancel{dt}} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\dot{m} = \rho A V;$$

$$\Rightarrow \rho_1 A_1 V_1 = \rho_2 A_2 V_2;$$

$$\Rightarrow \cancel{\frac{\rho_1 A_1}{\rho_2 A_2}}^{1} V_1 = V_2;$$

$$\Rightarrow V_1 = V_2 = 10\ \frac{\text{m}}{\text{s}}$$

(b) From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}(j_1 - j_2); \quad (\text{since } \dot{W}_{\text{ext}} = \dot{Q} \cong 0)$$

$$\Rightarrow 0 = \Delta h + \Delta \text{ke} + \Delta \text{pe};$$

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

$$\Rightarrow p_1 = p_2 - \left[\frac{g}{v}\left(\frac{z_1 - z_2}{1000}\right)\right];$$

$$\Rightarrow p_1 = 100 - \left[\left(\frac{9.81}{0.001}\right)\left(\frac{10 - 0}{1000}\right)\right];$$

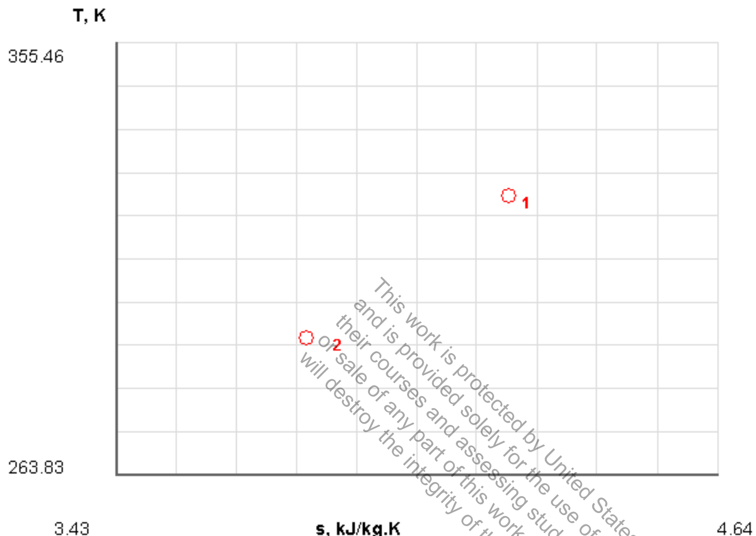
$$\Rightarrow p_1 = 1.9\ \text{kPa}$$

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.

4-1-5 [JQ] Water flows down steadily through a long 10-cm diameter vertical pipe. At the inlet: p = 300 kPa, T = 50oC, V = 5 m/s, and z = 125 m; At the exit: p = 1250 kPa, T = 20oC, and z = 10 m. If the surrounding ambient temperature is 10oC, use SL model (ρ = 997 kg/m3, cv = 4.184 kJ/kg.K) to determine the (a) velocity at the exit in m/s, (b) mass flow rate in kg/s, (c) the rate of heat transfer in kW, and (d) rate of entropy generation in the pipe's universe. (e) ***What-if Scenario:***What would be the answer in part c if the change in potential energy was neglected?

SOLUTION



Given:

$$c_p = c_v = c = \ 4.184 \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$v_1 = v_2 = 0.001 \frac{\text{m}^3}{\text{kg}};$$

$$\rho_1 = \rho_2 = 997 \frac{\text{kg}}{\text{m}^3};$$

$$A_1 = A_2;$$

$$D = 10 \text{ cm};$$

$$T_B = 10°\text{C};$$

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

State-1 (given p_1, T_1, V_1, z_1)

State-2 (given $p_2, T_2, z_2, \dot{m}_2 = \dot{m}_1$)

(a) From the mass balance equation, we have

$$\frac{d\cancel{m}^{0}}{\cancel{dt}} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\dot{m} = \rho A V;$$

$$\Rightarrow \rho_1 A_1 V_1 = \rho_2 A_2 V_2;$$

$$\Rightarrow \cancel{\frac{\rho_1 A_1}{\rho_2 A_2}}^{1} V_1 = V_2;$$

$$\Rightarrow V_1 = V_2 = 5\ \frac{\text{m}}{\text{s}}$$

(b) $\dot{m} = \rho A V;$

$$\Rightarrow \dot{m} = (997)\left(\pi \frac{0.1^2}{4}\right)(5);$$

$$\Rightarrow \dot{m} = 39.15\ \frac{\text{kg}}{\text{s}}$$

(c) From the energy balance equation, we have

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

$$\Rightarrow \dot{Q} = \dot{m}(j_2 - j_1); \quad (\text{since } \dot{W}_{\text{ext}} = 0)$$

$$\Rightarrow \dot{Q} = \dot{m}(\Delta h + \Delta \text{ke} + \Delta \text{pe});$$

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

$$\Rightarrow \dot{Q} = (39.15)\left[(4.184)(20-50) + (0.001)(1250-300) + \cancel{\frac{V_1^2 - V_2^2}{2000}}^{0} + (9.81)\frac{10-125}{1000}\right];$$

$$\Rightarrow \dot{Q} = -4921.1\ \text{kW}$$

(d) From the entropy balance equation, we have

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_2 - s_1\right) - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}c \ln\frac{T_2}{T_1} - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (39.15)(4.184)\ln\left(\frac{293}{323}\right) - \frac{-4921.1}{283};$$

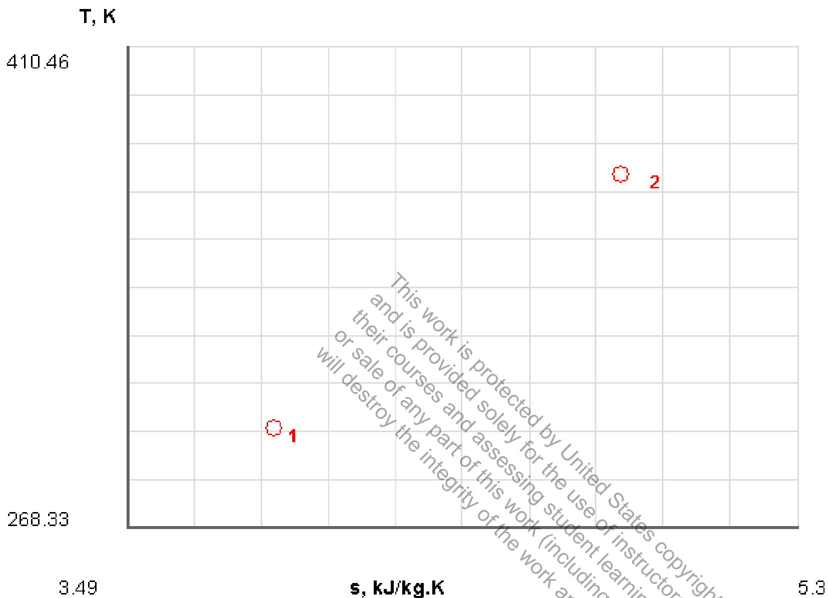
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 1.421\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-6 [JC] Water flows steadily into a well-insulated electrical water heater (see Anim. 4-1-1) with a mass flow rate of 1 kg/s at 100 kPa, 25oC. Determine (a) the rate of entropy generation in the water heater's universe if the water becomes saturated (liquid) at the exit. Assume no pressure loss, neglect changes in *ke* and *pe*, and use the SL model (use *cv* = 4.184 kJ/kg.K for water). The ambient atmospheric conditions are 100 kPa and 20oC. (b) ***What-if Scenario:*** What would the entropy generation rate be if the PC model were used instead?

SOLUTION



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

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

State-2 (given $p_2 = p_1$, x_2, $\dot{m}_2 = \dot{m}_1$):

$T_2 = T_{\text{sat@100kPa}} = 100°\text{C}$;

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

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

$$\Rightarrow 0 = \dot{m}\left(c_p \ln\frac{T_1}{T_2}\right) + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = \left[4.184\ln\left(\frac{298}{373}\right)\right] + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = -0.939 + \dot{S}_{\text{gen,univ}};$$

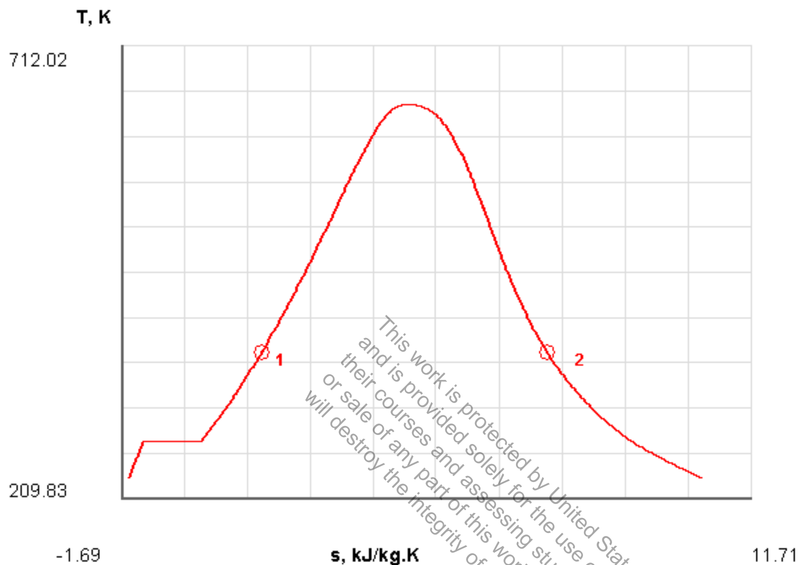
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.939\,\frac{\text{kW}}{\text{K}}$$

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.

4-1-7 [JV] Saturated liquid water flows steadily into a well-insulated electrical water heater (see Anim. 4-1-1) with a mass flow rate of 1 kg/s at 100 kPa. Determine (a) the electrical power consumption, and (b) the rate of entropy generation in the water heater's universe if the heater turns water into saturated vapor at the exit. Assume no pressure loss, neglect changes in ke and pe, and use the PC model. The ambient atmospheric conditions are 100 kPa and 20oC.

SOLUTION



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

State-1 (given $p_1, x_1, \dot{m}_1$):

$T_1 = T_{\text{sat@100kPa}} = 100°\text{C};$

$h_1 = h_{f\text{@100kPa}} = 417.46 \ \frac{\text{kJ}}{\text{kg}};$

$s_1 = s_{f\text{@100kPa}} = 1.3026 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

State-2 (given $p_2 = p_1, x_2, \dot{m}_2 = \dot{m}_1$):

$T_2 = T_{\text{sat@100kPa}} = 100°\text{C};$

$h_2 = h_{g\text{@100kPa}} = 2675.5 \ \frac{\text{kJ}}{\text{kg}};$

$s_2 = s_{g\text{@100kPa}} = 7.3594 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

(a) From the energy balance equation, we have

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

$$\Rightarrow \dot{W}_{\text{el}} = \dot{m}\left(h_1 - h_2\right); \quad (\text{since } \dot{Q} \cong 0, \text{ and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{\text{el}} = 417.46 - 2675.5;$$

$$\Rightarrow \dot{W}_{\text{el}} = -2258 \text{ kW} \therefore \dot{W}_{\text{el,in}} = 2258 \text{ kW}$$

(b) From the entropy balance equation, we have

$$\frac{d\cancel{S}^{0}}{\cancel{dt}} = \dot{m}\left(s_1 - s_2\right) + \frac{\cancel{\dot{Q}}^{0}}{T_B} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(7.3594 - 1.3026\right);$$

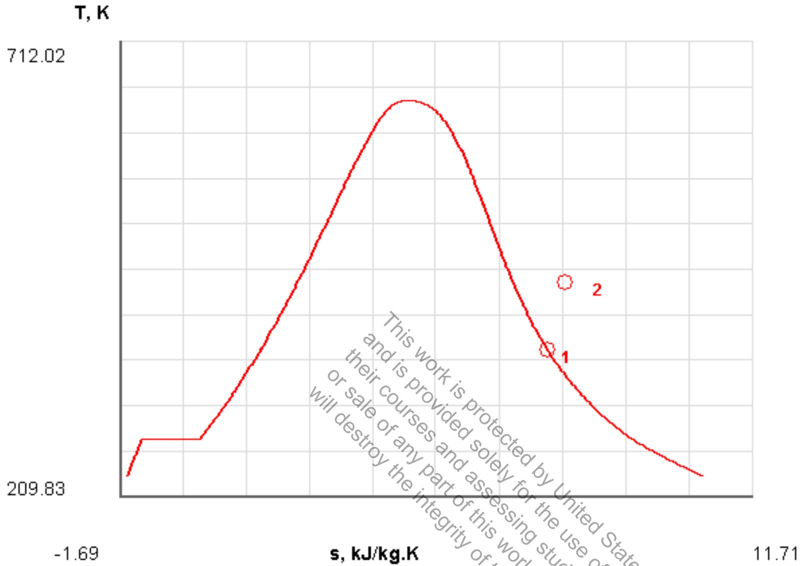
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 6.0568 \frac{\text{kW}}{\text{K}}$$

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.

4-1-8 [JT] Saturated vapor of water flows steadily into a well-insulated electrical super heater with a mass flow rate of 1 kg/s at 100 kPa. Determine (a) the electrical power consumption, and (b) the rate of entropy generation in the water heater's universe if the vapor is superheated to 175oC at the exit. Assume no pressure loss, neglect changes in ke and pe, and use the PC model. The ambient atmospheric conditions are 100 kPa and 20oC.

SOLUTION



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

State-1 (given $p_1, x_1, \dot{m}_1$):

$$T_1 = T_{\text{sat@100kPa}} = 100°\text{C};$$

$$h_1 = h_{g@100\text{kPa}} = 2675.5\ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_{g@100\text{kPa}} = 7.3594\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 2825.8\ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 7.7237\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) From the energy balance equation, we have

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

$$\Rightarrow \dot{W}_{el} = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{ and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{el} = 2675.5 - 2825.8;$$

$$\Rightarrow \dot{W}_{el} = -150.3 \text{ kW} \therefore \dot{W}_{el,in} = 150.3 \text{ kW}$$

(b) From the entropy balance equation, we have

$$\frac{d\cancel{S}^{\,0}}{\cancel{dt}} = \dot{m}(s_1 - s_2) + \frac{\cancel{\dot{Q}}^{\,0}}{T_B} + \dot{S}_{gen,univ};$$

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

$$\Rightarrow \dot{S}_{gen,univ} = (7.7237 - 7.3594);$$

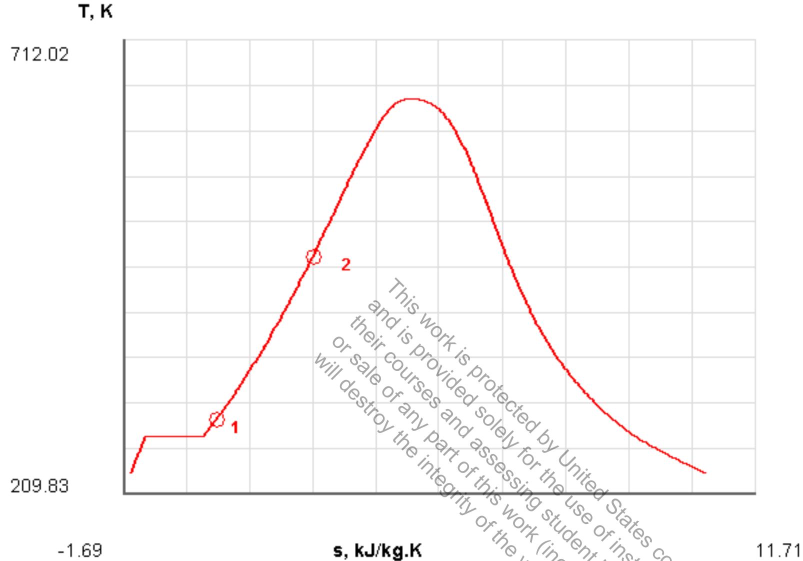
$$\Rightarrow \dot{S}_{gen,univ} = 0.3643 \ \frac{\text{kW}}{\text{K}}$$

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.

4-1-9 [JY] An insulated high-pressure electric water heater operates at steady state at a constant pressure of 10 MPa, supplying hot water at a mass flow rate of 10 kg/s. If the inlet temperature is 20oC and the exit temperature is 200°C, determine (a) the electrical power consumption, (b) the volume flow rate in L/min at the inlet,(c) the volume flow rate in L/min at the exit, and (d) the rate of entropy generation in the heater. Use the PC model for water, neglect any pressure drop in the heater, and also neglect any change in ke or pe.

SOLUTION



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

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

$T_{\text{sat@10MPa}} = 311.06°\text{C} \therefore$ subcooled liquid

$$h_1 = h_{f@20°\text{C}} = 83.96 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_{f@20°\text{C}} = 0.2966 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$v_1 = v_{f@20°\text{C}} = 0.00100 \ \frac{\text{m}^3}{\text{kg}};$$

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

$T_{\text{sat@10MPa}} = 311.06°\text{C} \therefore$ subcooled liquid

$$h_2 = h_{f\,@\,200°\text{C}} = 852.45\ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_{f\,@\,200°\text{C}} = 2.3309\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_2 = v_{f\,@\,200°\text{C}} = 0.00116\ \frac{\text{m}^3}{\text{kg}};$$

(a) From the energy balance equation, we have

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_2\right); \quad (\text{since } \dot{Q} \cong 0, \text{ and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{\text{ext}} = (10)(83.96 - 852.45);$$

$$\Rightarrow \dot{W}_{\text{ext}} = -7684.9\ \text{kW}$$

Therefore, the amount of power consumed is 7684.9 kW.

(b) $\dot{\mathcal{V}} = \dot{m}v;$

$$\Rightarrow \dot{\mathcal{V}} = (\dot{m})(v)(60)(1000); \quad \left[\left(\frac{\text{kg}}{\text{s}}\right)\left(\frac{\text{m}^3}{\text{kg}}\right)\left(\frac{\text{L}}{\text{m}^3}\right)\left(\frac{\text{s}}{\text{min}}\right) = \frac{\text{L}}{\text{min}}\right]$$

$$\Rightarrow \dot{\mathcal{V}}_1 = (10)(0.00100)(60)(1000);$$

$$\Rightarrow \dot{\mathcal{V}}_1 = 600\ \frac{\text{L}}{\text{min}}$$

(c) $\dot{\mathcal{V}} = \dot{m}v;$

$$\Rightarrow \dot{\mathcal{V}}_2 = (10)(0.00116)(60)(1000);$$

$$\Rightarrow \dot{\mathcal{V}}_2 = 696\ \frac{\text{L}}{\text{min}}$$

(d) From the entropy balance equation, we have

$$\cancel{\frac{dS}{dt}}^{\,0} = \dot{m}\left(s_1 - s_2\right) + \frac{\cancel{\dot{Q}}^{\,0}}{T_B} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (10)(2.3309 - 0.2966);$$

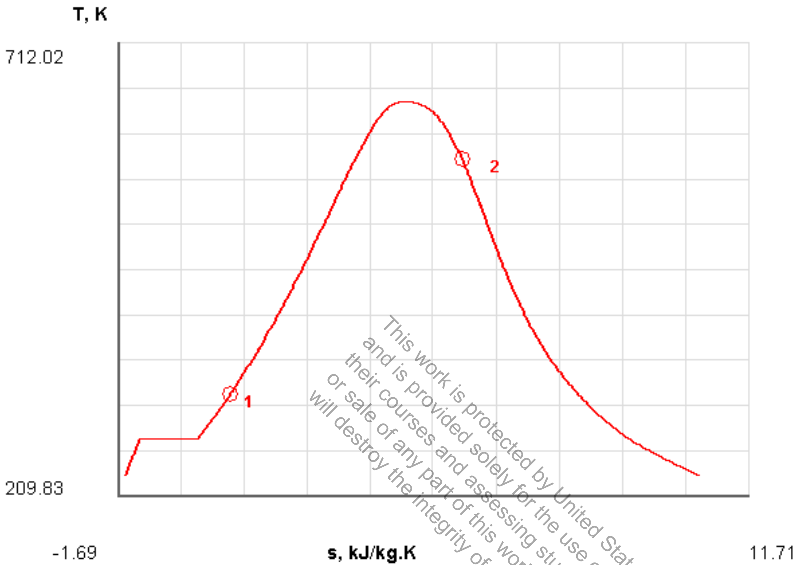
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 20.343\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-10 [JF] Water enters a boiler tube at 50 deg-C, 10 MPa at a rate of 10 kg/s. Heat is transferred from the hot surroundings in the boiler (created by combustion of coal) maintained at 1000 deg-C. Water exits the boiler as saturated vapor. Determine (a) the heating rate in MW, (b) the rate at which entropy is generated in the boiler tube's universe in kW/K. Assume steady state. Neglect any pressure drop in the boiler, and changes in ke and pe.

SOLUTION



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

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

$$T_{\text{sat@10MPa}} = 311.06°\text{C} \therefore \text{ subcooled liquid}$$

$$h_1 = h_{f\,@50°\text{C}} = 209.33\ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_{f\,@50°\text{C}} = 0.7038\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_1, x_2, \dot{m}_2 = \dot{m}_1$):

$$T_2 = T_{\text{sat@10MPa}} = 311.06°\text{C};$$

$$h_2 = h_{g\,@10\text{MPa}} = 2724.7\ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_{g\,@10\text{MPa}} = 5.6141\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) From the energy balance equation, we have

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

$$\Rightarrow \dot{Q} = \dot{m}\left(h_2 - h_1\right); \quad \left(\text{since } \dot{W}_{\text{ext}} = 0, \text{ and } \Delta\text{ke} = \Delta\text{pe} \cong 0\right)$$

$$\Rightarrow \dot{Q} = (10)(2724.7 - 209.33);$$

$$\Rightarrow \dot{Q} = 25153.7 \text{ kW} = 25.1 \text{ MW}$$

(b) From the entropy balance equation, we have

$$\frac{\cancel{dS}^{0}}{\cancel{dt}} = \dot{m}\left(s_1 - s_2\right) + \frac{\dot{Q}}{T_B} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_2 - s_1\right) - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (10)(5.6141 - 0.7038) - \frac{25100}{1273};$$

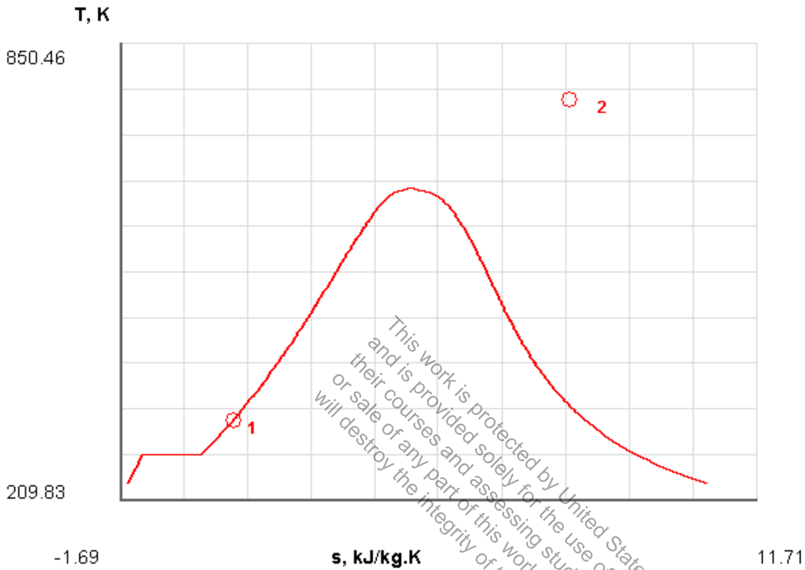
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 29.39 \frac{\text{kW}}{\text{K}}$$

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.

4-1-11 [JJ]A coal-fired boiler produces superheated steam steadily at 1 MPa, 500°C from the feed water which enters the boiler at 1 MPa, 50°C. For a flow rate of 10 kg/s, determine (a) the rate of heat transfer from the boiler to the water. (b) If the energetic efficiency of the boiler is 80% and the heating value of coal is 32.8 MJ/kg, determine the rate of fuel consumption in tons/hr. (c) ***What-if scenario:*** How would the answer in part (a) change if the boiler pressure was 3 MPa?

SOLUTION



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

State-1 (given p_1, T_1):

$$h_1 = 210.33 \ \frac{\text{kJ}}{\text{kg}}; \qquad v_1 = 0.00101 \ \frac{\text{m}^3}{\text{kg}};$$

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

$$h_2 = 3478.42 \ \frac{\text{kJ}}{\text{kg}}; \qquad v_2 = 0.35411 \ \frac{\text{m}^3}{\text{kg}};$$

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

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

$$\Rightarrow \dot{Q} = \dot{m}\left(h_2 - h_1\right); \qquad (\text{Since } \dot{W}_{\text{ext}} = 0, \Delta\text{ke} = \Delta\text{pe} \cong 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow \dot{Q} = 10\left(3478.42 - 210.33\right);$$

$$\Rightarrow \dot{Q} = 32.68 \text{ MW}$$

(b) The rate of fuel consumption is:

$$\eta = \frac{\dot{Q}_{\text{out}}}{\dot{Q}_{\text{in}}} = 0.8;$$

$$\Rightarrow \dot{Q}_{\text{in}} = \frac{\dot{Q}_{\text{out}}}{0.8};$$

$$\Rightarrow \dot{Q}_{\text{in}} = \frac{32.68}{0.8};$$

$$\Rightarrow \dot{Q}_{\text{in}} = 40.85 \text{ MW};$$

Given, heating value = 32.8 $\frac{\text{MJ}}{\text{kg}}$;

$$\dot{m}_F = \frac{\dot{Q}_{\text{in}}}{q_{\text{comb}}};$$

$$\Rightarrow \dot{m}_F = \frac{40.85}{32.8};$$

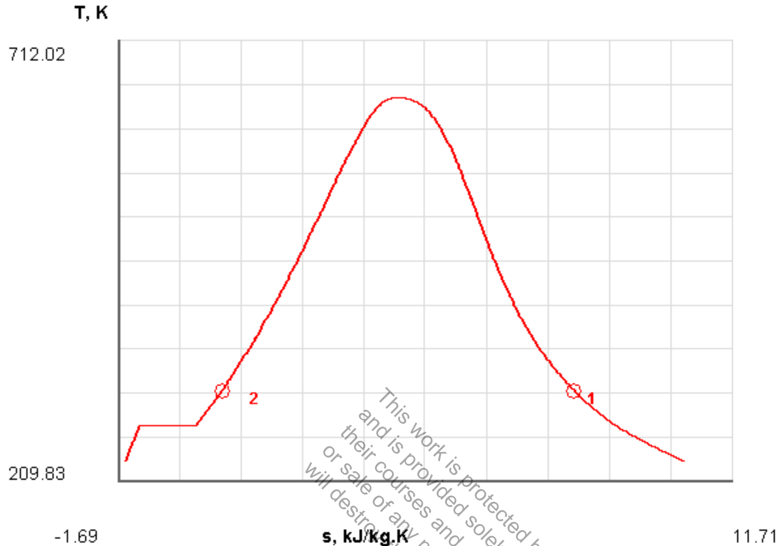
$$\Rightarrow \dot{m}_F = 1.245 \; \frac{\text{kg}}{\text{s}} = 4.482 \; \frac{\text{tons}}{\text{hr}}$$

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.

4-1-12 [JM] Saturated steam at 40oC is to be cooled to saturated liquid in a condenser. If the mass flow rate of the steam is 20 kg/s, (a) determine the rate of heat transfer in MW. Assume no pressure loss. (b) ***What-if Scenario:*** What would the rate of heat transfer be if the steam were at 90oC?

SOLUTION



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

State-1 (given $T_1, x_1, \dot{m}_1$):

$p_{\text{sat@40°C}}$ =7.384 kPa;

$$h_1 = h_{g@40°\text{C}} = 2574.3 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = p_1, x_2, \dot{m}_2 = \dot{m}_1$):

$T_2 = T_{\text{sat@}p_2} = 40°\text{C};$

$$h_2 = h_{f@40°\text{C}} = 167.57 \ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation, we have

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

$$\Rightarrow \dot{Q} = \dot{m}\left(h_2 - h_1\right); \quad (\text{since } \dot{W}_{\text{ext}} = 0, \text{ and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

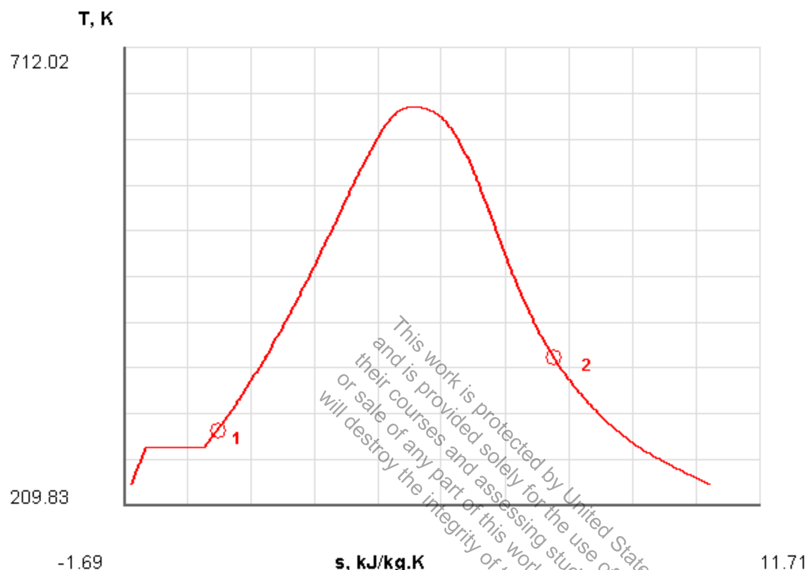
$$\Rightarrow \dot{Q} = (20)(167.57 - 2574.3);$$

$$\Rightarrow \dot{Q} = -48134.6 \text{ kW} = -48.1 \text{ MW}$$

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.

4-1-13 [WO] Water enters a boiler with a flow rate of 1 kg/s at 100 kPa, 20oC and leaves as saturated vapor. Assuming no pressure loss and neglecting changes in ke and pe, determine (a) the rate of heat transfer in kW. (b) If the heating value of gasoline is 44 MJ/kg, what is the consumption rate of gasoline in kg/s? Use PC model for H2O. ***What-if Scenario:*** What would the fuel consumption rate if the water were preheated by solar radiation to 90oC?

SOLUTION



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

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

$h_1 = 84.06 \ \dfrac{\text{kJ}}{\text{kg}};$

State-2 (given $p_2 = p_1, x_2, \dot{m}_2 = \dot{m}_1$):

$h_2 = 2675.4 \ \dfrac{\text{kJ}}{\text{kg}};$

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

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

$$\Rightarrow \dot{m}\left(h_2 - h_1\right) = \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0}; \quad (\text{Since } \Delta\text{ke} = \Delta\text{pe} \cong 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow \dot{Q} = (1)(2675.4 - 84.06);$$

$$\Rightarrow \dot{Q} = 2591.34 \ \text{kW}$$

(b) Given, heating value = 44 $\dfrac{\text{MJ}}{\text{kg}}$;

$$\dot{m}_F = \frac{\dot{Q}_{\text{in}}}{q_{\text{comb}}};$$

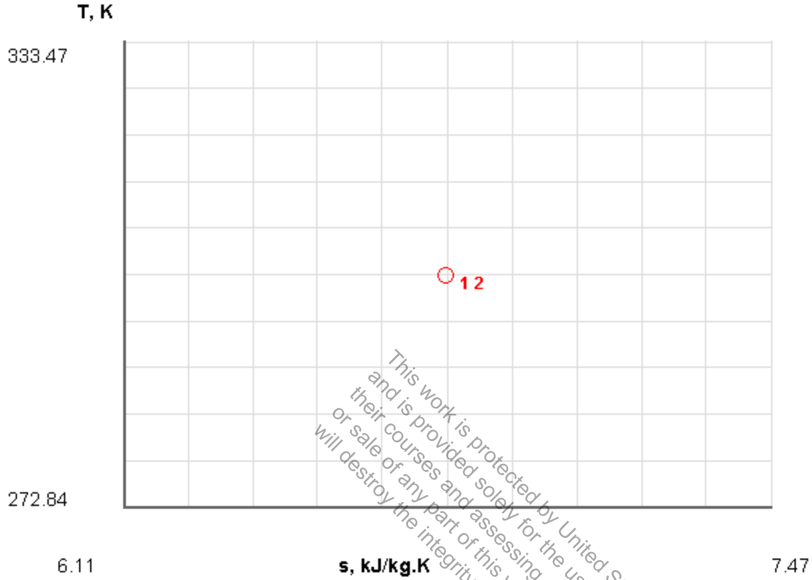
$$\Rightarrow \dot{m}_F = \frac{2591}{44000};$$

$$\Rightarrow \dot{m}_F = 0.06 \ \frac{\text{kg}}{\text{s}}$$

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.

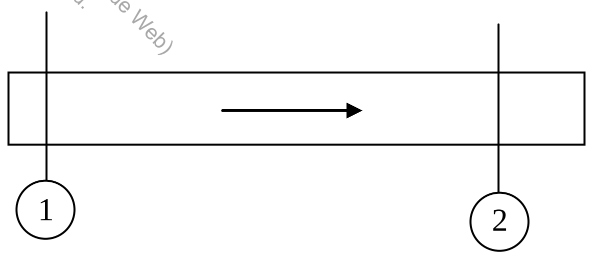
4-1-14 [JW] Air at a pressure of 150 kPa, a velocity of 0.2 m/s, and a temperature of 30oC flows steadily in a 10 cm-diameter duct. After a transition, the duct is exhausted uniformly through a rectangular slot 3 cm x 6 cm in cross section. (a) Determine the exit velocity. Assume incompressible flow and use the PG model for air. (b) ***What-if scenario:*** Would the answer be affected if the IG model was used?

SOLUTION



Steady state process with one inlet and one exit.

$$v_1 = \frac{RT_1}{P_1}; \quad \Rightarrow v_1 = \frac{(0.287)(303)}{150}; \quad \Rightarrow v_1 = 0.58\ \frac{\text{m}^3}{\text{kg}};$$



$$A_1 = \frac{\pi D^2}{4}; \quad \Rightarrow A_1 = \frac{\pi(0.1)^2}{4};$$
$$\Rightarrow A_1 = 0.00785\ \text{m}^2;$$

$$A_2 = l \text{ x } b; \quad \Rightarrow A_2 = (0.03)(0.06);$$
$$\Rightarrow A_2 = 0.0018\ \text{m}^2;$$

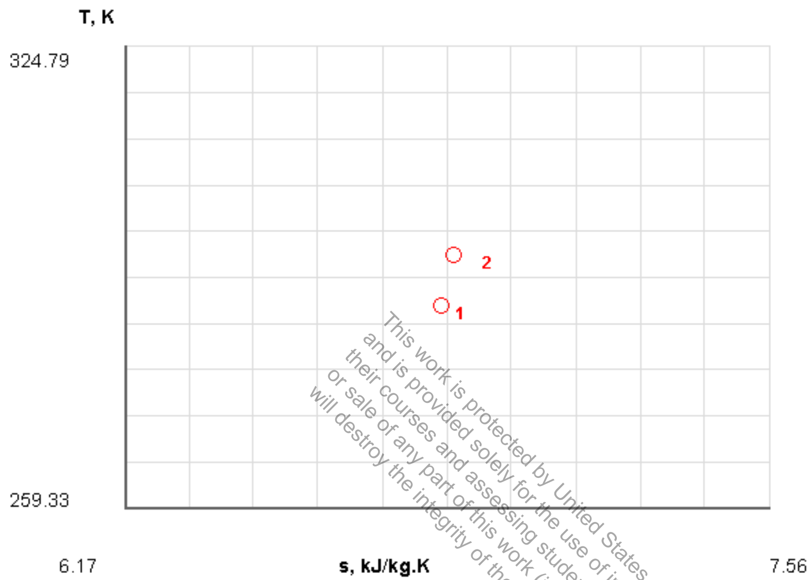
$$\dot{m} = \frac{A_1 V_1}{v_1}; \quad \Rightarrow \dot{m} = \frac{(0.00785)(0.2)}{0.58}; \quad \Rightarrow \dot{m} = 0.0027\ \frac{\text{kg}}{\text{s}};$$

(a) $$V_2 = \frac{\dot{m} v_2}{A_2}; \quad \Rightarrow V_2 = \frac{(0.0027)(0.58)}{0.0018}; \quad \Rightarrow V_2 = 0.87\ \frac{\text{m}}{\text{s}}$$

TEST Solution and What-if Scenario:
Launch the IG 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.

4-1-15 [WR] Air is heated in a duct as it flows over resistance wires. Consider a 20 kW electric heating system. Air enters the heating section at 100 kPa and 15oC with a volume flow rate of 140 m3/min. If heat is lost from air in the duct to the surroundings at a rate of 150 W, determine (a) the exit temperature of air, and (b) the energetic efficiency. Use the PG model for air and neglect the power consumed by the fan. (c) Draw an energy flow diagram for the system.

SOLUTION



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

State-1 (given $p_1, T_1, \dot{V}_1, A_1$):

$$\dot{m}_1 = \rho A V_1; \quad \Rightarrow \dot{m}_1 = \rho \dot{V}_1; \quad \Rightarrow \dot{m}_1 = (1.21)(2.33); \quad \Rightarrow \dot{m}_1 = 2.82 \ \frac{\text{kg}}{\text{s}};$$

State-2 (given $\dot{m}_2 = \dot{m}_1$)

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

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

$$\Rightarrow \dot{m}(h_2 - h_1) = \dot{m}c_p(T_2 - T_1) = \dot{Q} - \dot{W}_{\text{ext}}; \quad (\text{Since } \Delta\text{ke} = \Delta\text{pe} \cong 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow (2.82)(1.003)(T_2 - T_1) = .150 - (-20);$$

$$\Rightarrow T_2 = \frac{20.15}{2.83} + 288 = 295.12 \text{ K};$$

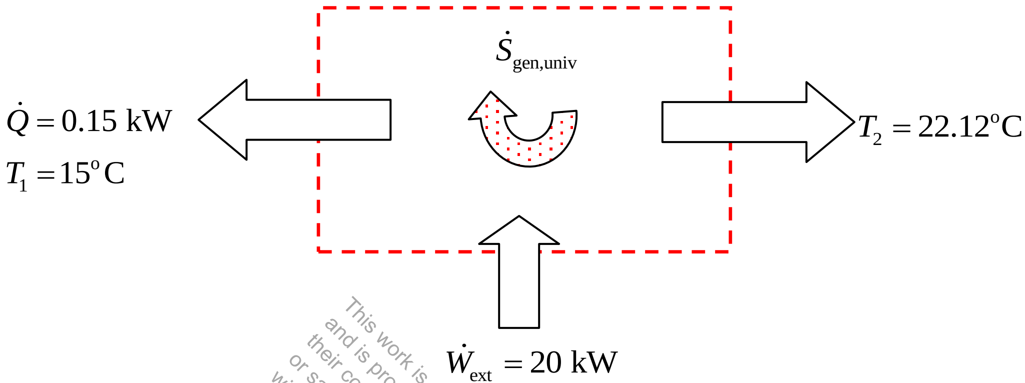
$$\Rightarrow T_2 = 22.12^{\circ}\text{C}$$

(b) The energetic efficiency

$$\eta_{\mathrm{I}} = \frac{\dot{m}\left(j_2 - j_1\right)}{-\dot{W}_{\mathrm{ext}}}; \quad \Rightarrow \eta_{\mathrm{I}} = \frac{\dot{Q} + \dot{W}_{\mathrm{ext}}}{-\dot{W}_{\mathrm{ext}}}; \quad \Rightarrow \eta_{\mathrm{I}} = \frac{(0.15) + (-20)}{-(20)};$$

$$\Rightarrow \eta_{\mathrm{I}} = \frac{19.85}{20}; \quad \Rightarrow \eta_{\mathrm{I}} = 99.25\ \%$$

(c) Energy flow diagram

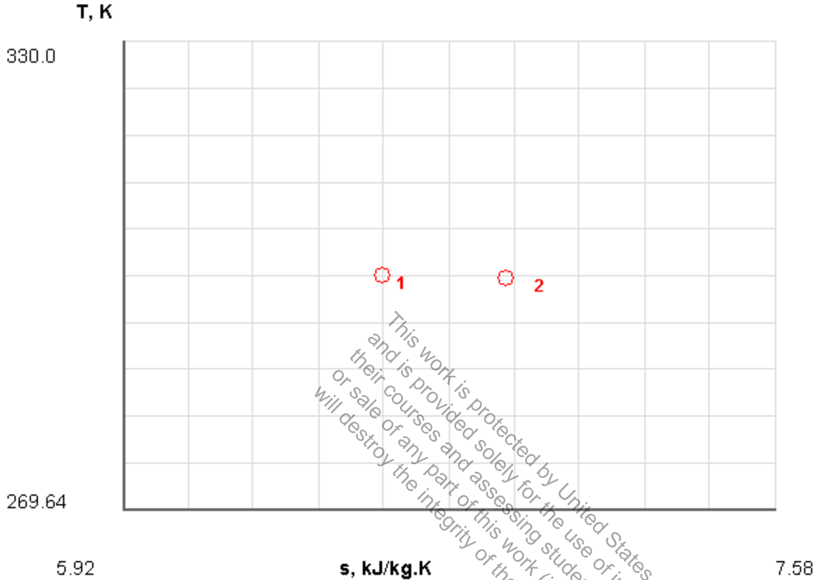


TEST Solution:

Launch the PG 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.

4-1-16 [WB] Air flows steadily through a long insulated duct with a cross-sectional area of 100 cm2. At the inlet, the conditions are 300 kPa, 300 K, and 10 m/s. At the exit, the pressure drops to 100 kPa due to frictional losses in the duct. Determine (a) the exit temperature and (b) the exit velocity. Use the PG model for air. (c) Explain why the temperature does not increase despite the presence of friction. (d) ***What-if scenario:*** Would the answers change significantly if the IG model was used for air? Why?

SOLUTION



The specific heat ratio of air $k = 1.4$. The constant pressure specific heat of air is

$$c_p = 1.00349 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

State-1 (given p_1, T_1)

State-2 (given p_2)

(a) The energy equation, for the system can be simplified as follows.

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}(h_1 - h_2) + \cancel{\dot{Q}}^{0} - \cancel{\dot{W}_{\text{ext}}}^{0};$$

$$\Rightarrow h_1 - h_2 = c_p(T_1 - T_2) = 0;$$

$$\Rightarrow T_2 = T_1 = 300 \text{ K}$$

(b) The mass flow equation, $\dot{m}_i = \dot{m}_e = \dot{m};$

$$\dot{m} = \frac{A_1 V_1}{v_1}; \qquad \Rightarrow \dot{m} = \frac{A_1 V_1 p_1}{RT_1}; \qquad \Rightarrow \dot{m} = \frac{\left(100 \times 10^{-4}\right)(10)(300)}{(0.28699)(300)};$$

$$\Rightarrow \dot{m} = 0.34844 \ \frac{\text{kg}}{\text{s}};$$

$$V_2 = \frac{\dot{m} v_2}{A_2}; \qquad \Rightarrow V_2 = \frac{\dot{m} R T_2}{A_2 p_2}; \qquad \Rightarrow V_2 = \frac{(0.34844)(0.28699)(300)}{\left(100 \times 10^{-4}\right)(100)};$$

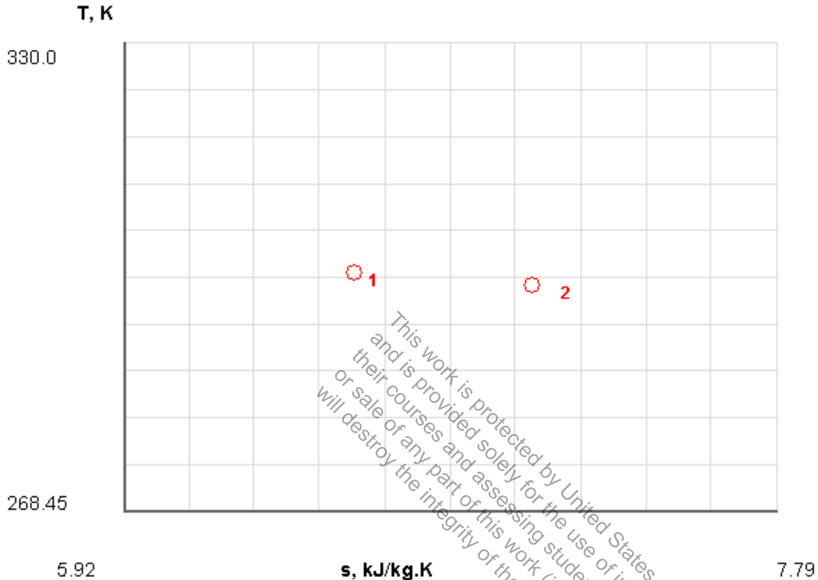
$$\Rightarrow V_2 = 29.96 \ \frac{\text{m}}{\text{s}}$$

TEST Solution:

Launch the PG 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.

4-1-17 [WS] Air flows steadily through a long insulated duct with a constant cross-sectional area of 100 cm2. At the inlet, the conditions are 300 kPa, 300 K and 10 m/s. At the exit, the pressure drops to 50 kPa due to frictional losses in the duct. Determine (a) the mass flow rate of air, (b) the exit temperature in K, and (c) the exit velocity in m/s. Use the PG model for air. (d) Determine the entropy generated due to thermodynamic friction in the duct.

SOLUTION



The specific heat ratio of air k =1.4. The constant pressure specific heat of air is

$$c_p = 1.00349 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

State-1 (given p_1, T_1, A_1)

State-2 (given p_2)

(a) $\dot{m} = \frac{A_1V_1}{v_1}; \quad \Rightarrow \dot{m} = \frac{A_1V_1p_1}{RT_1}; \quad \Rightarrow \dot{m} = \frac{(0.01)(10)(300)}{(0.28699)(300)}; \quad \Rightarrow \dot{m} = 0.348 \frac{\text{kg}}{\text{s}}$

(b) The energy equation, for the system can be simplified as follows.

$$\cancel{\frac{dE}{dt}}^0 = \dot{m}(h_1 - h_2) + \cancel{\dot{Q}}^0 - \cancel{\dot{W}_{\text{ext}}}^0;$$

$$\Rightarrow h_1 - h_2 = c_p(T_1 - T_2) = 0;$$

$$\Rightarrow T_2 = T_1 = 300 \text{ K}$$

(c) The mass flow equation, $\dot{m}_i = \dot{m}_e = \dot{m}$;

$$V_2 = \frac{\dot{m}v_2}{A_2}; \quad \Rightarrow V_2 = \frac{\dot{m}RT_2}{A_2 p_2}; \quad \Rightarrow V_2 = \frac{(0.34844)(0.28699)(300)}{(100\times10^{-4})(50)};$$

$$\Rightarrow V_2 = 59.92 \ \frac{\text{m}}{\text{s}}$$

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

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}(s_2 - s_1) + \frac{\cancel{\dot{Q}}^{0}}{T_B};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (0.348)(7.086 - 6.577);$$

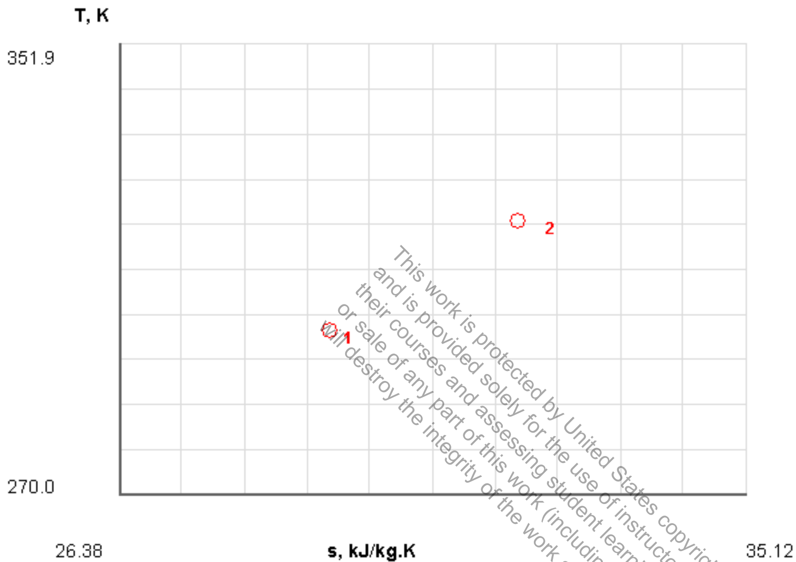
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.1771 \ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

Launch the PG 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.

4-1-18 [BET] Helium flows steadily through a long insulated duct with a constant cross-sectional area of 100 cm^2. At the inlet, the conditions are 300 kPa, 300 K and 10 m/s. A 5 kW internal electrical heater is used to raise the temperature of the gas. At the exit, the pressure drops to 100 kPa due to frictional losses in the duct. Determine (a) the exit velocity (V_2), and (b) the rate of entropy generation ($\dot{S}_{gen}$) in the system's universe. Use the PG model. (c) What-if Scenario: How would the answer in part (b) change if the heater were turned off? (assume the exit pressure to be 100 kPa).

SOLUTION



(a) State-1 (given p_1, T_1, A_1, V_1):

$$\rho_1 = \frac{p}{RT} = \frac{300}{(2.0785)(300)} = 0.4811 \ \frac{\text{kg}}{\text{m}^3};$$

$$\dot{m} = \rho A V = (0.4811)(0.01)(10) = 0.04811 \ \frac{\text{kg}}{\text{s}};$$

State-2 (given $p_2, A_2 = A_2, \dot{m}_2 = \dot{m}_1$)

From the mass balance equation

$$\dot{m}_2 = \dot{m}_1$$
$$\Rightarrow \rho_1 A_1 V_1 = \rho_2 A_2 V_2$$
$$\Rightarrow \left(\frac{p_1}{RT_1}\right) V_1 = \left(\frac{p_2}{RT_2}\right) V_2$$
$$\Rightarrow T_2 = T_1 \left(\frac{p_2}{p_1}\right)\left(\frac{V_2}{V_1}\right) = (300)\left(\frac{100}{300}\right)\left(\frac{V_2}{10}\right) = 10 V_2$$

From the energy balance equation

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

$$\Rightarrow 0 = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right) - \dot{W}_{\text{ext}};$$

$$\Rightarrow V_2^2 = V_1^2 - 2000\left(\frac{\dot{W}_{\text{ext}}}{\dot{m}} + h_2 - h_1\right) = 10^2 - 2000\left(\frac{-5}{0.04811} + 5.197\left(T_2 - T_1\right)\right);$$

Substituting the expression for T_2

$$V_2^2 = 10^2 - 2000\left(-103.93 + 5.197\left(10V_2 - 300\right)\right);$$

Solving the quadratic equation we obtain:

$$V_2 = 31.99 \text{ m/s}$$

(b) The entropy equation produces

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_2 - s_1\right) = \dot{m}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.1259\ \frac{\text{kW}}{\text{K}}$$

(c) If the heater is turned off, the entropy equation produces

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_2 - s_1\right) = \dot{m}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right);$$

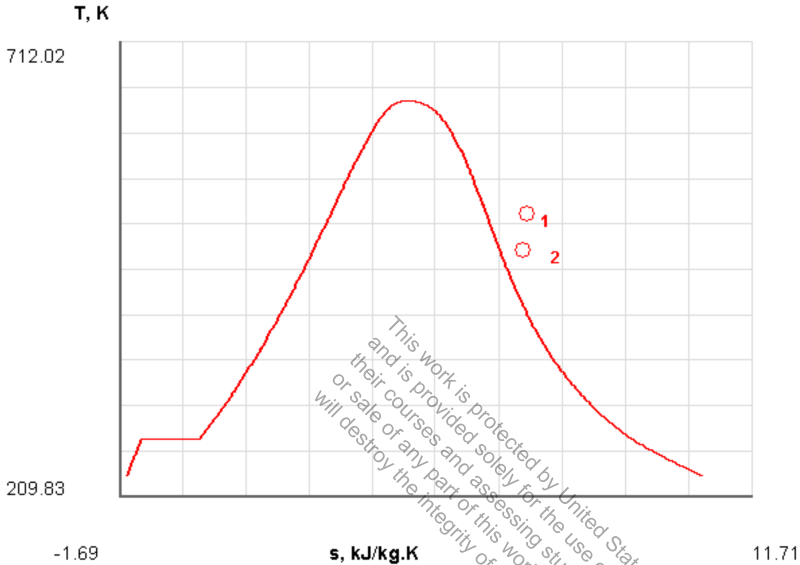
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.1098\frac{\text{kW}}{\text{K}}$$

TEST Solution and What-if Scenario:

Launch the PG 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.

4-1-19 [WH] Steam enters a long, horizontal pipe with an inlet diameter of 14 cm at 1 MPa, 250oC with a velocity of 1.2 m/s. Further downstream, the conditions are 800 kPa and 210oC, and the diameter is 12 cm. Determine (a) the rate of heat transfer to the surroundings, which is at 25oC, and (b) the rate of entropy generation in the system's universe. (c) Draw an entropy flow diagram for the system.

SOLUTION



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

State-1 (given $p_1, T_1,\ V_1$ and A_1):

$$v_1 = 0.23267\ \frac{\text{m}^3}{\text{kg}};\quad h_1 = 2942.57\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 6.92\ \frac{\text{kJ}}{\text{kg}};$$

$$\dot{m}_1 = \frac{A_1V_1}{v_1};\quad \Rightarrow \dot{m}_1 = \frac{(0.01538)(1.2)}{0.23267};\quad \Rightarrow \dot{m}_1 = 0.0793\ \frac{\text{m}}{\text{s}};$$

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

$$v_2 = 0.26726\ \frac{\text{m}^3}{\text{kg}};\quad h_2 = 2861.37\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 6.86\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$V_2 = \frac{\dot{m}_2 v_2}{A_2};\quad \Rightarrow V_2 = \frac{(0.0793)(0.26726)}{0.0113};\quad \Rightarrow V_2 = 1.875\ \frac{\text{m}}{\text{s}};$$

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

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

$$\Rightarrow \dot{Q} = \dot{m}\left(j_2 - j_1\right); \qquad \text{(Since } \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2\text{)}$$

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

$$\Rightarrow \dot{Q} = \dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2000}\right);$$

$$\Rightarrow \dot{Q} = 0.0793\left(2861.37 - 2942.57 + \frac{1.875^2 - 1.2^2}{2000}\right);$$

$$\Rightarrow \dot{Q} = -6.44 \text{ kW}$$

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

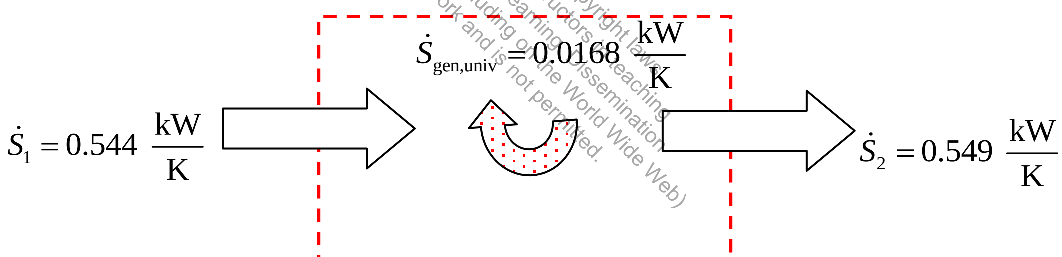
$$\frac{d\cancel{S}^{\,0}}{\cancel{dt}} = \dot{m}_1 s_1 - \dot{m}_2 s_2 + \frac{\dot{Q}}{T_B} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(0.0793\right)\left(6.86 - 6.92\right) + \frac{6.44}{298};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.0168 \ \frac{\text{kW}}{\text{K}}$$

(c)

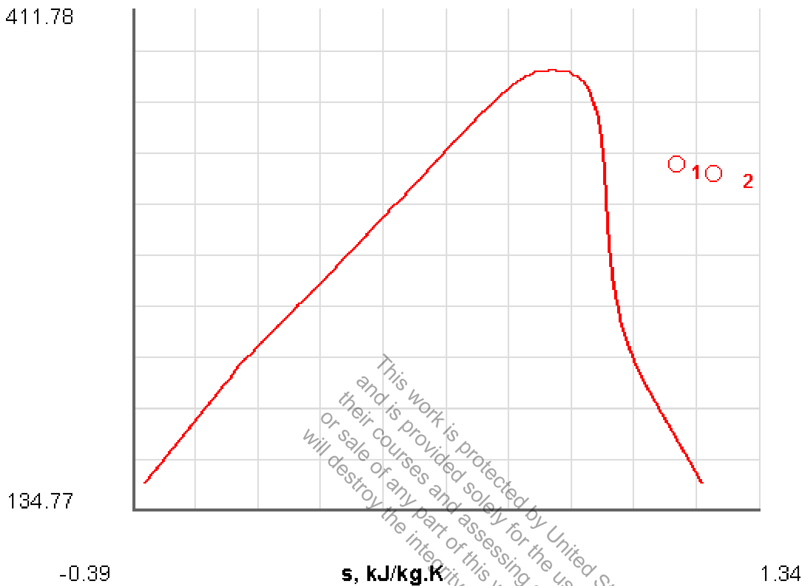


TEST Solution:

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.

4-1-20 [WA] Refrigerant R-134a flows through a long, insulated pipe of constant cross-sectional area. At the inlet, the state is 200 kPa, 50oC. At another section further downstream, the state is 150 kPa, 34.3oC. Determine the velocity of the refrigerant at the inlet.

SOLUTION



Given:

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

State-1 (given p_1, T_1):

$T_{\text{sat@200kPa}} = -10.22°\text{C} \therefore$ superheated vapor

$$v_1 = 0.1275 \ \frac{\text{m}^3}{\text{kg}}; \quad h_1 = 295.12 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given p_2, $A_1 = A_2$, $\dot{m}_2 = \dot{m}_1$):

$T_{\text{sat@150kPa}} = -17.30°\text{C} \therefore$ superheated vapor

$$v_2 = 0.1626 \ \frac{\text{m}^3}{\text{kg}}; \quad h_2 = 282.499 \ \frac{\text{kJ}}{\text{kg}};$$

From the mass balance equation, we have

$\rho_1 A_1 V_1 = \rho_2 A_2 V_2;$

$$\Rightarrow V_2 = \frac{\rho_1}{\rho_2} V_1 = \frac{v_2}{v_1} V_1 = \left(\frac{v_2}{0.1275}\right)(200) = 1568.6 v_2;$$

From the energy balance equation, we have

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

$$\Rightarrow 0 = j_1 - j_2;$$

$$\Rightarrow 0 = h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000};$$

$$\Rightarrow 0 = 295.12 - h_2 + \frac{200^2 - 1568.6^2 v_2^2}{2000};$$

$$\Rightarrow h_2 + 1.2303 \times 10^3 v_2^2 - 315.12 = 0;$$

By guessing the temperature T_2, the unknown properties h_2 and v_2 can be evaluated. The equation is satisfied when a few iteration yields:

$$T_2 = 34.3^{\circ}\text{C};\ v_2 = 0.1626\ \frac{\text{m}}{\text{s}};$$

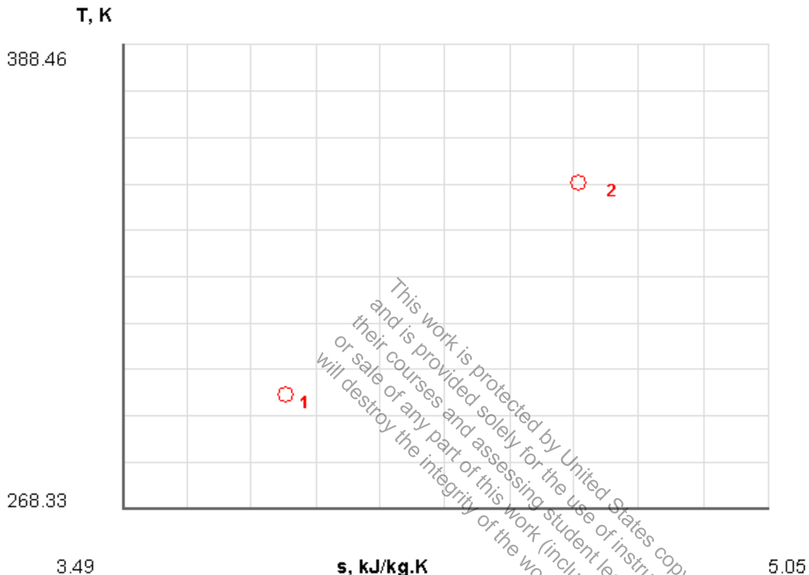
$$\Rightarrow V_2 = 254.5\frac{\text{m}}{\text{s}}$$

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.

4-1-21 [WI] An electric water heater supplies hot water at 200 kPa, 80oC at a flow rate of 8 L/min while consuming 32 kW of electrical power as shown in the accompanying animation. The water temperature at the inlet is 25oC, same as the temperature of the surroundings. Using the SL (solid/liquid) model for water and neglecting kinetic and potential energy changes, determine (a) the rate of heat loss to the atmosphere, (b) the energetic efficiency, and (c) the rate of entropy generation in the heater's universe. Assume no pressure loss in the system.

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 represent the inlet and state-2 the exit state.

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

$$v_1 = 0.0010 \frac{\text{m}^3}{\text{kg}};$$

$$\dot{m}_1 = \frac{\dot{V}_1}{v_1}; \qquad \Rightarrow \dot{m}_1 = \frac{\left(1.33\text{x}10^{-4}\right)}{0.0010}; \qquad \Rightarrow \dot{m}_1 = 0.133 \frac{\text{kg}}{\text{s}};$$

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

$$v_2 = 0.0010 \frac{\text{m}^3}{\text{kg}};$$

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

$$\frac{d\cancel{E}^{\,0}}{\cancel{dt}} = \dot{m}(u_1 - u_2) + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{Q} = \dot{m}c(T_2 - T_1) - \dot{W}_{\text{ext}}; \qquad (\text{Since } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow \dot{Q} = (0.133)(4.184)(353 - 298) - 32;$$

$$\Rightarrow \dot{Q} = -1.4 \text{ kW} \therefore \dot{Q}_{\text{loss}} = 1.4 \text{ kW}$$

(b) The energetic efficiency

$$\eta_{\text{I}} = \frac{\dot{Q} + \dot{W}_{\text{ext}}}{-\dot{W}_{\text{ext}}};$$

$$\Rightarrow \eta_{\text{I}} = \frac{(-1.4) - (-32)}{-(-32)};$$

$$\Rightarrow \eta_{\text{I}} = \frac{30.6}{32};$$

$$\Rightarrow \eta_{\text{I}} = 95.6\ \%$$

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

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

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}c \ln\frac{T_2}{T_1} + \frac{\dot{Q}}{T_B};$$

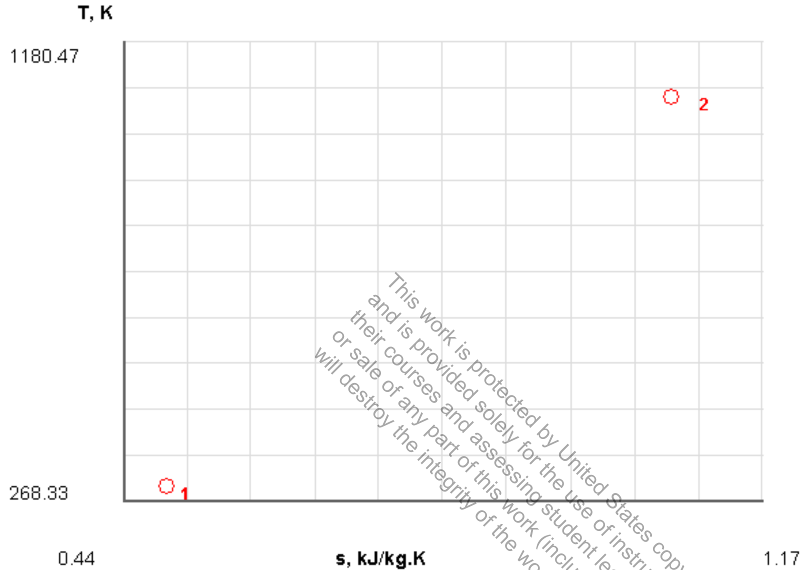
$$\Rightarrow \dot{S}_{\text{gen,univ}} = (0.133)(4.184)\ln\frac{353}{298} + \frac{1.4}{298};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.0989\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-22 [WN] Long steel rods of 5 cm diameter are heat-treated by drawing them at a velocity of 5 m/s through an oven maintained at a constant temperature of 1000°C. The rods enter the oven at 25°C and leave at 800°C. Determine (a) the rate of heat transfer to the rods from the oven and (b) the rate of entropy generation in the system's universe. Use the SL model and assume steel to have the same material properties as iron. (c) ***What-if scenario:*** How would the answer in part (b) change if the oven was maintained at 800°C?

SOLUTION



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

The specific heat $c = 0.45 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$;

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

State-1 (given $p_1, T_1,\ V_1$):

$$A_1 = \frac{\pi(0.005)^2}{4}; \quad \Rightarrow A_1 = 0.00196 \text{ m}^2;$$

$$\rho_1 = 7840.0 \ \frac{\text{kg}}{\text{m}^3};$$

$$\dot{m}_1 = \rho_1 A_1 V_1; \quad \Rightarrow \dot{m}_1 = (7840)(0.00196)(5); \quad \Rightarrow \dot{m}_1 = 76.97 \ \frac{\text{kg}}{\text{s}};$$

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

$$\rho_1 = 7840.0 \ \frac{\text{kg}}{\text{m}^3};$$

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

$$\frac{d\cancel{E}^{\,0}}{dt} = \dot{m}(u_1 - u_2) + \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{\,0};$$

$$\Rightarrow \dot{Q} = \dot{m}c(T_2 - T_1); \qquad (\text{Since } \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow \dot{Q} = (76.97)(0.45)(1073 - 298);$$

$$\Rightarrow \dot{Q} = 26.843 \text{ MW}$$

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

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

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}c \ln\frac{T_2}{T_1} - \frac{\dot{Q}}{T_B};$$

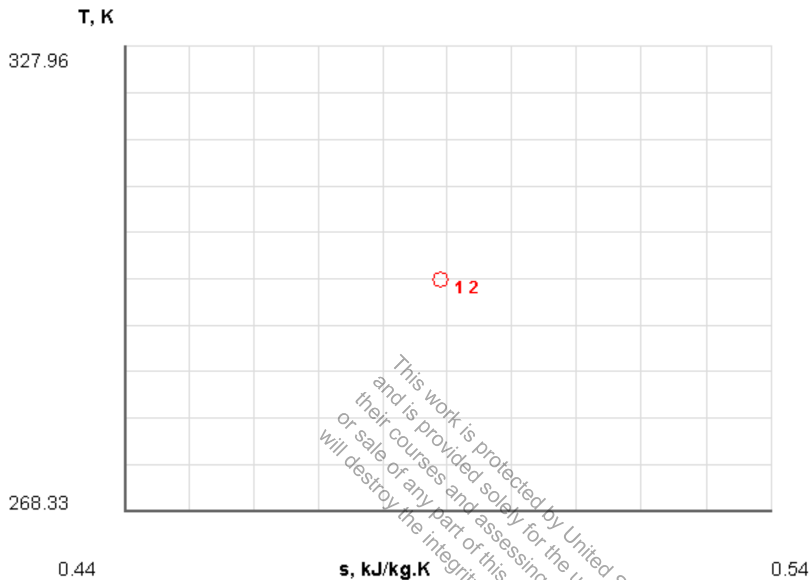
$$\Rightarrow \dot{S}_{\text{gen,univ}} = (76.97)(0.45)\ln\frac{1073}{298} - \frac{26843}{1273};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 23.3 \ \frac{\text{kW}}{\text{K}}$$

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.

4-1-23 [WE] Liquid water flows steadily through an insulated nozzle. The following data are supplied. Inlet: p= 500 kPa, T=25°C, V= 10 m/s; Exit: p=100 kPa, T=25°C. Determine the exit velocity by using (a) the SL model and (b) the PC model for water. (c) ***What-if scenario:*** How would the exit velocity be affected if the exit area was reduced without changing other inlet or exit conditions?

SOLUTION



Use the 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,

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

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

$$\Rightarrow j_1 = j_2; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$
$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$
$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$
$$\Rightarrow \cancel{c(T_1 - T_2)}^{0} + v(p_1 - p_2) = \frac{V_2^2 - V_1^2}{2000};$$
$$\Rightarrow V_2 = \sqrt{\left(2000v(p_1 - p_2) + V_1^2\right)};$$
$$\Rightarrow V_2 = \sqrt{\left((2000)(0.0010)(500-100) + 10^2\right)};$$
$$\Rightarrow V_2 = 30\ \frac{\text{m}}{\text{s}}$$

Using the steady state PC model for water, with one inlet and one exit

State-1 (given $p_1,\ T_1,\ V_1$):

$$h_1 = 105.38\ \frac{\text{kJ}}{\text{kg}};$$

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

$$h_2 = 104.97\ \frac{\text{kJ}}{\text{kg}};$$

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

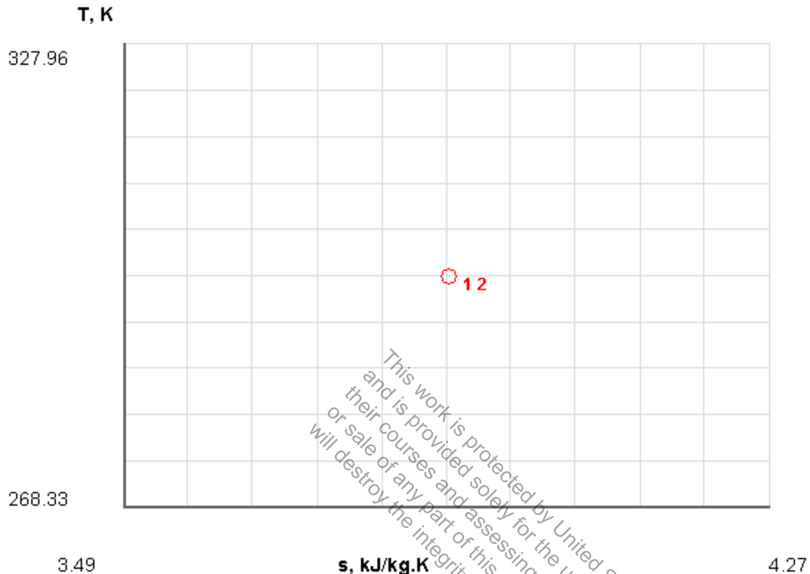
$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}(j_1 - j_2) + \dot{Q} - \dot{W}_{\text{ext}}$$
$$\Rightarrow j_1 = j_2; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$
$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$
$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$
$$\Rightarrow 105.38 - 104.97 = \frac{V_2^2 - 10^2}{2000};$$
$$\Rightarrow V_2 = \sqrt{\left(2000(105.38 - 104.97) + 10^2\right)};$$
$$\Rightarrow V_2 = 30.33\ \frac{\text{m}}{\text{s}}$$

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.

4-1-24 [WL] A water tower in a chemical plant holds 2000 L of liquid water at 25°C, 100 kPa in a tank on top of a 10-m-tall tower. A pipe leads to the ground level with a tap that can open a 1 cm-diameter hole. Neglect friction and pipe losses and estimate the time it will take to empty the tank. Use the SL model for water.

SOLUTION



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

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

$$m = \rho \cancel{V}; \qquad \Rightarrow m = (997)(2); \qquad \Rightarrow m = 1994 \text{ kg};$$

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

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

$$\Rightarrow j_1 = j_2; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow h_1 + \text{ke}_1 + \text{pe}_1 = h_2 + \text{ke}_2 + \text{pe}_2;$$

$$\Rightarrow \frac{g(z_1 - z_2)}{1000} = \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow V_2^2 = 2(9.81)(10); \qquad (\text{Since } V_1 = 0)$$

$$\Rightarrow V_2 = 14 \ \frac{\text{m}}{\text{s}};$$

Then we can use the mass flow rate to determine the time:

$$\dot{m} = \frac{m}{t}; \quad \Rightarrow \dot{m} = \rho A_2 V_2;$$

$$\Rightarrow t = \frac{m}{\rho A_2 V_2};$$

$$\Rightarrow t = \frac{1994}{(997)\left(7.85\times10^{-5}\right)(14)};$$

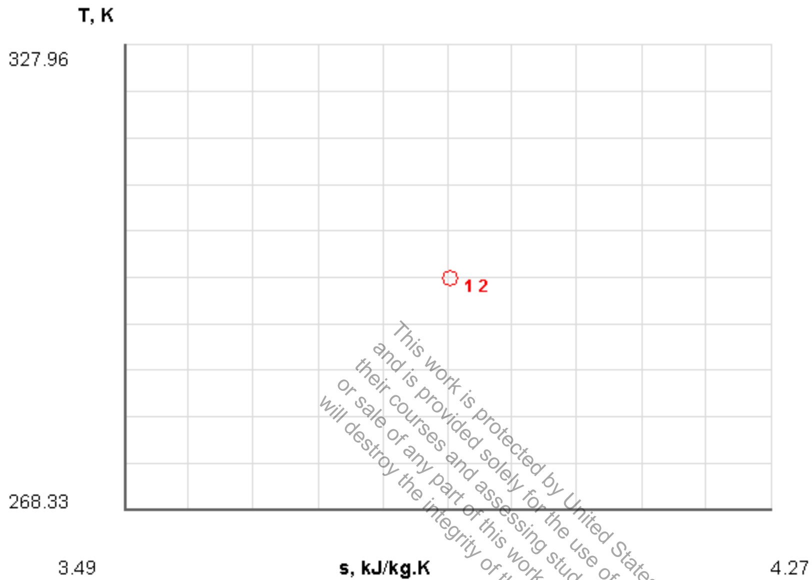
$$\Rightarrow t = 1819 \text{ s} = 30.3 \text{ min}$$

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.

4-1-25 [WG] A large supply line carries water at a pressure of 1 MPa. A small leak with an area of 1 cm2 develops on the pipe which is exposed to the atmosphere at 100 kPa. Assuming the resulting flow to be isentropic, determine (a) the velocity of the jet and (b) the leakage rate in kg/min. (c) ***What-if scenario:*** How would the answers change as the leakage area increased to 2 cm2?

SOLUTION



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

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

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

State-2 (given $p_2,\ T_2,\ s_2 = s_1, \dot{m}_2 = \dot{m}_1$)

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

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

$$\Rightarrow j_1 = j_2; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$

$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow \cancelto{0}{c(T_1 - T_2)} + v(p_1 - p_2) = \frac{V_2^2 - \cancelto{0}{V_1^2}}{2000};$$

$$\Rightarrow V_2 = \sqrt{(2000v(p_1 - p_2))};$$

$$\Rightarrow V_2 = \sqrt{((2000)(0.0010)(1000 - 100))};$$

$$\Rightarrow V_2 = 42.4\ \frac{\text{m}}{\text{s}}$$

(b) The mass flow rate is

$$\dot{m} = \rho AV; \qquad \Rightarrow \dot{m} = \frac{AV}{v}; \qquad \Rightarrow \dot{m} = \frac{(0.0001)(42.4)}{0.001}; \qquad \Rightarrow \dot{m} = 4.24\ \frac{\text{kg}}{\text{s}};$$

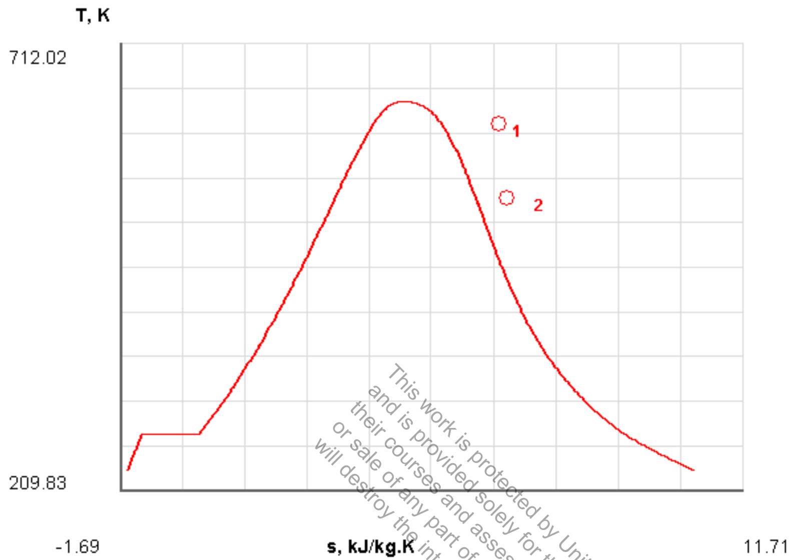
$$\Rightarrow \dot{m} = 254.4\ \frac{\text{kg}}{\text{min}}$$

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.

4-1-26 [WZ] Steam enters a nozzle operating steadily at 5 MPa, 350°C, 10 m/s and exits at 2 MPa, 267°C. The steam flows through the nozzle with negligible heat transfer and PE. The mass flow rate ($\dot{m}$) is 2 kg/s. Determine (a) the exit velocity (V_2) and (b) the exit area. (c) Draw an energy flow diagram for the nozzle.

SOLUTION



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

State-1 (given $p_1, T_1, V_1, \dot{m}$):

$$v_1 = 0.0519\,\frac{\text{m}^3}{\text{kg}}; \quad h_1 = 3068.4\,\frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.449\,\frac{\text{kJ}}{\text{kg}}$$

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

$$v_2 = 0.1162\,\frac{\text{m}^3}{\text{kg}}; \quad h_2 = 2943.6\,\frac{\text{kJ}}{\text{kg}};$$

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

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

$$\Rightarrow j_1 = j_2; \qquad \text{(Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2\text{)}$$

$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$

$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow V_2 = \sqrt{\left(2000\left(h_1 - h_2\right) + V_1^2\right)};$$

$$\Rightarrow V_2 = \sqrt{\left(2000\left(3068.5 - 2943.6\right) + 100\right)};$$

$$\Rightarrow V_2 = 499.9\ \frac{\text{m}}{\text{s}}$$

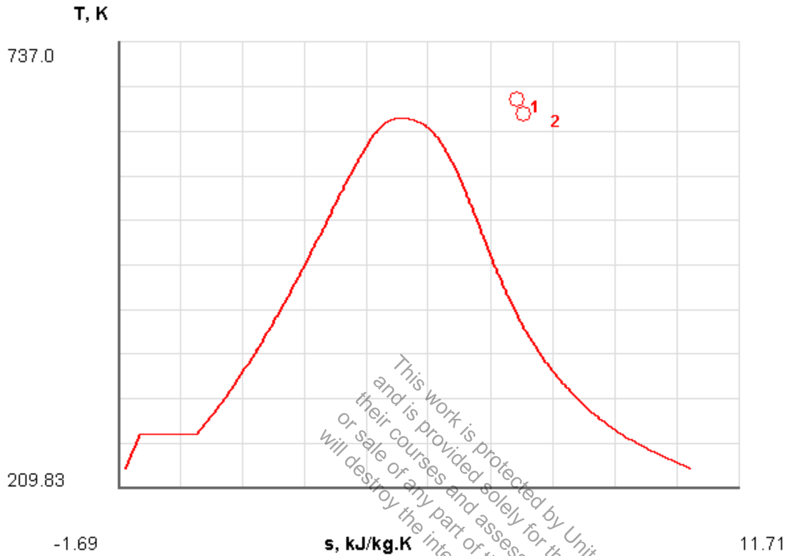
(b) $A_2 = \dfrac{\dot{m}v_2}{V_2}; \qquad \Rightarrow A_2 = \dfrac{(2)(0.1162)}{499.9};$

$$\Rightarrow A_2 = 4.65\text{x}10^{-4}\ \text{m}^2 = 4.65\ \text{cm}^2$$

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.

4-1-27 [WK] Steam enters an adiabatic nozzle steadily at 3 MPa, 670 K, 50 m/s, and exits at 2 MPa and 200 m/s. If the nozzle has an inlet area of 7 cm2. Determine (a) the exit area. (b) ***What-if scenario:*** How would the conclusion change if the exit velocity was 400 m/s?

SOLUTION



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

State-1 (given p_1, T_1, V_1, A_1):

$$v_1 = 0.0988\ \frac{\text{m}^3}{\text{kg}}; \quad h_1 = 3223.515\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.909\ \frac{\text{kJ}}{\text{kg}};$$

$$\dot{m} = \frac{A_1 V_1}{v_1}; \quad \Rightarrow \dot{m} = \frac{(0.0007)(50)}{0.0988}; \quad \Rightarrow \dot{m} = 0.354\ \frac{\text{kg}}{\text{s}};$$

State-2 (given $p_2, V_2, \dot{m}$)

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

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

$$\Rightarrow j_1 = j_2; \qquad \left(\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2\right)$$

$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$

$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow h_2 = h_1 - \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow h_2 = 3223.515 - \left(\frac{200^2 - 50^2}{2000}\right);$$

$$\Rightarrow h_2 = 3204.77\ \frac{\text{kJ}}{\text{kg}}; \qquad \therefore v_2 = 0.14631\ \frac{\text{m}^3}{\text{kg}};$$

The exit area of the nozzle

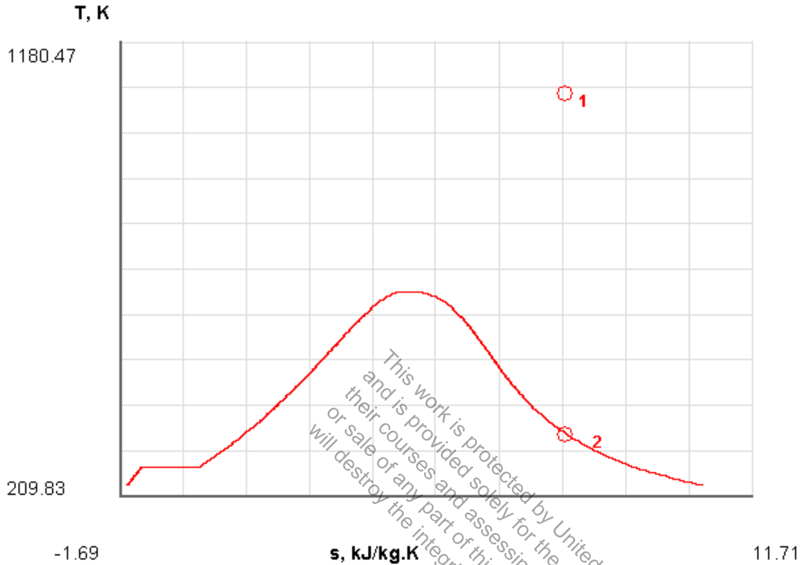
$$A_2 = \frac{\dot{m}v_2}{V_2}; \qquad \Rightarrow A_2 = \frac{(0.354)(0.14631)}{200}; \qquad \Rightarrow A_2 = 2.59\ \text{cm}^2$$

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.

4-1-28 [WP] Superheated steam is stored in a large tank at 5 MPa and 800oC. The steam is exhausted isentropically through a converging-diverging nozzle. Determine (a) the exit pressure, and (b) the exit velocity for the condensation to begin at the exit. Use the PC model for steam. (c) ***What-if scenario:*** How would the answer in part (b) change if steam was treated as a perfect gas?

SOLUTION



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

State-1 (given $p_1,\ T_1,\ x_1$):

$$h_1 = 4137.1\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 7.7440\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $s_2 = s_1,\ x_2$):

$$T_2 = 70.77^\circ\text{C};\qquad h_2 = 2628.1\ \frac{\text{kJ}}{\text{kg}};$$

(a) $p_2 = 32.2\ \text{kPa}$

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

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

$$\Rightarrow j_1 = j_2; \qquad \text{(Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2\text{)}$$

$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$

$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow V_2 = \sqrt{\left(2000\left(h_1 - h_2\right) + \cancelto{0}{V_1^2}\right)};$$

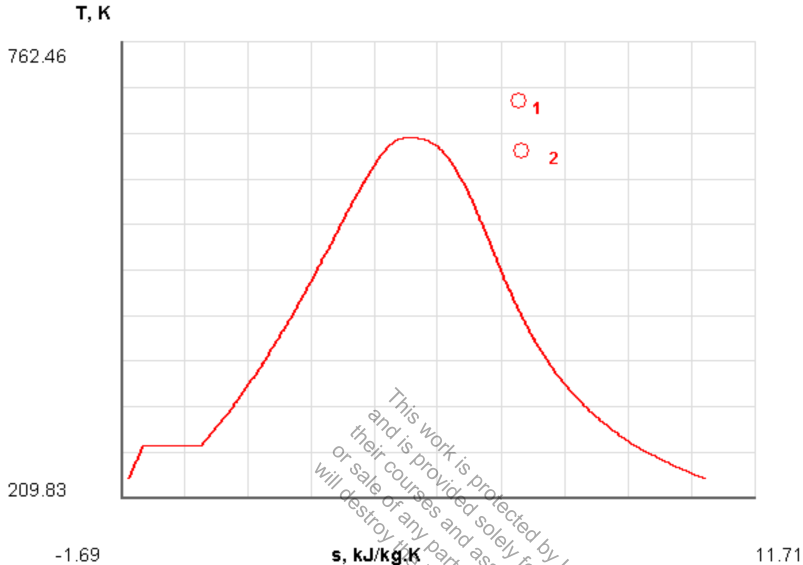
$$\Rightarrow V_2 = \sqrt{\left(2000\left(4137.1 - 2628.1\right)\right)};$$

$$\Rightarrow V_2 = 1737.24\ \frac{\text{m}}{\text{s}}$$

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.

4-1-29 [WU] Steam enters a nozzle operating at steady state at 5 MPa and 420oC with negligible velocity, and exits at 3 MPa and 466 m/s. If the mass flow rate is 3 kg/s. Determine (a) the exit area, (b) the exit temperature, and (c) the rate of entropy generation in the nozzle. Neglect heat transfer and PE.

SOLUTION



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

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

$$h_1 = 3243.81\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 6.714\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2, V_2, \dot{m}_2 = \dot{m}_1$)

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

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

$$\Rightarrow j_1 = j_2; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$
$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$
$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$
$$\Rightarrow h_2 = h_1 - \frac{V_2^2 - \cancel{V_1^2}^{\,0}}{2000};$$
$$\Rightarrow h_2 = 3243.81 - \frac{(466)^2}{2000};$$
$$\Rightarrow h_2 = 3135.23\ \frac{\text{kJ}}{\text{kg}};$$

$$\therefore v_2 = 0.09204\ \frac{\text{m}^3}{\text{kg}} \text{ and } s_2 = 6.773\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$A_2 = \frac{\dot{m}v_2}{V_2}; \qquad \Rightarrow A_2 = 5.9\ \text{cm}^2$$

(b) $T_2 = 358.55\ ^{\text{o}}\text{C}$

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

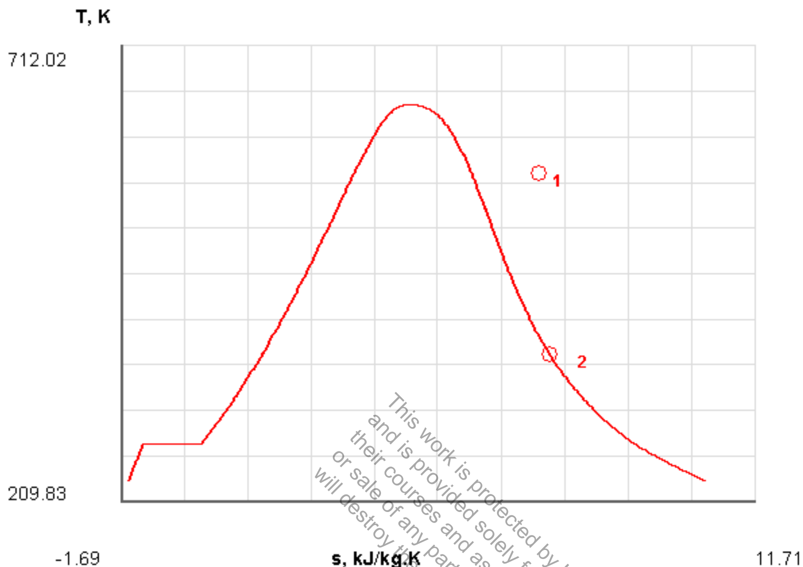
$$\cancel{\frac{dS}{dt}}^{\,0} = \dot{m}_1 s_1 - \dot{m}_2 s_2 + \cancel{\frac{\dot{Q}}{T_B}}^{\,0} + \dot{S}_{\text{gen,univ}};$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}(s_2 - s_1);$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = (3)(6.773 - 6.714);$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.177\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-30 [WX] An adiabatic steam nozzle operates steadily under the following conditions. Inlet: superheated vapor, p = 1 MPa, T = 300°C, A = 78.54 cm2; Exit: saturated vapor, p = 100 kPa. Determine (a) the exit velocity (m/s), (b) the rate of entropy generation (kW/K). The mass flow rate is 1 kg/s.

SOLUTION



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

State-1 (given $p_1, T_1, A_1, \dot{m}_1$):

$$v_1 = 0.2579\ \frac{\text{m}^3}{\text{kg}}; \quad h_1 = 3051.1\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.1228\ \frac{\text{kJ}}{\text{kg}};$$

$$V_1 = \frac{\dot{m}v_1}{A_1}; \quad \Rightarrow V_1 = \frac{(1)(0.2579)}{0.007854}; \quad \Rightarrow V_1 = 32.84\ \frac{\text{m}}{\text{s}};$$

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

$$v_1 = 1.694\ \frac{\text{m}^3}{\text{kg}}; \quad h_1 = 2675.5\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.3593\ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right); \qquad \text{(since } \dot{W}_\text{ext} = \dot{Q} \cong 0, \text{ and } \Delta\text{pe} \cong 0)$$

$$\Rightarrow V_2^2 = \left(2000\left(h_1 - h_2\right) + V_1^2\right);$$

$$\Rightarrow V_2 = \sqrt{\left(2000\left(h_1 - h_2\right) + V_1^2\right)};$$

$$\Rightarrow V_2 = \sqrt{\left(2000\left(3051.1 - 2675.5\right) + 32.84^2\right)};$$

$$\Rightarrow V_2 = 867.34\ \frac{\text{m}}{\text{s}}$$

(b) From the entropy balance equation, we have

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_1 - s_2\right) + \cancel{\frac{\dot{Q}}{T_B}}^{0} + \dot{S}_\text{gen,univ};$$

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

$$\Rightarrow \dot{S}_\text{gen,univ} = \left(7.3593 - 7.1228\right);$$

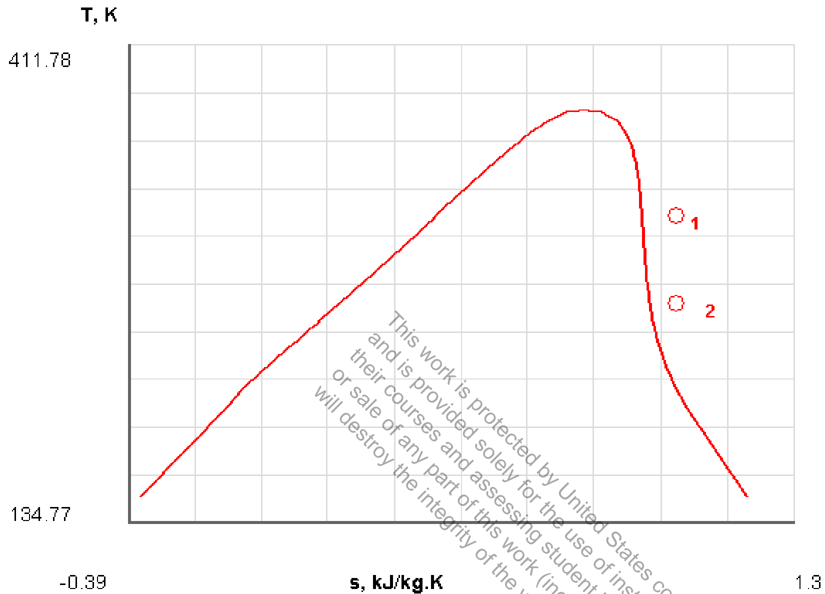
$$\Rightarrow \dot{S}_\text{gen,univ} = 0.237\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-31 [WV] Two options are available for reduction of pressure for superheated R-134a flowing steadily at 500 kPa and 40oC to a pressure of 100 kPa. In the first option, the vapor is allowed to expand through an isentropic nozzle. In the second option, a valve is used to throttle the flow down to the desired pressure. (a) Determine the temperature of the flow at the exit for each option. (b) ***What-if scenario:*** How would the answer change for the second option if R-134a is treated as an ideal gas?

SOLUTION



Use TEST or the manual approach to determine the anchor states – state-1 is the inlet state, let state-2 be the exit state for the first case (i.e the isentropic nozzle flow) and state-3 be the exit state for the second case (i.e flow through the throttle valve).

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

$$h_1 = 282.48\ \frac{\text{kJ}}{\text{kg}};\ s_1 = 1.0011\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a.1) State-2 (given $p_{2,}\ s_2 = s_1$):

$$T_2 = -10.22\ ^{\circ}\text{C}$$

(a.2) State-3 (given $p_3 = p_2,\ h_3 = h_1$):

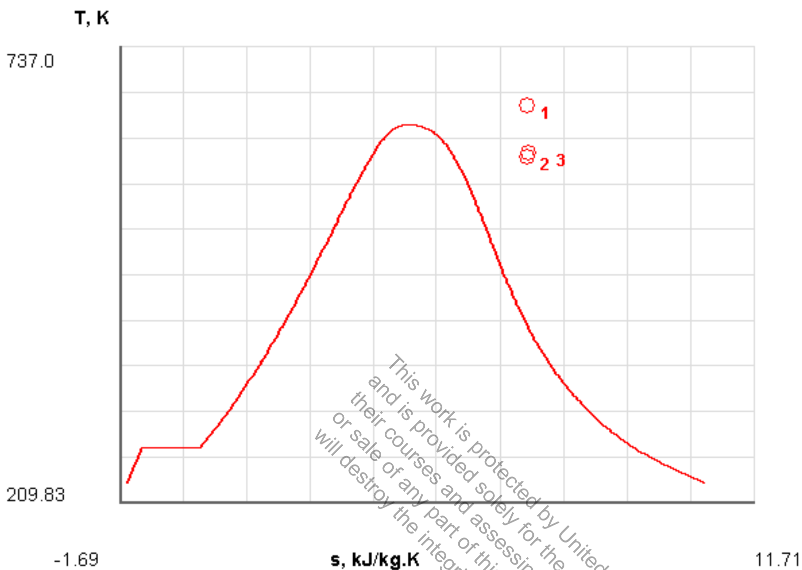
$$T_3 = 32.49\ ^{\circ}\text{C}$$

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.

4-1-32 [WC] Steam enters an adiabatic nozzle steadily at 3 MPa, 670 K, 50 m/s, and exits at 2 MPa. If the nozzle has an inlet area of 7 cm2 and an adiabatic efficiency of 90%. Determine (a) the exit velocity and (b) the rate of entropy generation in the nozzle's universe. Neglect pe. (c) ***What-if scenario:*** How would the conclusion in (a) change if the adiabatic efficiency was 80%?

SOLUTION



State-1 (given $p_1,\ T_1,\ V_1$):

$$h_1 = 3223.51\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 6.909\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad v_1 = 0.0988\ \frac{\text{m}^3}{\text{kg}};$$

$$\dot{m}_1 = \frac{A_1V_1}{v_1};\qquad \Rightarrow \dot{m}_1 = \frac{(.0007)(50)}{0.0988};\qquad \Rightarrow \dot{m}_1 = 0.35425\frac{\text{kg}}{\text{s}};$$

State-2 (given $p_{2,}\ s_2 = s_1$):

$$h_2 = 3109.25\ \frac{\text{kJ}}{\text{kg}};\qquad v_2 = 0.13537\ \frac{\text{m}^3}{\text{kg}};$$

State-3 (given $p_3 = p_2,\ \eta,\ \dot{m}_3 = \dot{m}_1$):

$$h_3 = h_1 - 0.9(h_1 - h_2);\qquad \Rightarrow h_3 = 3223.51 - (0.9)(3223.51 - 3109.25);\qquad \Rightarrow h_3 = 3120.67\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 6.92895\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad v_3 = 0.13669\ \frac{\text{m}^3}{\text{kg}};$$

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

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

$$\Rightarrow j_1 = j_3; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow h_1 + \text{ke}_1 = h_3 + \text{ke}_3;$$

$$\Rightarrow h_1 - h_3 = \frac{V_3^2 - V_1^2}{2000};$$

$$\Rightarrow V_3 = \sqrt{\left(2000\left(h_1 - h_3\right) + V_1^2\right)};$$

$$\Rightarrow V_3 = \sqrt{\left(2000\left(3223.51 - 3120.67\right) + 50^2\right)};$$

$$\Rightarrow V_3 = 456.27\ \frac{\text{m}}{\text{s}}$$

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

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_3 - s_1\right);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(0.35425\right)\left(6.92895 - 6.909\right);$$

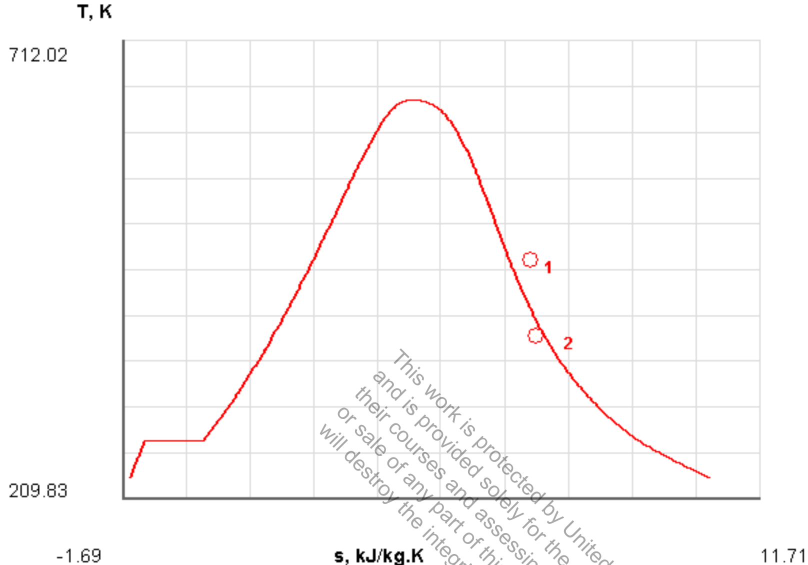
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.0070\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-33 [WY] Steam enters an insulated nozzle steadily at 0.7 MPa, 200oC, 50 m/s, and exits at 0.18 MPa and velocity of 650 m/s. If the nozzle has an inlet area of 0.5 m2. Determine (a) the exit temperature, (b) mass flow rate and (c) the rate of entropy generation in the nozzle's universe. Neglect PE. (d) Draw an entropy flow diagram for the device.

SOLUTION



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

State-1 (given $p_1,\ T_1,\ V_1$):

$$h_1 = 2844.66\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 6.885\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad v_1 = 0.29989\ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $p_2,\ V_2$)

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

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

$$\Rightarrow j_1 = j_2; \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0 \text{ and } \dot{m}_1 = \dot{m}_2)$$

$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$

$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{2000};$$

$$\Rightarrow h_2 = h_1 - \left(\frac{V_2^2 - V_1^2}{2000}\right);$$

$$\Rightarrow h_2 = 2844.66 - \left(\frac{650^2 - 50^2}{2000}\right);$$

$$\Rightarrow h_2 = 2634.66\ \frac{\text{kJ}}{\text{kg}};$$

$$\therefore s_2 = 6.9904\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \qquad T_2 = 116.9^{\circ}\text{C}$$

(b) The mass flow rate is

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

$$\dot{m} = \frac{A_1 V_1}{v_1}; \qquad \Rightarrow \dot{m} = \frac{(0.5)(50)}{0.29989}; \qquad \Rightarrow \dot{m} = 83.36\ \frac{\text{kg}}{\text{s}}$$

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

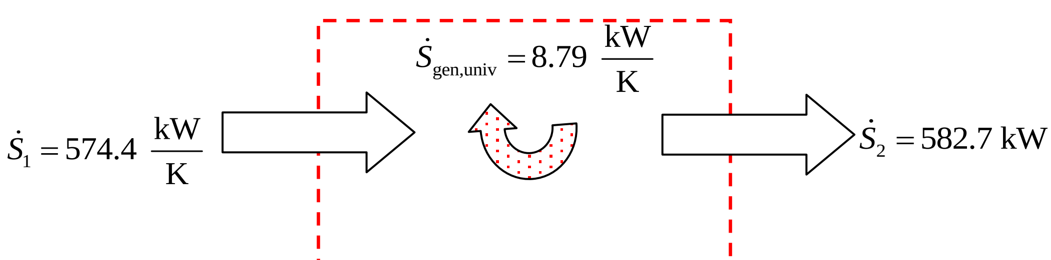
$$\cancelto{0}{\frac{dS}{dt}} = \dot{m}_1 s_1 - \dot{m}_2 s_2 + \cancelto{0}{\frac{\dot{Q}}{T_B}} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (83.36)(6.9904 - 6.885);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 8.79\ \frac{\text{kW}}{\text{K}}$$

(d) Entropy Flow Diagram:

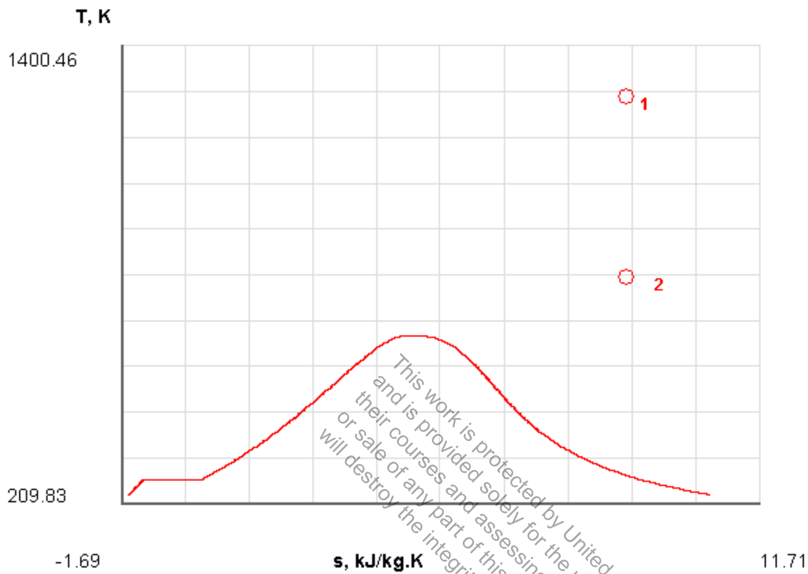


TEST Solution:

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.

4-1-34 [WQ] Steam flows steadily through an isentropic nozzle with a mass flow rate of 10 kg/s. At the inlet the conditions are: 1 MPa, 1000oC, and 10 m/s, and at the exit the pressure is 100 kPa. Determine the flow area at (a) the inlet and (b) the exit. (c) Determine the area of cross-section at an intermediate state where the flow velocity is 500 m/s. (d) Draw an approximate shape of the nozzle.

SOLUTION



State-1 (given $p_1,\ T_1,\ V_1,\ \dot{m}_1$):

$$h_1 = 4637.6\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 8.9118\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad v_1 = 0.5871\ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $p_2, s_2 = s_1, \dot{m}_2 = \dot{m}_1$):

$$h_2 = 3552.0\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 8.9118\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad v_2 = 3.702\ \frac{\text{m}^3}{\text{kg}};$$

State-3 (given $V_3,\ s_3 = s_1$)

From the energy balance equation, we have

For state-2:

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

$$\Rightarrow 0 = \dot{m}\left(j_1 - j_2\right); \qquad \left(\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0\right)$$

$$\Rightarrow 0 = h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000};$$

$$\Rightarrow V_2^2 = 2000\left(h_1 - h_2\right) + V_1^2;$$

$$\Rightarrow V_2 = \sqrt{2000\left(h_1 - h_2\right) + V_1^2};$$

$$\Rightarrow V_2 = \sqrt{2000\left(4637.6 - 3552.0\right) + 10^2};$$

$$\Rightarrow V_2 = 1473.5\ \frac{\text{m}}{\text{s}};$$

For state-3:

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

$$\Rightarrow 0 = \dot{m}\left(j_1 - j_3\right); \qquad \left(\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0\right)$$

$$\Rightarrow 0 = h_1 - h_3 + \frac{V_1^2 - V_3^2}{2000};$$

$$\Rightarrow h_3 = h_1 + \frac{V_1^2 - V_3^2}{2000};$$

$$\Rightarrow h_3 = 4637.6 + \frac{10^2 - 500^2}{2000};$$

$$\Rightarrow h_3 = 4512.65\ \frac{\text{kJ}}{\text{kg}};$$

Knowing specific entropy and specific enthalpy for state-3,

$$v_3 = 0.7032\ \frac{\text{m}^3}{\text{kg}};$$

From the mass balance equation, we have

$$\frac{d\cancel{m}^{\,0}}{\cancel{d}t} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\dot{m} = \rho A V;$$

(a) $\dot{m}_1 = \rho_1 A_1 V_1;$

$$\Rightarrow A_1 = \frac{\dot{m}_1 v_1}{V_1};$$

$$\Rightarrow A_1 = \frac{(10)(0.5871)}{(10)};$$

$$\Rightarrow A_1 = 0.5871\ \text{m}^2$$

(b) $\rho_1 A_1 V_1 = \rho_2 A_2 V_2;$

$$\Rightarrow A_2 = \frac{v_2}{v_1}\frac{V_1}{V_2}A_1;$$

$$\Rightarrow A_2 = \left(\frac{3.702}{0.5871}\right)\left(\frac{10}{1437.5}\right)(0.5871);$$

$$\Rightarrow A_2 = 0.0257\ \text{m}^2$$

(c) $\rho_1 A_1 V_1 = \rho_3 A_3 V_3;$

$$\Rightarrow A_3 = \frac{v_3}{v_1}\frac{V_1}{V_3}A_1;$$

$$\Rightarrow A_3 = \left(\frac{0.7032}{0.5871}\right)\left(\frac{10}{500}\right)(0.5871);$$

$$\Rightarrow A_3 = 0.0141\ \text{m}^2$$

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.

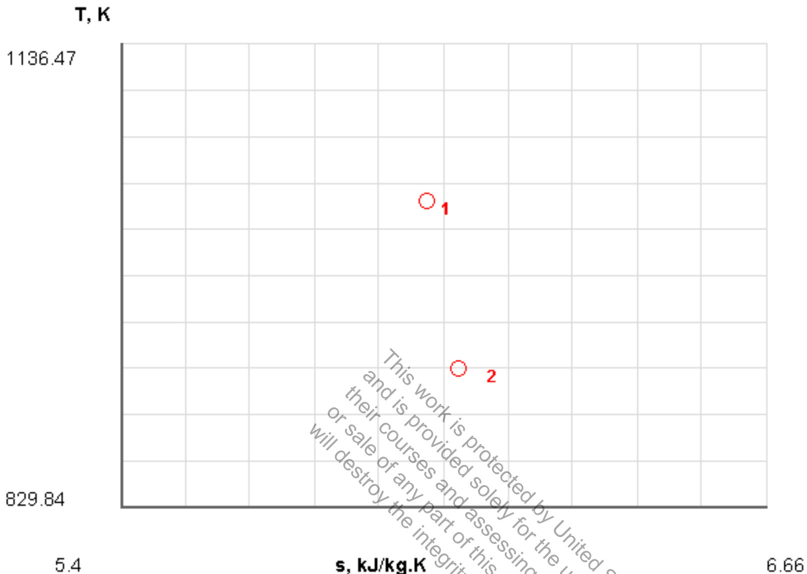
4-1-35 [WT] In problem 4-1-34 [WQ], determine the minimum area of cross-section of the steam nozzle. (Hint: Use TEST and vary the flow velocity in the intermediate station until the flow area is minimized.)

TEST Solution:

Launch the PC single-flow TESTcalc and load the TEST-code from problem 4-1-34. In State-3 (the intermediate state), change velocity Vel3 and click Super-Calculate to update the area A3. After a few iterations, the minimum area is found to be $A_3 = 0.0117\ \mathrm{m}^2$ The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

4-1-36 [WF] Carbon dioxide (CO2) enters a nozzle at 35 psia, 1400oF and 250 ft/s and exits at 12 psia and 1200oF. Assuming the nozzle to be adiabatic and the surroundings to be at 14.7 psia and 65oF. Determine (a) the exit velocity and (b) the entropy generation rate in the nozzle's universe.

SOLUTION



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

State-1 (given p_1, T_1, V_1)

State-2 (given p_2, T_2)

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

$$\left(\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0, \Delta\text{pe} \cong 0, \left(\text{Here, } 1\ \frac{\text{btu}}{\text{lbm}} = 25037\ \frac{\text{ft}^2}{\text{s}^2}\right)\right)$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{(2)(25037)}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{(2)(25037)}\right);$$

$$\Rightarrow h_1 - h_2 = \frac{V_2^2 - V_1^2}{50074};$$

$$\Rightarrow V_2 = \sqrt{\left(50074\left(h_1 - h_2\right) + V_1^2\right)};$$

$$\Rightarrow V_2 = \sqrt{\left(50074\left(343.94 - 285.30\right) + 250^2\right)};$$

$$\Rightarrow V_2 = 1731.7\ \frac{\text{ft}}{\text{s}}$$

(b) The rate of entropy generation

$$\frac{d\cancel{S}^{\,0}}{\cancel{dt}} = \dot{m}\left(s_1 - s_2\right) + \frac{\cancel{\dot{Q}}^{\,0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = \dot{m}\left(c_p \ln\frac{T_1}{T_2} - R\ln\frac{p_1}{p_2}\right) + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = \left(0.29679\ln\frac{(1859.67)}{(1659.67)} - 0.04512\ln\frac{(35)}{(12)}\right) + \dot{S}_{\text{gen,univ}}$$

$$\Rightarrow 0 = 0.0338 - 0.0483 + \dot{S}_{\text{gen,univ}}$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (0.0145)(60);$$

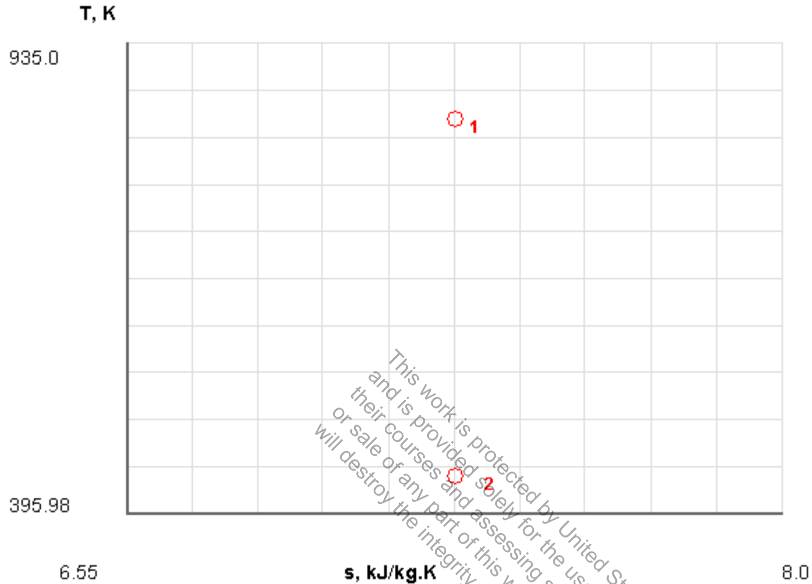
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.87\ \frac{\text{Btu}}{\text{R}\cdot\text{min}}$$

TEST Solution and What-if Scenario:

Launch the IG 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.

4-1-37 [WM] Air (use the PG model) expands in an isentropic horizontal nozzle from inlet conditions of 1.0 MPa, 850 K, 100 m/s to an exhaust pressure of 100 kPa. (a) Determine the exit velocity. ***What-if Scenario:*** What would the exit velocity be (b) if the inlet kinetic energy were neglected in the energy equation? (c) if the nozzle were vertical with the exhaust plane 4.0 m above the intake plane?

SOLUTION



State-1 (given p_1, T_1, V_1)

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

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}};$$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}};$$

$$\Rightarrow T_2 = (850)\left(\frac{100}{1000}\right)^{\frac{1.4-1}{1.4}};$$

$$\Rightarrow T_2 = 440 \text{ K};$$

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

(Since $\dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0, \Delta\text{pe} \cong 0$)

$$0 = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right);$$

$$\Rightarrow V_2 = \sqrt{2000\left(h_1 - h_2\right) + V_1^{\,2}};$$

$$\Rightarrow V_2 = \sqrt{2000 c_p\left(T_1 - T_2\right) + V_1^{\,2}};$$

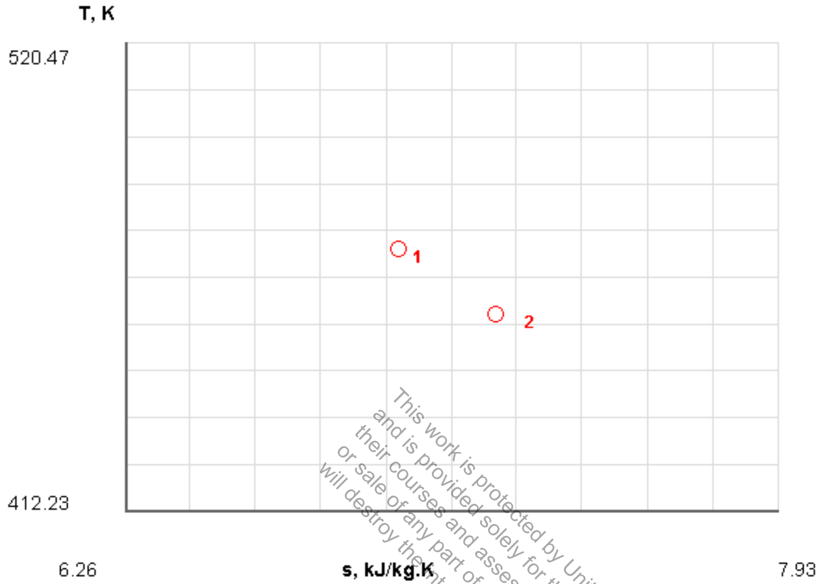
$$\Rightarrow V_2 = \sqrt{2000(1.003)(850 - 440) + 100^2};$$

$$\Rightarrow V_2 = 912.4\ \frac{\text{m}}{\text{s}}$$

TEST Solution and What-if Scenario:
Launch the PG 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.

4-1-38 [WD] Air enters an adiabatic nozzle steadily at 400kPa, 200oC and 35m/s and leaves at 150kPa and 180 m/s. The inlet area of the nozzle is 75cm2. Determine (a) the mass flow rate, (b) the exit temperature of the air, and (c) the exit area of the nozzle, and (d) the rate of entropy generation in the nozzle's universe. Use the IG model for air.

SOLUTION



State-1 (given p_1, T_1, A_1, V_1):

$$v_1 = \frac{RT_1}{p_1}; \quad \Rightarrow v_1 = \frac{(0.287)(473)}{(400)}; \quad \Rightarrow v_1 = 0.339\ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h_{@200°C} = 475.2\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given p_2, V_2)

(a) $$\dot{m} = \frac{V_1 A_1}{v_1}; \quad \Rightarrow \dot{m} = \frac{(35)(0.0075)}{(0.339)}; \quad \Rightarrow \dot{m} = 0.774\ \frac{\text{kg}}{\text{s}}$$

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

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right); \qquad (\text{Since } \dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0, \Delta\text{pe} \cong 0)$$

$$\Rightarrow h_2 = h_1 - \frac{V_2^2 - V_1^2}{2};$$

$$\Rightarrow h_2 = (475.2) - \frac{(180)^2 - (35)^2}{2000};$$

$$\Rightarrow h_2 = 459.6 \ \frac{\text{kJ}}{\text{kg}};$$

$$\therefore T_2 = 457 \text{ K} = 184^\circ\text{C}$$

(c) The exit area of the nozzle

$$v_2 = \frac{RT_2}{p_2}; \qquad \Rightarrow v_2 = \frac{(0.287)(457)}{(150)}; \qquad \Rightarrow v_2 = 0.874 \ \frac{\text{m}^3}{\text{kg}};$$

$$\dot{m} = \frac{V_2 A_2}{v_2}; \qquad \Rightarrow 0.774 = \frac{(180)(A_2)}{(0.874)}; \qquad \Rightarrow A_2 = \frac{(0.874)(0.774)}{(180)};$$

$$\Rightarrow A_2 = 0.00375 \text{ m}^2 = 37.5 \text{ cm}^2$$

(d) The rate of entropy generation

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_1 - s_2\right) + \frac{\cancel{\dot{Q}}^{0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = \dot{m}(c_p \ln\frac{T_1}{T_2} - R\ln\frac{p_1}{p_2}) + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = (0.774)(1.005\ln\frac{(200)}{(184)} - 0.287\ln\frac{(400)}{(150)}) + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = (-0.1919) + \frac{(0)}{(25)} + \dot{S}_{\text{gen,univ}};$$

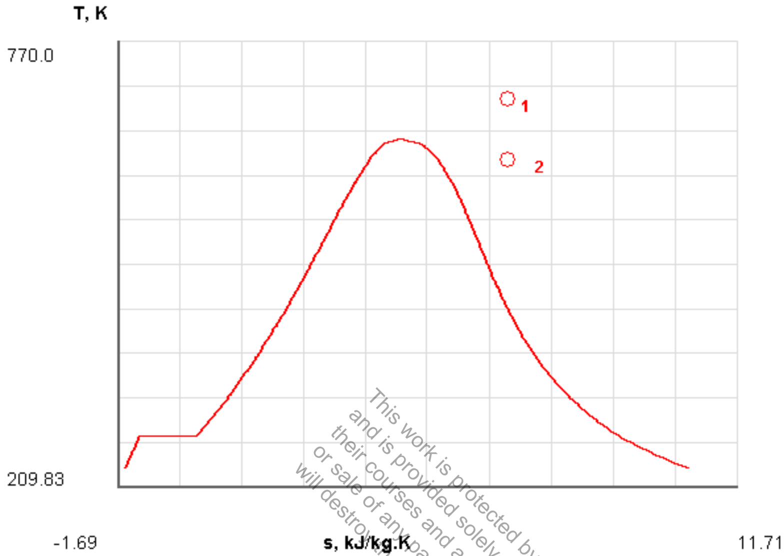
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.1919 \ \frac{\text{kW}}{\text{K}}$$

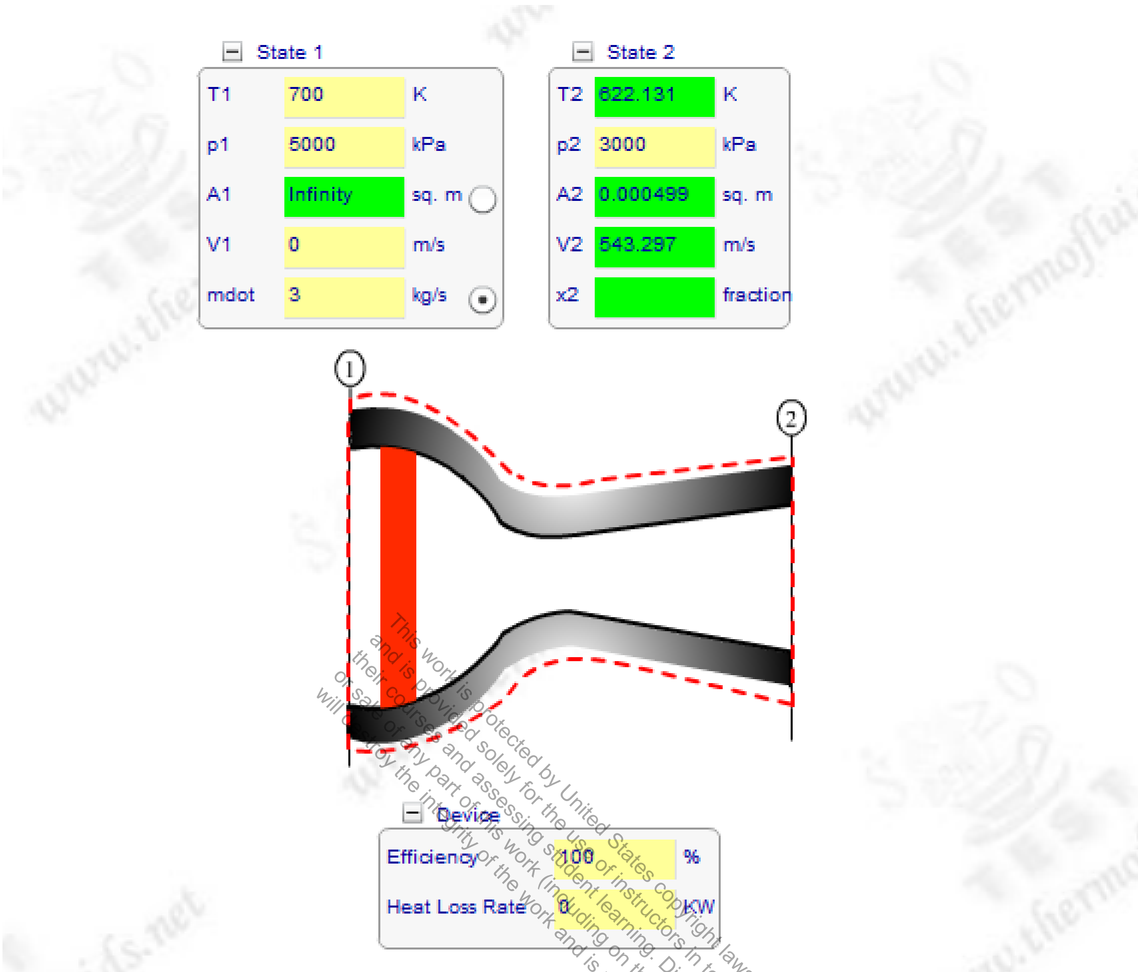
TEST Solution:

Launch the IG 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.

4-1-39 [BXF] Steam enters an insulated nozzle operating steadily at 5 MPa and 700 K with negligible velocity, and it exits at 3 MPa. If the mass flow rate (m·) is 3 kg/s, using the Nozzle Simulator RIA(linked from the left margin), determine (a) the exit velocity (V2), (b) the exit temperature (T2).

SOLUTION

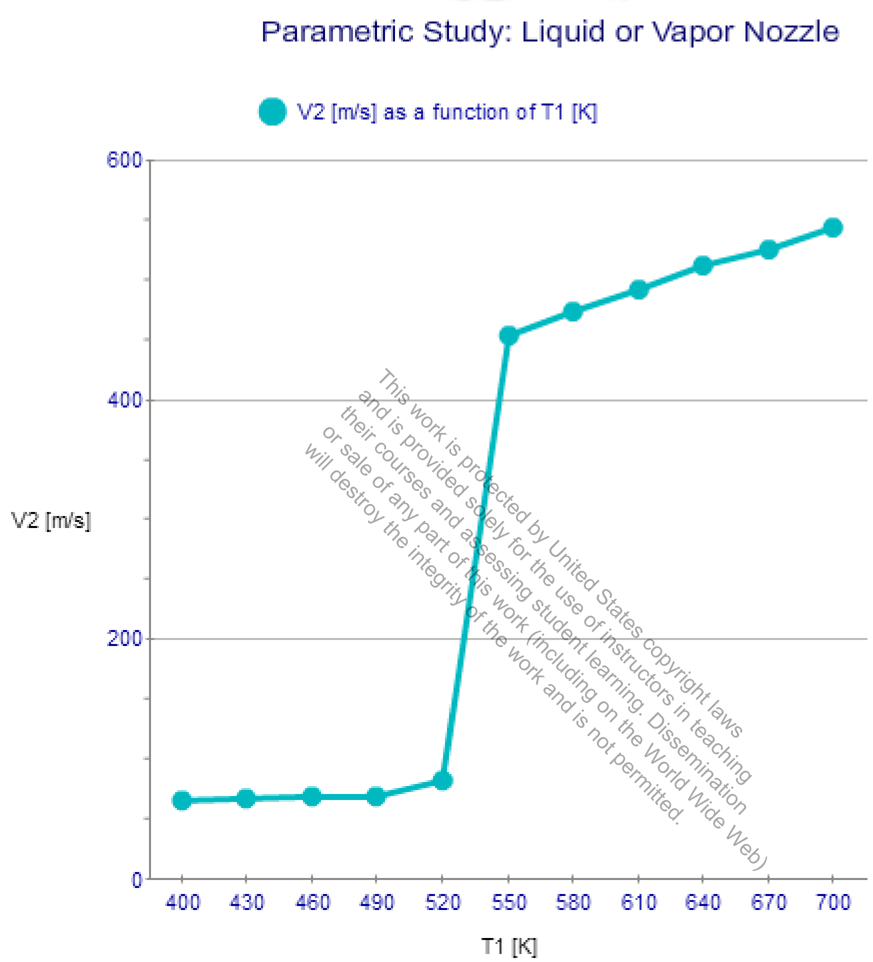




TEST Solution:
Launch the PC single-flow TESTcalc to verify the solution. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

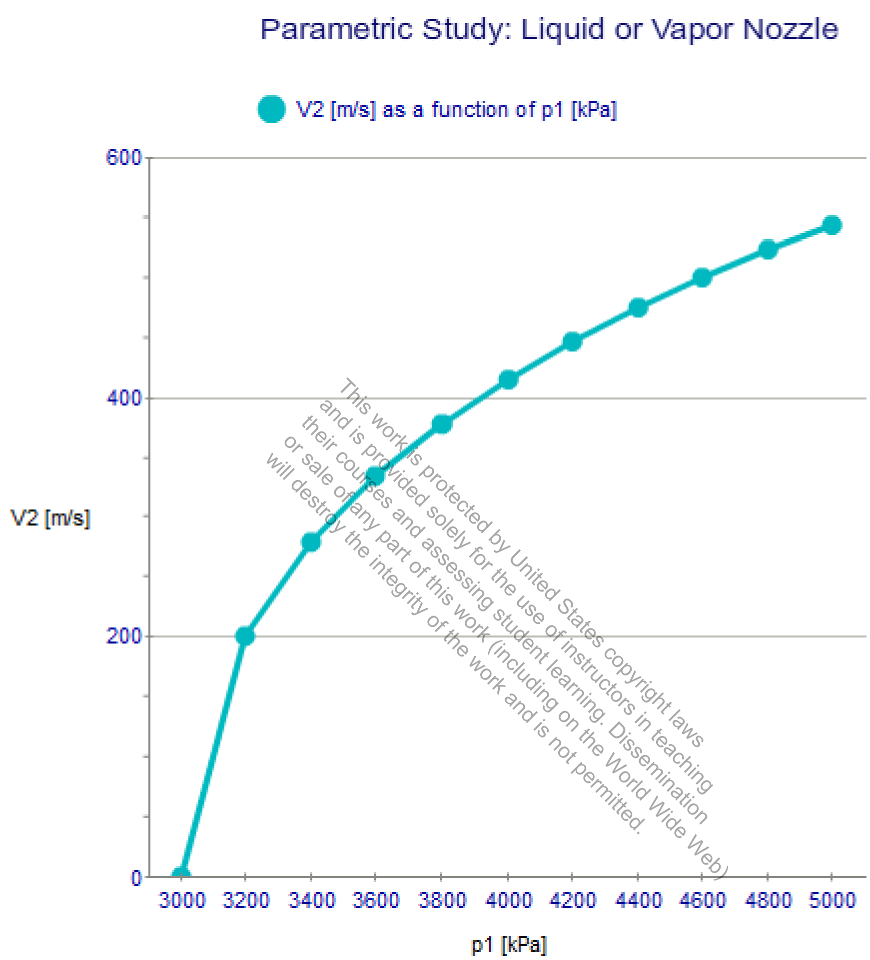
4-1-40 [BCE] For the nozzle described in previous problem, 4-1-39[BXF], plot how exit velocity (V2) varies with input temperature (T1) varying from 400 K to 700 K, all other input parameters remaining unchanged.

SOLUTION



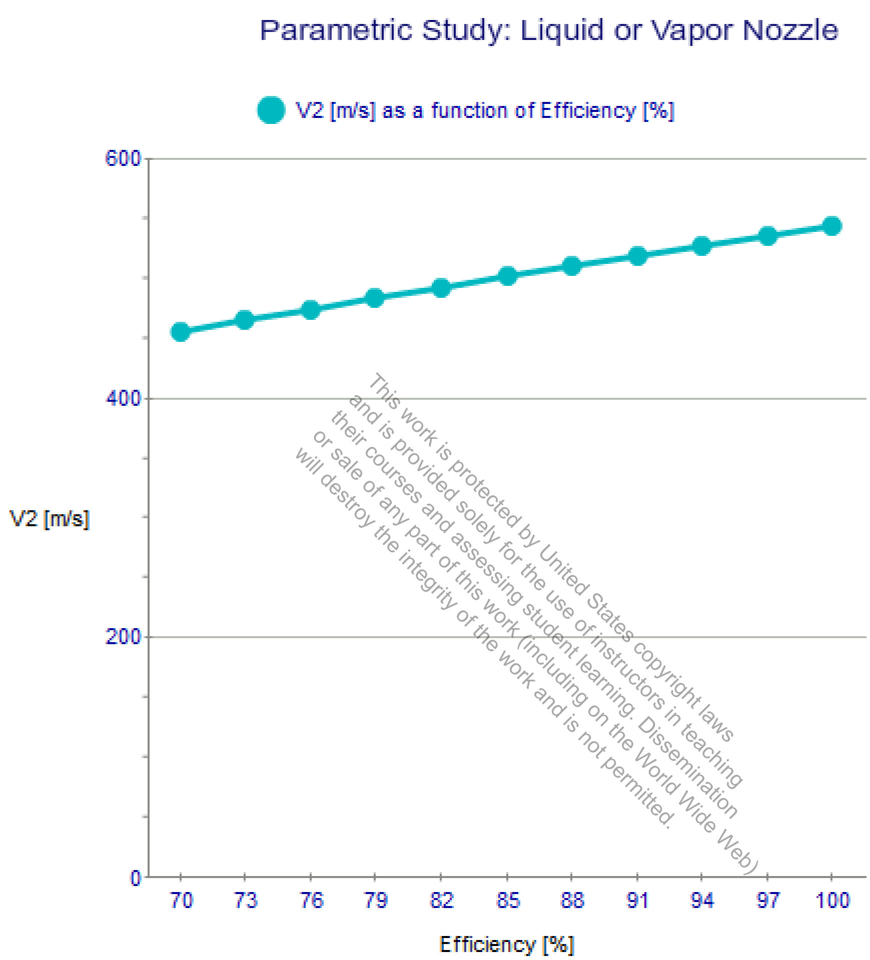
4-1-41 [BCI] For the nozzle described in previous problem, 4-1-44[BXF], plot how exit velocity (V2) varies with input pressure (p1) varying from 3 MPa to 5 MPa, all other input parameters remaining unchanged.

SOLUTION



4-1-42 [BCL] For the nozzle described in previous problem, 4-1-44[BXF], plot how exit velocity (V2) varies with isentropic efficiency of nozzle varying from 70% to 100%, all other input parameters remaining unchanged.

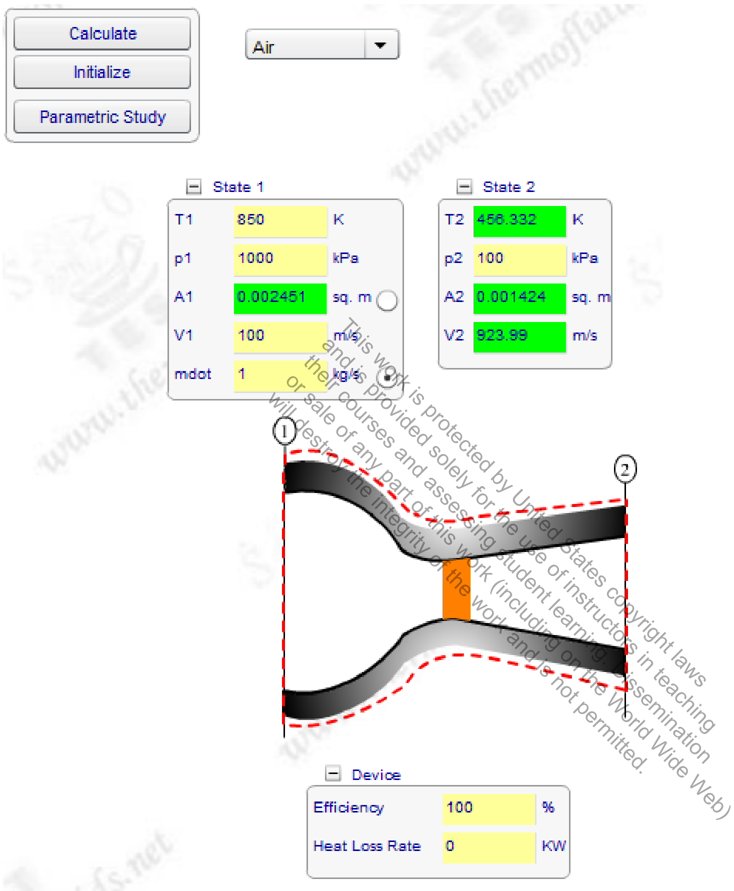
SOLUTION



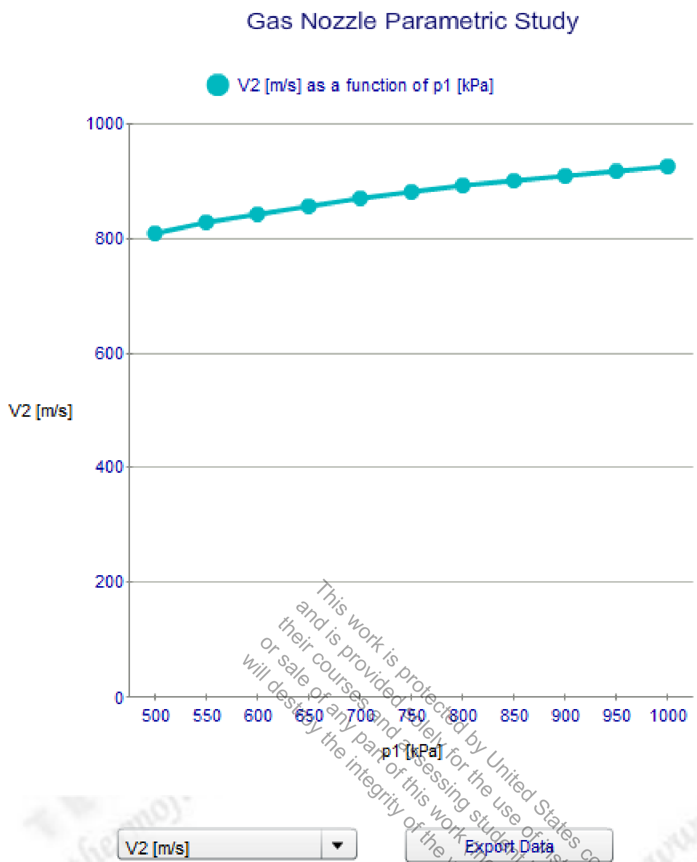
4-1-43 [BVA] Air expands in an isentropic horizontal nozzle from inlet conditions of 1.0 MPa, 850 K, 100 m/s to an exhaust pressure of 100 kPa. Using Nozzle Simulator RIA(linked from the left margin), (a) determine the exit velocity (V2), (b) plot how exit velocity varies with inlet pressure varying from 500 kPa to 1 MPa.

SOLUTION

(a)



(b)

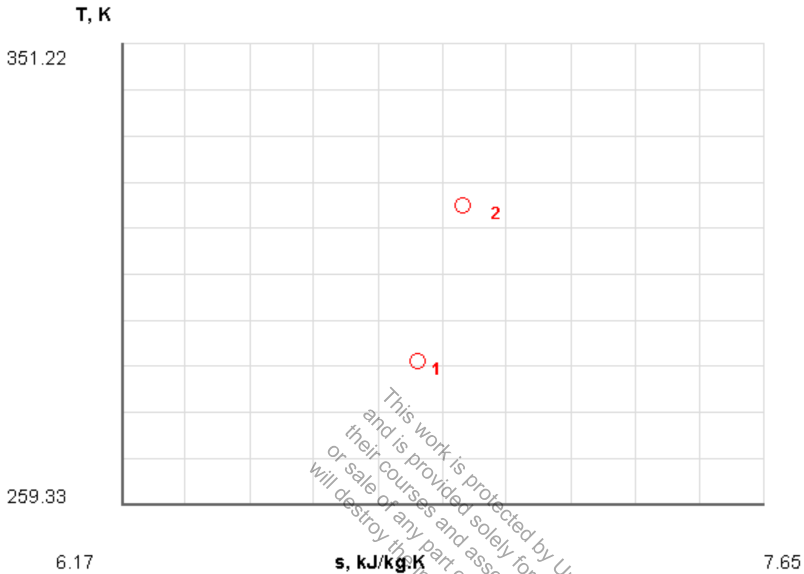


TEST Solution:

Launch the PG 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.

4-1-44 [WW] Air at 100kPa, 15oC and 250 m/s enters an insulated diffuser of a jet engine steadily. The inlet area of the diffuser is 0.5 m2. The air leaves the diffuser with a low velocity. Determine (a) the mass flow rate of the air and (b) the temperature of the air leaving the diffuser.

SOLUTION



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

State-1 (given p_1, T_1, A_1, V_1):

$$\rho_1 = \frac{p_1}{RT_1}; \quad \Rightarrow \rho_1 = 1.21 \ \frac{\text{kg}}{\text{m}^3};$$

(a) $\dot{m} = \rho_1 A_1 V_1; \quad \Rightarrow \dot{m} = (1.21)(0.5)(250); \quad \Rightarrow \dot{m} = 151.16 \ \frac{\text{kg}}{\text{s}}$

(b) From the energy balance equation

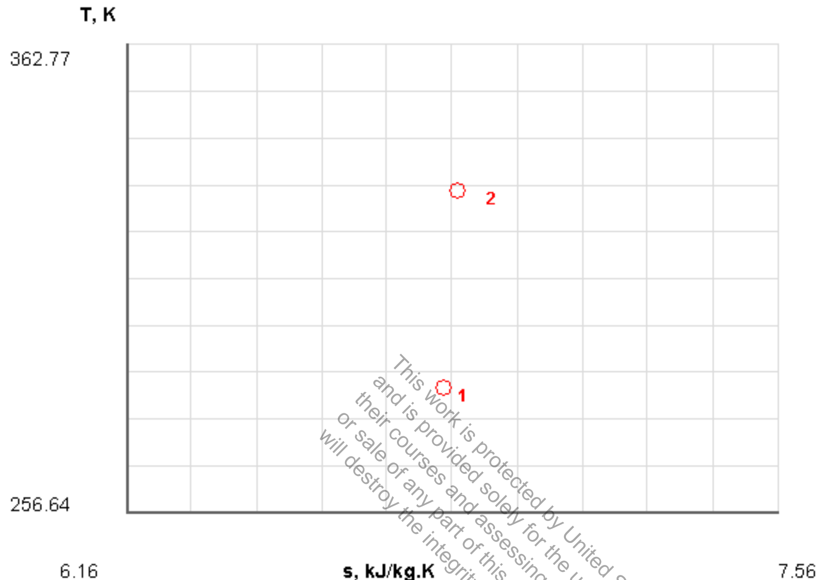
$$j_1 = j_2;$$
$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$
$$\Rightarrow h_2 - h_1 = \text{ke}_1 - \text{ke}_2;$$
$$\Rightarrow c_p(T_2 - T_1) = \text{ke}_1;$$
$$\Rightarrow T_2 = 15 + \frac{250^2}{(2000)(1.005)};$$
$$\Rightarrow T_2 = 46.09\ ^\circ\text{C}$$

TEST Solution:

Launch the PG 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.

4-1-45 [ORR] Air at 100kPa, 12oC, and 300 m/s enters the adiabatic diffuser of a jet engine steadily. The inlet area of the diffuser is 0.4 m2. The air leaves at 150 kPa and 20 m/s. Determine (a) the mass flow rate of the air, (b) the temperature of the air leaving the diffuser, and (c) the rate of entropy generation in the diffuser's universe. Neglect pe.

SOLUTION



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

State-1 (given $p_1,\ T_1,\ V_1,\ A_1$)

State-2 (given $p_2,\ V_2,\ \dot{m}$)

(a) $\dot{m} = \rho A_1 V_1; \quad \Rightarrow \dot{m} = (1.22)(0.4)(300); \quad \Rightarrow \dot{m} = 146.63\ \frac{\text{kg}}{\text{s}}$

(b) Using the PG model to evaluate the temperature of the air leaving the diffuser

$j_1 = j_2;$

$$\Rightarrow h_1 + \frac{V_1^2}{2000} = h_2 + \frac{V_2^2}{2000};$$

$$\Rightarrow \frac{V_2^2}{2000} - \frac{V_1^2}{2000} = h_1 - h_2;$$

$$\Rightarrow \frac{V_2^2}{2000} - \frac{V_1^2}{2000} = c_p(T_1 - T_2);$$

$$\Rightarrow T_2 = 285 - \frac{20^2 - 300^2}{(2000)(1.005)};$$

$$\Rightarrow T_2 = 329.57 \text{ K} = 56.57°\text{C}$$

(c) The rate of entropy generation

$$\frac{\cancel{dS}^{\,0}}{\cancel{dt}} = \dot{m}(s_1 - s_2) + \frac{\cancel{\dot{Q}}^{\,0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = \dot{m}\left(c_p \ln\frac{T_1}{T_2} - R\ln\frac{p_1}{p_2}\right) + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = (146.63)\left(1.005\ln\frac{(329.57)}{(285)} - 0.287\ln\frac{(150)}{(100)}\right) + \dot{S}_{\text{gen,univ}};$$

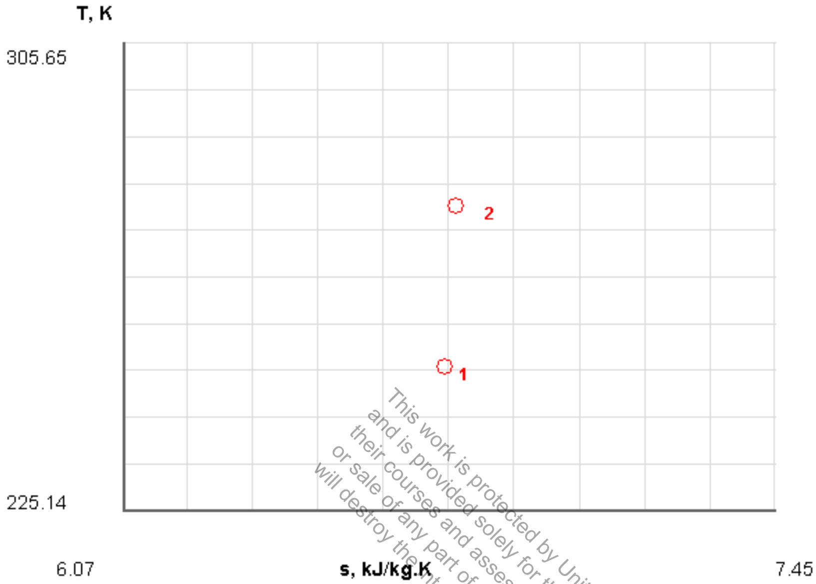
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 4.39 \ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

Launch the PG 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.

4-1-46 [WJ] Nitrogen enters an adiabatic diffuser at 75 kPa, -23oC and 240 m/s. The inlet diameter of the diffuser is 80 mm. It leaves at 100kPa, and 21 m/s. Determine (a) the mass flow rate of the air, (b) the temperature of the air leaving the diffuser, and (c) the rate of entropy generation in the diffuser's universe. Neglect PE.

SOLUTION



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

State-1 (given p_1, T_1, A_1, V_1):

$$\rho_1 = \frac{p_1}{RT_1}; \quad \Rightarrow \rho_1 = 1.009 \ \frac{\text{kg}}{\text{m}^3};$$

State-2 (given p_2, V_2)

(a) $\dot{m} = \rho_1 A_1 V_1; \quad \Rightarrow \dot{m} = (1.009)(0.005)(240); \quad \Rightarrow \dot{m} = 1.21 \ \frac{\text{kg}}{\text{s}}$

(b) Using the PG model to evaluate the temperature of the air leaving the diffuser

$$j_1 = j_2;$$
$$\Rightarrow h_1 + \text{ke}_1 = h_2 + \text{ke}_2;$$
$$\Rightarrow \text{ke}_2 - \text{ke}_1 = h_1 - h_2;$$
$$\Rightarrow \text{ke}_2 - \text{ke}_1 = c_p(T_1 - T_2);$$
$$\Rightarrow T_2 = 250 - \frac{21^2 - 240^2}{(2000)(1.039)};$$
$$\Rightarrow T_2 = 277.5 \text{ K} = 4.5°\text{C}$$

(c) The change in entropy between the inlet and exit can be evaluated using the PG model.

$$\Delta s = s_2 - s_1;$$

$$\Rightarrow \Delta s = c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1};$$

$$\Rightarrow \Delta s = (1.039)\ln\frac{277.5}{250} - (0.296)\ln\frac{100}{75};$$

$$\Rightarrow \Delta s = 0.0234\ \frac{\text{kW}}{\text{K}}$$

The rate of entropy generation

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}(s_1 - s_2) + \frac{\cancel{\dot{Q}}^{0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow 0 = \dot{m}\Delta s + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\Delta s;$$

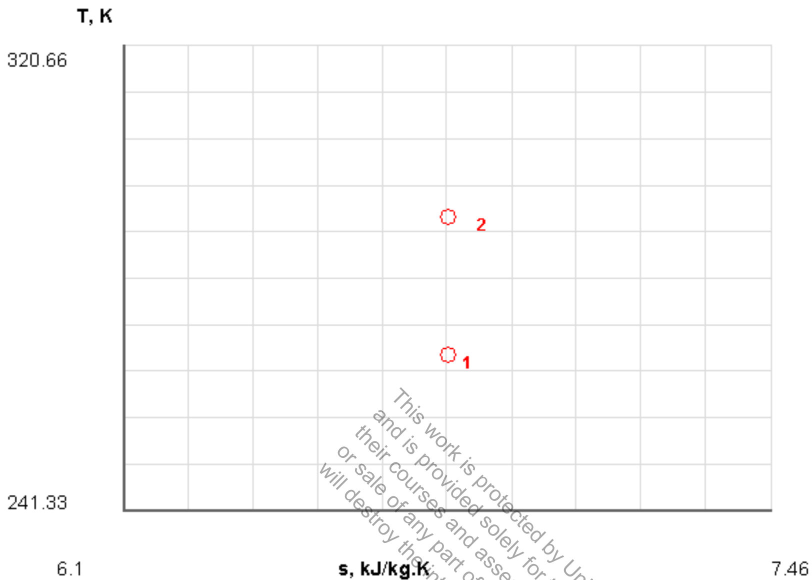
$$\Rightarrow 0 = (1.21)(0.0234) + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.028\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:
Launch the PG 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.

4-1-47 [ORB] Air enters an insulated diffuser operating at steady state at 100 kPa, -5oC and 250 m/s and exits with a velocity of 125 m/s. Neglecting any change in *pe* and thermodynamic friction, determine: (a) The temperature of air at the exit. (b) The pressure at the exit. (c) The exit-to-inlet area ratio.

SOLUTION



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

State-1 (given $p_1,\ T_1,\ V_1$)

State-2 (given $V_2,\ s_2 = s_1$)

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

(Since $\dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0, \Delta\text{pe} \cong 0$)

$$0 = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right);$$

$$\Rightarrow h_2 - h_1 = \frac{V_1^2 - V_2^2}{2000};$$

$$\Rightarrow h_2 - h_1 = \frac{250^2 - 125^2}{2000};$$

$$\Rightarrow h_2 - h_1 = 23.4375;$$

$$\Rightarrow c_p\left(T_2 - T_1\right) = 23.4375;$$

$$\Rightarrow T_2 = T_1 + \frac{23.4375}{c_p};$$

$$\Rightarrow T_2 = -5 + \frac{23.4375}{1.003};$$

$$\Rightarrow T_2 = 18.37°\text{C}$$

(b) The isentropic relations provide

$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}};$$

$$p_2 = p_1\left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}};$$

$$\Rightarrow p_2 = (100)\left(\frac{291.37}{268}\right)^{\frac{1.4}{1.4-1}};$$

$$\Rightarrow p_2 = 134\ \text{kPa}$$

(c) $$\frac{v_1}{v_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{k}};$$

$$\Rightarrow \frac{v_1}{v_2} = \left(\frac{134}{100}\right)^{\frac{1}{1.4}};$$

$$\Rightarrow \frac{v_1}{v_2} = 1.233;$$

$$\Rightarrow \frac{v_2}{v_1} = 0.811;$$

From the mass balance equation:

$$\frac{d\cancel{m}^{0}}{\cancel{dt}} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\dot{m} = \rho A V;$$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2;$$

$$\frac{A_2}{A_1} = \frac{v_2}{v_1}\frac{V_1}{V_2};$$

$$\Rightarrow \frac{A_2}{A_1} = (0.811)\left(\frac{250}{125}\right);$$

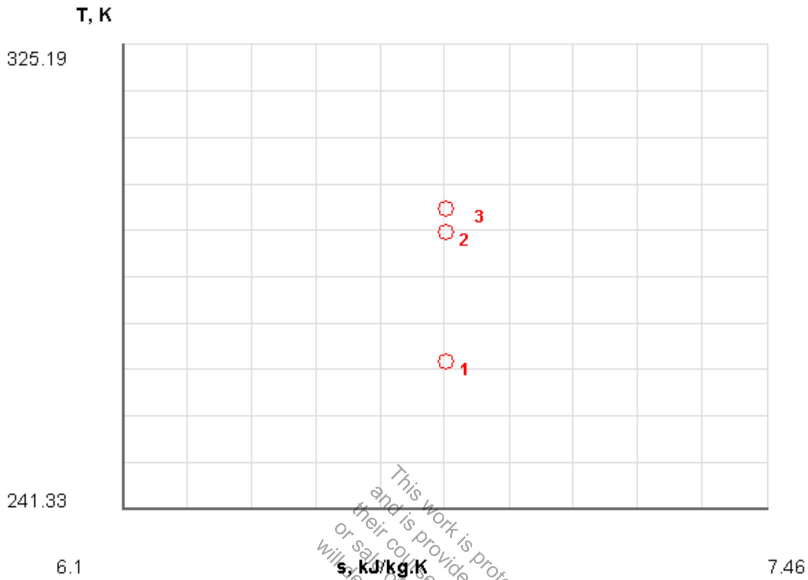
$$\Rightarrow \frac{A_2}{A_1} = 1.622$$

TEST Solution:

Launch the PG 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.

4-1-48 [ORO] Repeat problem 4-1-41 [ORB] assuming thermodynamic friction in the diffuser causes its efficiency to go down to 85%.

SOLUTION



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

State-1 (given $p_1,\ T_1,\ V_1$)

State-2 (given $V_2,\ s_2 = s_1$)

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

(Since $\dot{Q} \cong 0,\ \dot{W}_{\text{ext}} = 0, \Delta\text{pe} \cong 0$)

$$0 = \dot{m}\left(0.85\left(h_1 - h_2\right) + \frac{V_1^2 - V_2^2}{2000}\right);$$

$$\Rightarrow h_2 - h_1 = \frac{V_1^2 - V_2^2}{0.85(2000)};$$

$$\Rightarrow h_2 - h_1 = \frac{250^2 - 125^2}{0.85(2000)};$$

$$\Rightarrow h_2 - h_1 = 27.5735;$$

$$\Rightarrow c_p(T_2 - T_1) = 27.5735;$$

$$\Rightarrow T_2 = T_1 + \frac{27.5735}{c_p};$$

$$\Rightarrow T_2 = -5 + \frac{27.5735}{1.003};$$

$$\Rightarrow T_2 = 22.5°\text{C}$$

(b) The isentropic relations provide

$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}};$$

$$p_2 = p_1\left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}};$$

$$\Rightarrow p_2 = (100)\left(\frac{295.5}{268}\right)^{\frac{1.4}{1.4-1}};$$

$$\Rightarrow p_2 = 140.8 \text{ kPa}$$

(c) $\frac{v_1}{v_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{k}};$

$$\Rightarrow \frac{v_1}{v_2} = \left(\frac{140.8}{100}\right)^{\frac{1}{1.4}};$$

$$\Rightarrow \frac{v_1}{v_2} = 1.277;$$

$$\Rightarrow \frac{v_2}{v_1} = 0.783;$$

From the mass balance equation:

$$\frac{d\cancel{m}^{0}}{\cancel{dt}} = \sum \dot{m}_i - \sum \dot{m}_e;$$

$$\dot{m} = \rho A V;$$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2;$$

$$\frac{A_2}{A_1} = \frac{v_2}{v_1}\frac{V_1}{V_2};$$

$$\Rightarrow \frac{A_2}{A_1} = (0.783)\left(\frac{250}{125}\right);$$

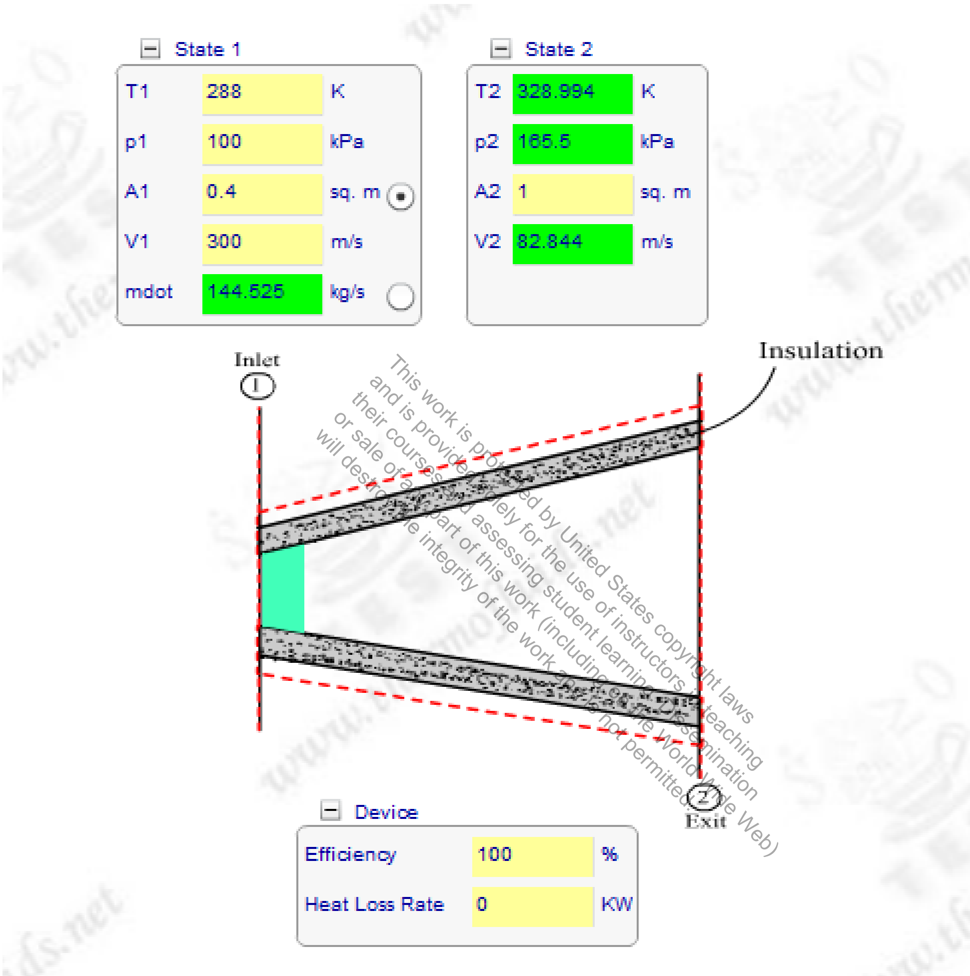
$$\Rightarrow \frac{A_2}{A_1} = 1.566$$

TEST Solution:

Launch the PG 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.

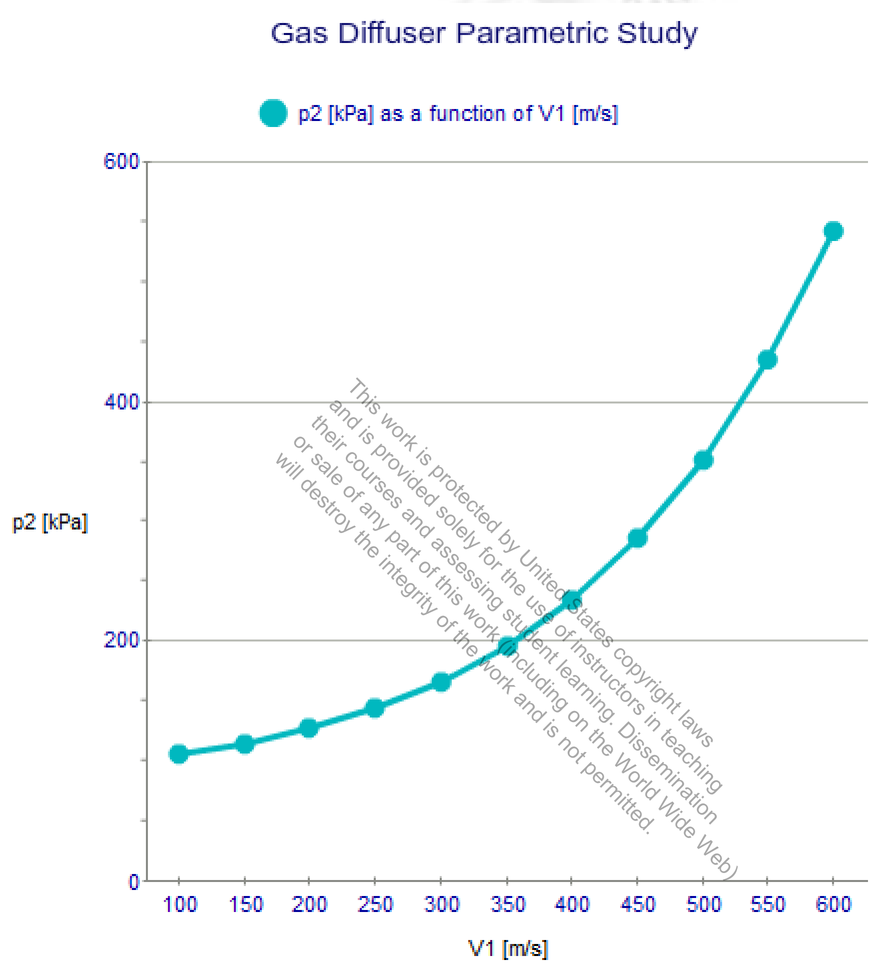
4-1-49 [BCX] Air at 100 kPa, 15oC, and 300 m/s enters the adiabatic diffuser of a jet engine steadily. The inlet area of the diffuser is 0.4 m2, and exit area of the diffuser is 1 m2. Using the Diffuser Simulator (linked from the left margin), calculate (a) exit pressure (p2), (b) exit temperature (T2).

SOLUTION



4-1-50 [BCC] Using the diffuser described in the previous problem, 4-1-55[BCX], plot how exit pressure (p2) varies with inlet velocity (V1) varying from 100 m/s to 600 m/s, all other input parameters remaining unchanged.

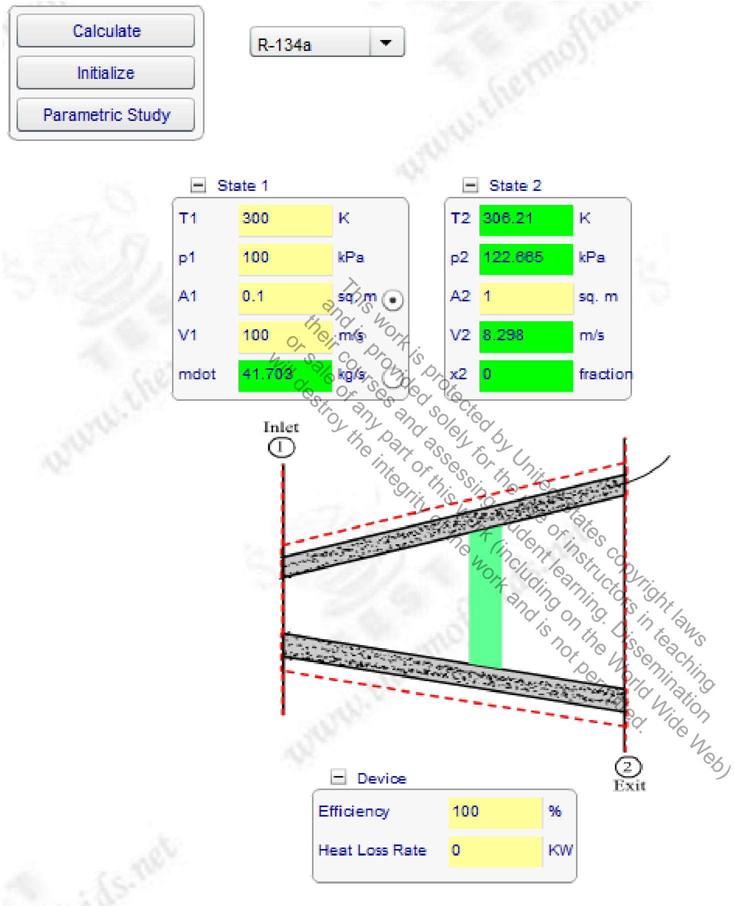
SOLUTION



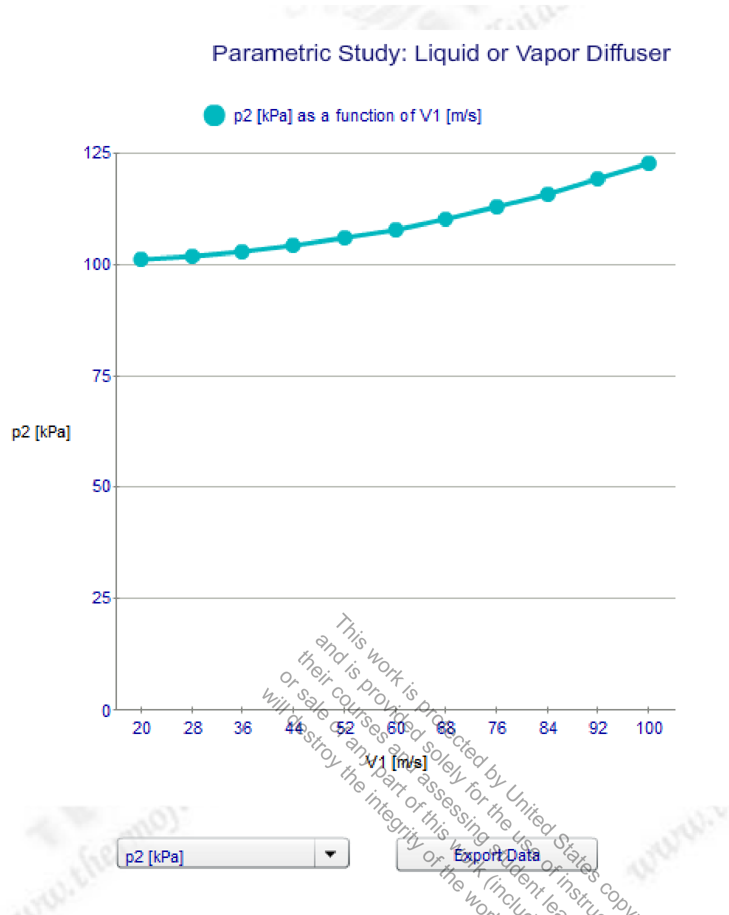
4-1-51 [BVI] Refrigerant R-134a at 100 kPa, 300 K, and 100 m/s enters the adiabatic diffuser of a jet engine steadily. The inlet area of the diffuser is 0.1 m2, and exit area of the diffuser is 1 m2. Using the Diffuser Simulator (linked from the left margin), calculate (a) exit pressure (p2), (b) exit temperature (T2). Plot how exit pressure varies with inlet velocity varying from 20 m/s to 100 m/s.

SOLUTION

(a)

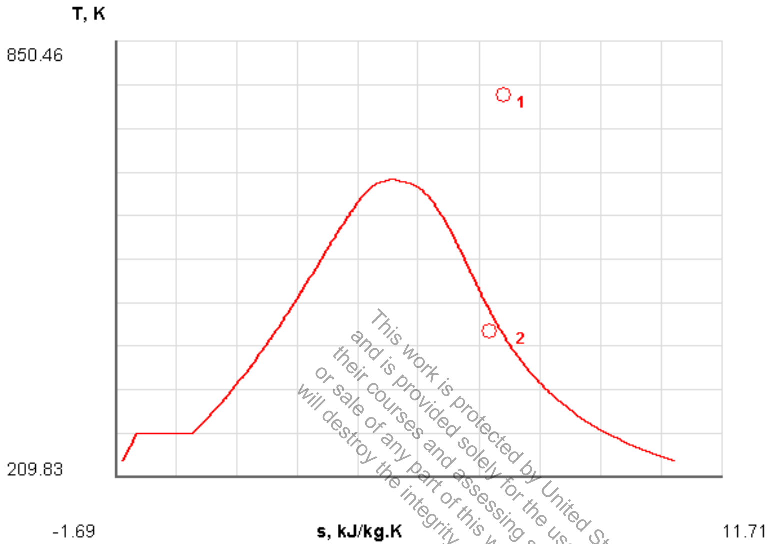


(b)


Parametric Study: Liquid or Vapor Diffuser
p2 [kPa] as a function of V1 [m/s]
p2 [kPa]
V1 [m/s]
125
100
75
50
25
0
20
28
36
44
52
60
68
76
84
92
100
p2 [kPa]
Export Data

4-1-52 [ORH] Steam enters a turbine operating at steady state with a mass flow rate of 1.5 kg/s. At the inlet, the pressure is 6 MPa, the temperature is 500oC, and the velocity is 20 m/s. At the exit , the pressure is 0.5 MPa, the quality is 0.95(95%), and the velocity is 75 m/s The turbine develops a power output of 2500 kW. Determine (a) the rate of heat transfer (b) ***What-if scenario:*** How would the answer change if ke was neglected at the inlet and exit?

SOLUTION



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

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

$$h_1 = 3422.21 \ \frac{\text{kJ}}{\text{kg}};$$

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

$$h_f + x_2 h_{fg} = [640.23 + (.95)(2108.5)] = 2643.30 \ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation on the steady turbine, we have

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

$$\Rightarrow \dot{Q} = \dot{m}(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2000}) + \dot{W}_T; \quad (\text{since } \Delta pe \cong 0)$$

$$\Rightarrow \dot{Q} = 1.5(2643.30 - 3422.2 + \frac{75^2 - 20^2}{2000}) + 2500;$$

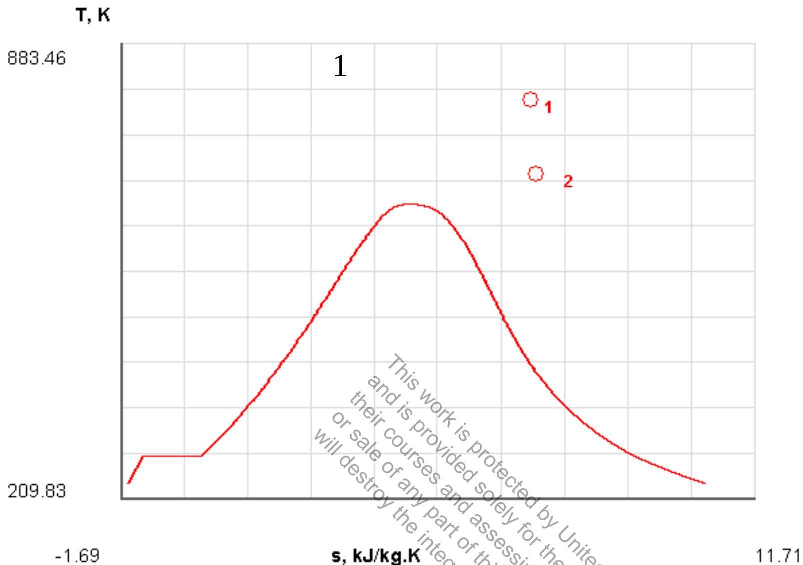
$$\Rightarrow \dot{Q} = 1335.5 \text{ kW} = 1.336 \text{ MW}$$

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.

4-1-53 [ORS] Steam enters an adiabatic turbine steadily at 6 MPa and 530oC, and exits at 2.5 MPa, 420oC. The mass flow rate is 0.127 kg/s. Determine (a) the external power, (b) the ratio of exit flow area to the inlet flow area to keep the exit velocity equal to the inlet velocity. Neglect ke and pe.

SOLUTION



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

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

$$h_1 = 3493.19\ \frac{\text{kJ}}{\text{kg}};$$

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

$$h_2 = 3283.85\ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation on the steady turbine, we have

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

$$\Rightarrow \dot{W}_T = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \ \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_T = 0.127(3492.19 - 3283.85);$$

$$\Rightarrow \dot{W}_T = 26.58 \text{ kW}$$

(b) The ratio of exit flow area to the inlet flow area to keep the exit velocity equal to the inlet velocity is

$$\dot{m} = \frac{A_1 V}{v_1}; \quad \dot{m} = \frac{A_2 V}{v_2}; \quad (V_1 = V_2)$$

$$\Rightarrow \frac{A_2}{A_1} = \frac{v_2}{v_1};$$

$$\Rightarrow \frac{A_2}{A_1} = \frac{0.12411}{0.0592};$$

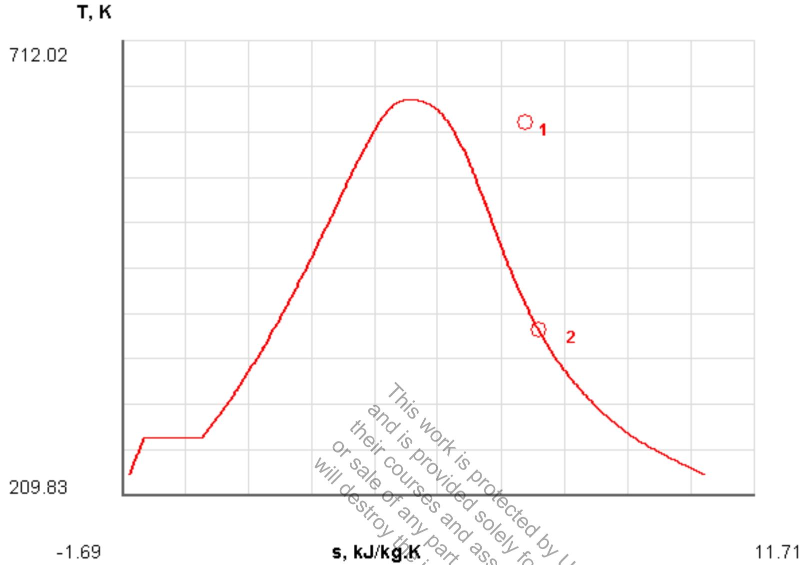
$$\Rightarrow \frac{A_2}{A_1} = 2.09$$

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.

4-1-54 [ORA] Steam enters a turbine steadily at 2.5 MPa, 350oC, 60 m/s, and exits at 0.2 MPa, 100% quality, and 230 m/s. The mass flow rate into the turbine is 1.7 kg/s, and the heat transfer from the turbine is 8 kW. Determine (a) the power output of the turbine and (b) the energetic efficiency. (c) Draw an energy flow diagram for the turbine.

SOLUTION



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

State-1 (given $p_1, T_1, V_1, \dot{m}_1$):

$$h_1 = 3126.21 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2, x_2, V_2, \dot{m}_2 = \dot{m}_1$):

$$h_2 = 2706.62 \ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation on the steady turbine, we have

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

$$\Rightarrow \dot{W}_T = \dot{m}(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}) - \dot{Q}; \qquad (\text{since } \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_T = 1.7\left(3126.21 - 2706.624 + \frac{60^2 - 230^2}{2000}\right) - 8;$$

$$\Rightarrow \dot{W}_T = 663.39 \text{ kW}$$

(b) The energetic efficiency

$$\eta_{\mathrm{I}} = \frac{\dot{m}\left(j_2 - j_1\right)}{-\dot{W}_{\mathrm{ext}}};$$

$$\Rightarrow \eta_{\mathrm{I}} = \frac{\dot{Q} - \dot{W}_{\mathrm{ext}}}{-\dot{W}_{\mathrm{ext}}};$$

$$\Rightarrow \eta_{\mathrm{I}} = \frac{(8) - (663.4)}{-(663.4)};$$

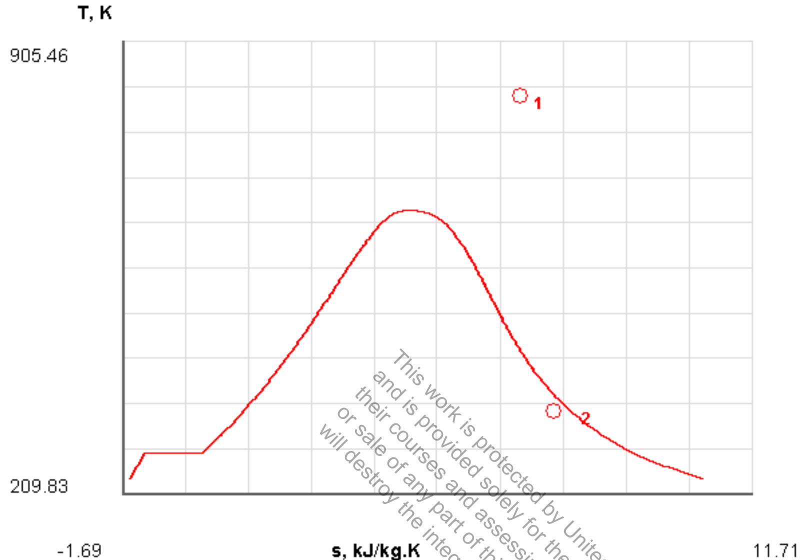
$$\Rightarrow \eta_{\mathrm{I}} = 98.8\ \%$$

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.

4-1-55 [ORN] Steam enters a turbine steadily at 10 MPa, 550 oC, 50 m/s, and exits at 25 kPa and 95% quality. The inlet and exit areas are 150 cm2 and 4000 cm2 respectively. A heat loss of 50 kJ/kg occurs in the turbine. Determine (a) the mass flow rate, (b) exit velocity, and (c) the power output. (d) ***What-if scenario:*** How would the answers in parts (b) and (c) change if the turbine was redesigned with an exit area of 5000 cm2?

SOLUTION



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

State-1 (given p_1, T_1, A_1, V_1):

$$h_1 = 3500.94\ \frac{\text{kJ}}{\text{kg}}; \quad v_1 = 0.03564\ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given p_2, x_2, A_2):

$$h_2 = h_f + x_2 h_{fg} = [271 + (.95)(2346.3)] = 2499.98\ \frac{\text{kJ}}{\text{kg}};$$

$$v_2 = 5.8948\ \frac{\text{m}^3}{\text{kg}};$$

(a) From the mass balance equation on the steady turbine, we have

$$\dot{m} = \frac{A_1 V_1}{v_1} = \frac{(0.015)(50)}{0.03564} = 21.04\ \frac{\text{kg}}{\text{s}}$$

(b) $$V_2 = \frac{\dot{m} v_2}{A_2} = \frac{(21.04)(5.8948)}{0.4} = 310.06\ \frac{\text{m}}{\text{s}}$$

(c) From the energy balance equation on the steady turbine, we have

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

$$\Rightarrow \dot{W}_T = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right) - \dot{Q}; \quad \text{(since } \Delta\text{pe} \cong 0\text{)}$$

$$\Rightarrow \dot{W}_T = 21.04\left(3500.9 - 2499.98 + \frac{50^2 - 310.06^2}{2000}\right) - (50)(21.04);$$

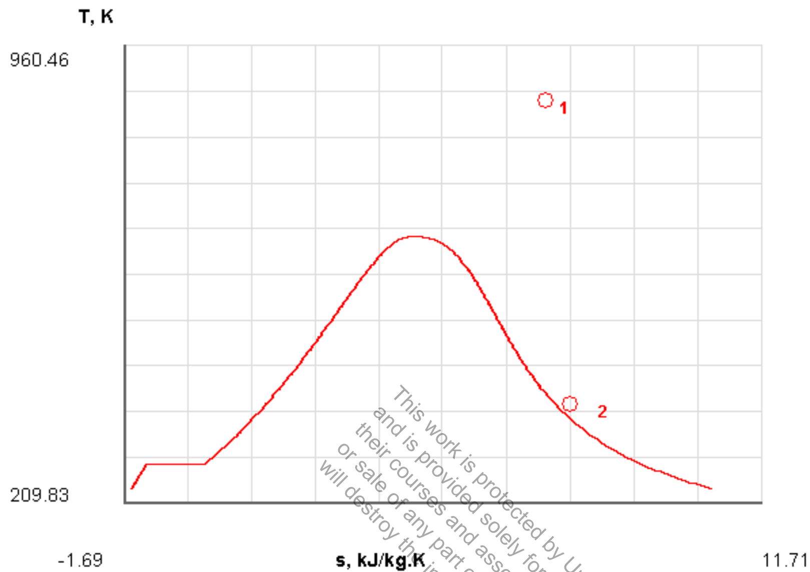
$$\Rightarrow \dot{W}_T = 19.022 \text{ MW}$$

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.

4-1-56 [ORE] Steam enters an adiabatic turbine steadily at 6 MPa and 600oC, 50 m/s, and exits at 50 kPa, 100oC, 150 m/s. The turbine produces 5 MW. Determine (a) the mass flow rate. Neglects pe. (b) ***What-if scenario:*** How would the answer change if ke was also neglected?

SOLUTION



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

State-1 (given p_1, T_1, V_1):

$$h_1 = 3658.37 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given p_2, T_2, V_2):

$$h_2 = 2682.36 \ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation on the steady turbine, we have

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

$$\Rightarrow \dot{W}_T = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{m} = \frac{\dot{W}_T}{\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right)};$$

$$\Rightarrow \dot{m} = \frac{5000}{\left(3658.37 - 2682.36 + \frac{50^2 - 150^2}{2000}\right)};$$

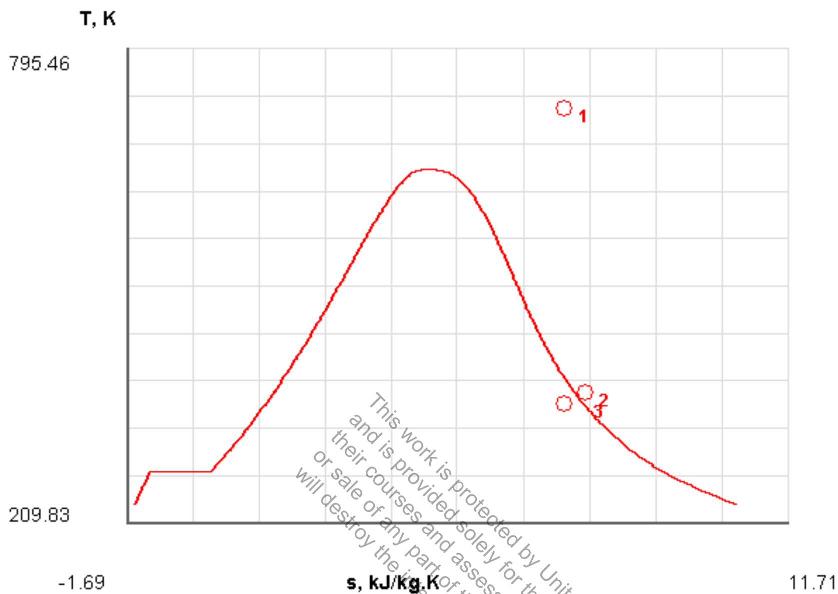
$$\Rightarrow \dot{m} = 5.17 \ \frac{\text{kg}}{\text{s}}$$

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.

4-1-57 [ORI] Steam enters an adiabatic turbine steadily at 2.5 MPa and 450 oC, and exits at 60 kPa, 100oC. If the power output of the turbine is 3 MW, determine (a) the mass flow rate, (b) the isentropic efficiency, and (c) the rate of internal entropy generation in the turbine.

SOLUTION



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

State-1 (given p_1, T_1):

$$h_1 = 3350.80\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.174\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given p_2, T_2):

$$h_2 = 2681.07\ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 7.603\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_2, s_3 = s_1$):

$$h_3 = 2524.85\ \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation on the steady turbine, we have

$$\dot{W}_T = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

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

$$\Rightarrow \dot{m} = \frac{3000}{(3350.80 - 2681.07)};$$

$$\Rightarrow \dot{m} = 4.48 \ \frac{\text{kg}}{\text{s}}$$

(b) Isentropic work:

$$\dot{W}_{T,s} = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{T,s} = 4.48(3350.80 - 2524.85);$$

$$\Rightarrow \dot{W}_{T,s} = 3700.3 \text{ kW};$$

The isentropic efficiency now can be evaluated as

$$\eta_T \equiv \frac{\dot{W}_T}{\dot{W}_{T,s}} = \frac{3000.0}{3700.3} = 81.1\%$$

(c) The entropy balance equation, applied on the turbine's universe produces

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_1 - s_2\right) + \frac{\cancel{\dot{Q}}^{0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(4.48\right)\left(7.603 - 7.174\right);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 1.92 \ \frac{\text{kW}}{\text{K}}$$

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.

4-1-58 [ORL] Steam enters an adiabatic turbine, operating at steady state, with a flow rate of 10 kg/s at 1000 kPa, 400°C and leaves at 40°C with a quality of 0.9 (90%). Neglecting changes in ke and pe, determine (a) the pressure (in kPa) at the turbine exit, (b) the turbine output in MW, and (c) the rate of entropy generation, (d) ***What-if Scenario:*** If the exit velocity was to be limited to 30 m/s, what would be the required exit area in m2?

SOLUTION

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

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

$$h_1 = 3263.86\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 7.4649\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $T_2, x_2, \dot{m}_2 = \dot{m}_1$):

$$h_2 = 2333.61\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 7.4887\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_2 = p_{\text{sat@40°C}} = 7.38\ \text{kPa}$

(b) From the energy balance equation on the steady turbine, we have

$$\dot{W}_T = \dot{m}(h_1 - h_2);\quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_T = (10)(3263.86 - 2333.61);$$

$$\Rightarrow \dot{W}_T = 9302.5\ \text{kW} = 9.3\ \text{MW}$$

(c) From the entropy balance equation on the steady turbine, we have

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

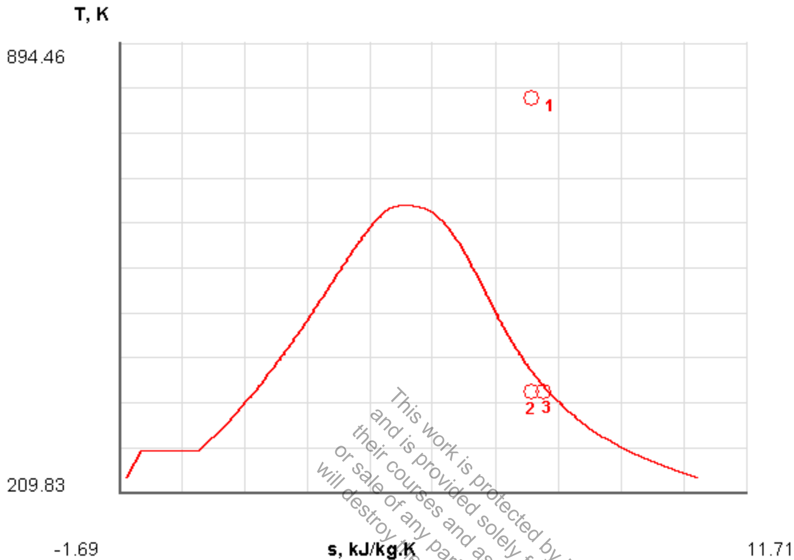
$$\Rightarrow \dot{S}_{\text{gen,univ}} = (10)(7.4887 - 7.4649);$$

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

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.

4-1-59 [ORG] Steam enters an adiabatic turbine steadily at 5 MPa and 540 oC, with a mass flow rate of 5 kg/s and leaves at 75 kPa. The isentropic efficiency of the turbine is 0.90. Determine (a) the temperature at the exit of the turbine and (b) the power output of the turbine. (c) Draw energy and entropy flow diagrams for the turbine.

SOLUTION



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

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

$$h_1 = 3526.91 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.092 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

State-3 (given $p_3 = p_2, s_3 = s_1, \dot{m}_3 = \dot{m}_1$):

$$h_3 = 2529.93 \ \frac{\text{kJ}}{\text{kg}};$$

The efficiency of the turbine is:

$$\eta_T \equiv \frac{\dot{W}_T}{\dot{W}_{T,s}} = \frac{h_1 - h_2}{h_1 - h_3} = 0.9;$$

$$h_2 = h_1 - \left(0.9\left(h_1 - h_3\right)\right);$$

$$\Rightarrow h_2 = 3526.91 - \left(0.9\left(3526.91 - 2529.93\right)\right);$$

$$\Rightarrow h_2 = 2629.63 \ \frac{\text{kJ}}{\text{kg}};$$

(a) The temperature at 75 kPa and specific enthalpy of $2629.63\ \dfrac{\text{kJ}}{\text{kg}}$

$$T_2 = 91.7^\circ\text{C}$$

(b) From the energy balance equation on the steady turbine, we have

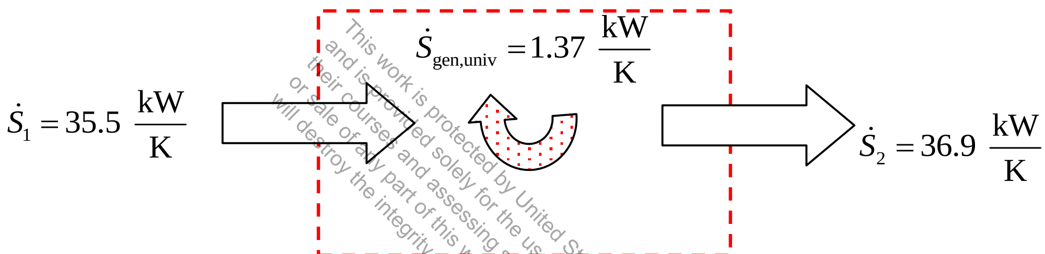
$$\dot{W}_T = \dot{m}\left(j_1 - j_2\right);$$

$$\Rightarrow \dot{W}_T = \dot{m}\left(h_1 - h_2\right); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \ \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_T = 5\left(3526.91 - 2629.63\right);$$

$$\Rightarrow \dot{W}_T = 4486\ \text{kW}$$

(c) Energy and entropy flow diagram.

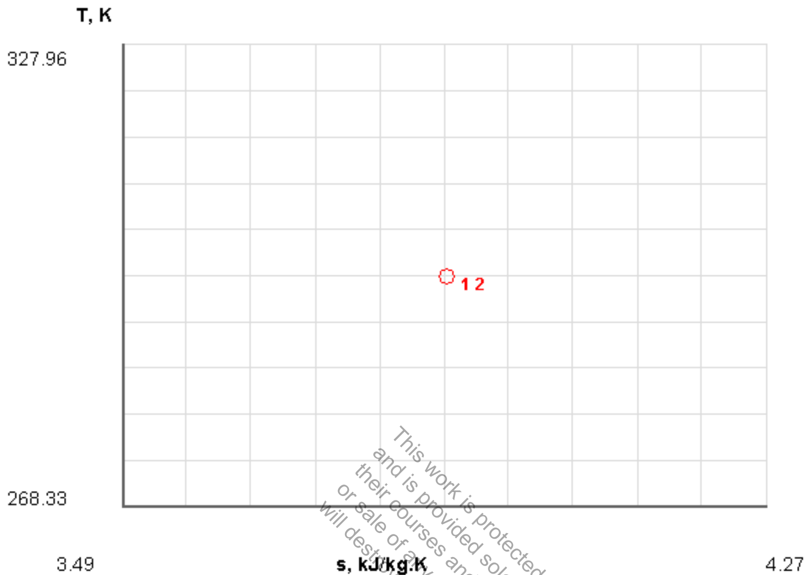


TEST Solution:

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.

4-1-60 [ORP] A hydroelectric power plant operates at steady state. The difference of elevation between the upstream and downstream reservoirs is 600 m. For a discharge of 150 m3s, determine the maximum power output. Use the SL model for water.

SOLUTION



Let state-1 represent the inlet, and state-2 the exit state.

Given:
$\Delta z = 600 \text{ m}$

State-1 (given p_1, T_1)

State-2 (given $p_2 = p_1, T_2 = T_1$)

At room temperature the density of water is 997 $\frac{\text{kg}}{\text{m}^3}$

The mass flow rate becomes

$$\dot{m} = \rho \dot{V} = (997)(150);$$

$$\Rightarrow \dot{m} = 149550 \ \frac{\text{kg}}{\text{s}};$$

From the energy balance equation for the steady state, we have

$$\dot{W}_T = \dot{m}\left(g\frac{\Delta z}{1000}\right); \quad (\text{since } \dot{Q} \cong 0, \, \Delta \text{h} \cong 0, \text{and } \Delta \text{ke} \cong 0)$$

$$\Rightarrow \dot{W}_T = 149550\left(9.8\frac{600}{1000}\right);$$

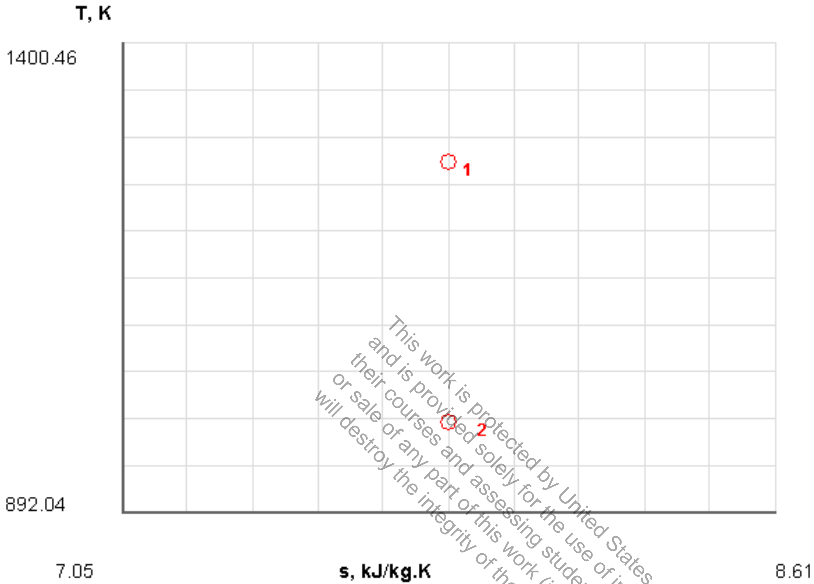
$$\Rightarrow \dot{W}_T = 879.4 \text{ MW}$$

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.

4-1-61 [ORZ] Hot gases enter a well-insulated jet engine turbine with a velocity of 50 m/s, a temperature of 1000oC, and a pressure of 600 kPa. The gases exit the turbine at a pressure of 250 kPa and a velocity of 75 m/s. Assume isentropic steady flow and that the hot gases behave as a perfect gas with mean molar mass of 25 and specific heat ratio of 1.38. (a) Find the turbine power per unit mass of the working fluid. (b) ***What-if scenario:*** How would the answer change if the hot gases were modeled as cold air?

SOLUTION



The specific heat ratio of hot gases k=1.38. The constant pressure specific heat is

$$c_p = 1.20772 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Let state-1 represent the inlet, state-2 the isentropic exit state.

State-1 (given p_1, T_1, V_1)

State-2 (given $p_2, s_2 = s_1, V_2$):

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{(k-1)}{k}} = (1273)\left(\frac{250}{600}\right)^{\frac{(1.38-1)}{1.38}} = 1000.3 \text{ K};$$

(a) Using the energy equation

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

$$\Rightarrow \dot{W}_T = \dot{m}c_p(T_1 - T_2);$$

$$\Rightarrow w_T = 1.20772(1273 - 1000.3);$$

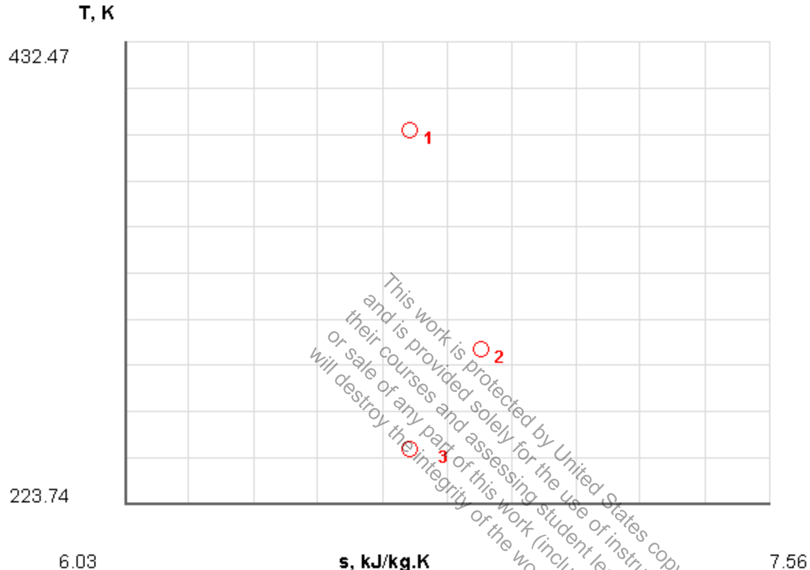
$$\Rightarrow w_T = 329.3 \ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution and What-if Scenario:

Launch the PG 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.

4-1-62 [ORK] A turbine at steady state receives air at a pressure of 5 bar and a temperature of 120oC. Air exits the turbine at a pressure of 1 bar. The work developed is measured as 100 kJ per kg of air flowing through the turbine. The turbine operates adiabatically, and change in ke and pe can be neglected. Determine (a) the turbine efficiency, and (b) the entropy generated per kg of air flow in the turbine's universe. Use the PG model for air. (c) ***What-if scenario:*** How would the answers change if the IG model was used?

SOLUTION



The specific heat ratio of air k=1.4. The constant pressure specific heat of air is

$$c_p = 1.00349 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

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

State-1 (given p_1, T_1)

State-2 (given p_2)

State-3 (given $p_3 = p_2, s_3 = s_1$):

$$T_3 = T_1 \left(\frac{p_3}{p_1} \right)^{\frac{(k-1)}{k}} = (393.15) \left(\frac{100}{500} \right)^{\frac{(1.4-1)}{1.4}} = 248.23 \text{ K};$$

Isentropic work:

$$\dot{W}_{T,s} = \dot{m} \left(j_1 - j_3 \right);$$

$$\Rightarrow \dot{W}_{T,s} = \dot{m}c_p(T_1 - T_3);$$
$$\Rightarrow \dot{W}_{T,s} = 1.00349(393.15 - 248.23);$$
$$\Rightarrow \dot{W}_{T,s} = 145.4 \text{ kW};$$

(a) The isentropic efficiency now can be evaluated as

$$\eta_T \equiv \frac{\dot{W}_T}{\dot{W}_{T,s}} = \frac{100.0}{145.4} = 68.7\%$$

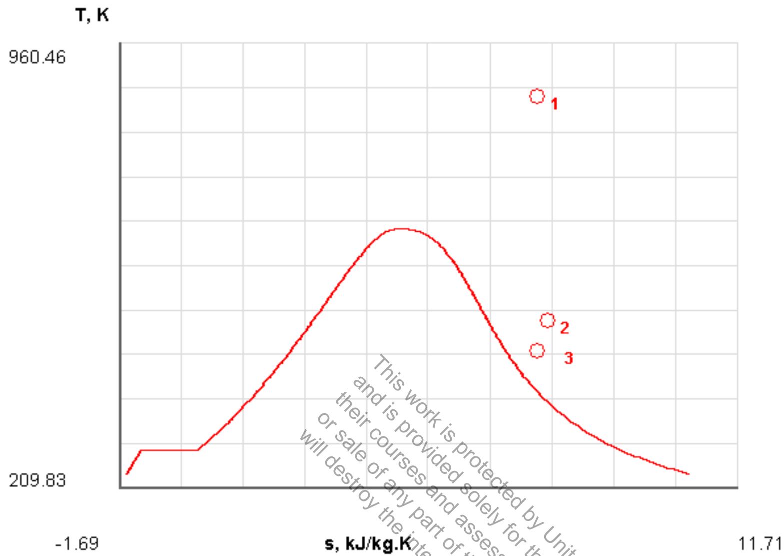
(b) The entropy balance equation, applied on the turbine's universe produces

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}(s_1 - s_2) + \frac{\cancel{\dot{Q}}^{0}}{T_0} + \dot{S}_{\text{gen,univ}};$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right);$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(1.00349 \ln\frac{293.15}{393.15} - 0.2869 \ln\frac{100}{500}\right);$$
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.167 \frac{\text{kW}}{\text{K}}$$

TEST Solution and What-if Scenario:
Launch the IG 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.

4-1-63 [ORC] Steam at 4 MPa, 600^{o}C enters an insulated turbine operating at steady state with a mass flow rate of 5 kg/s and exits at 200 kPa. Determine (a) the maximium theoretical power that can be developed by the turbine, and (b) the corresponding exit temperature. Also determine (b) the isentropic efficiency if steam exits the turbine at 220oC.

SOLUTION



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

State-1 (given p_1, T_1):

$$h_1 = 3674.41 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.368 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given p_2, T_2):

$$h_2 = 2910.64 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 7.587 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-3 (given $p_3 = p_2, s_3 = s_1$):

$$h_3 = 2808.76 \ \frac{\text{kJ}}{\text{kg}};$$

(a) The maximum theoretical power that can be developed (i.e. the isentropic work)

$$\dot{W}_{T,s} = \dot{m}\left(j_1 - j_3\right);$$

$$\Rightarrow \dot{W}_{T,s} = \dot{m}\left(h_1 - h_3\right); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_{T,s} = 5\left(3674.41 - 2808.76\right);$$

$$\Rightarrow \dot{W}_{T,s} = 4328.25 \text{ kW}$$

(b) At 200 kPa and enthalpy of $2808.76\ \frac{\text{kJ}}{\text{kg}}$

$T_3 = 169.9°\text{C}$

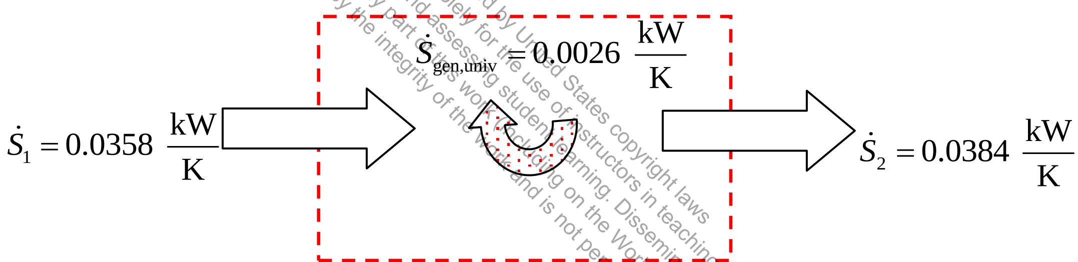
(c) Actual Work

From the energy balance equation on the steady turbine, we have

$$\dot{W}_T = \dot{m}(j_1 - j_2);$$
$$\Rightarrow \dot{W}_T = \dot{m}(h_1 - h_2); \quad (\text{since } \dot{Q} \cong 0, \text{and } \Delta\text{ke} = \Delta\text{pe} \cong 0)$$
$$\Rightarrow \dot{W}_T = 5(3674.41 - 2910.64);$$
$$\Rightarrow \dot{W}_T = 3818.85\ \text{kW};$$

The isentropic efficiency now can be evaluated as

$$\eta_T \equiv \frac{\dot{W}_T}{\dot{W}_{T,s}} = \frac{3818.85}{4328.25} = 88.2\%$$

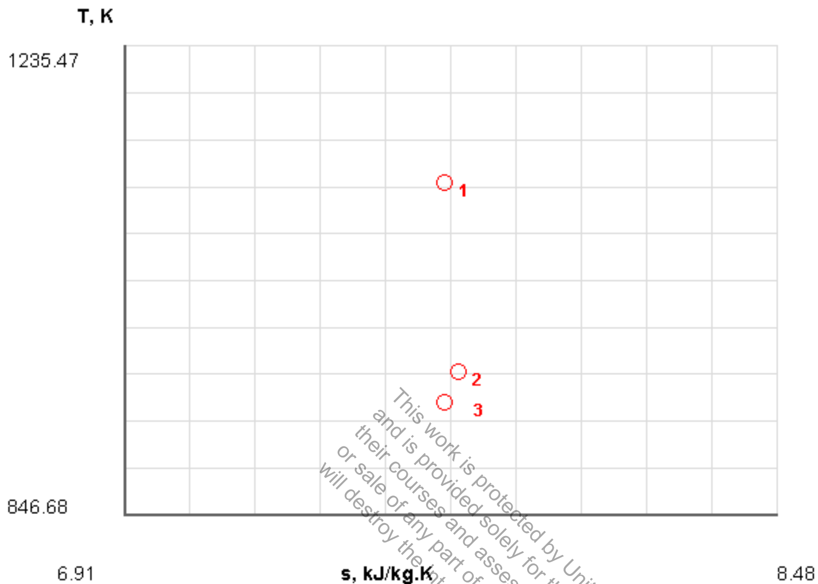


TEST Solution:

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.

4-1-64 [ORU] Combustion gases enters an adiabatic gas turbine steadily at 850 kPa and 850 oC, with a mass flow rate of 1 kg/s and leaves at 420 kPa. Treating the combustion gases as air with variable specific heat and assuming an isentropic efficiency of 86 %, determine the work output of the turbine.

SOLUTION



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

$$h_1 = 890.28\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2, s_2 = s_1, \dot{m}_2 = \dot{m}_1$):

$$h_2 = 681.95\ \frac{\text{kJ}}{\text{kg}}; \quad T_2 = 940.7\ \text{K};$$

State-3 (given $p_3 = p_2, \eta, \dot{m}_3 = \dot{m}_1$):

$$h_3 = h_1 - \left(0.86\left(h_1 - h_2\right)\right);$$

$$\Rightarrow h_3 = 890.28 - \left(0.86\left(890.28 - 681.95\right)\right);$$

$$\Rightarrow h_3 = 711.12\ \frac{\text{kJ}}{\text{kg}};$$

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

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

$$\Rightarrow \dot{W}_T = \dot{m}\left(h_1 - h_3\right); \qquad (\text{Since } \dot{Q} \cong 0, \text{ke} \cong \text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_T = 890.28 - 711.12;$$

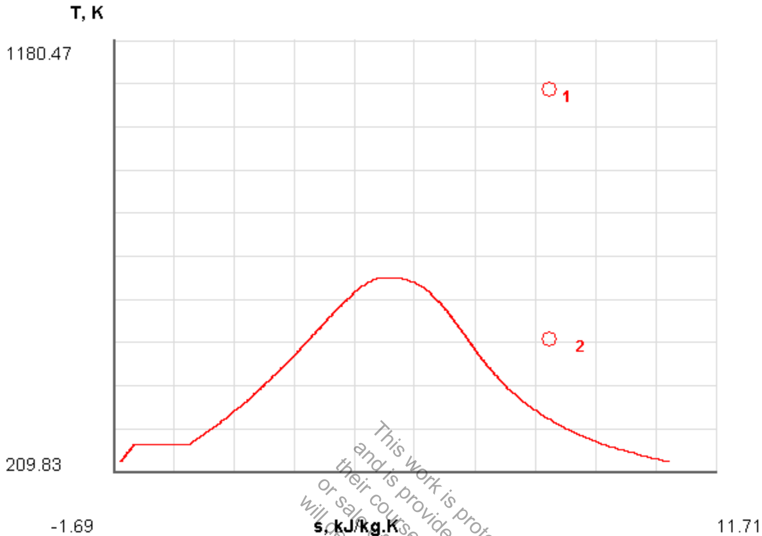
$$\Rightarrow \dot{W}_T = 179.16 \text{ kW}$$

TEST Solution:

Launch the IG 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.

4-1-65 [ORX] Steam (H2O) enters a steady isentropic turbine with a mass flow rate of 10 kg/s at 3 MPa, 800oC and leaves at 100 kPa. Determine the power produced by the turbine using (a) the PC model for steam, (b) the PG model and (c) the IG model.

SOLUTION



(a) PC model:

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

$$h_1 = 4145.9 \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.9862 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2, s_2 = s_1, \dot{m}_2 = \dot{m}_1$):

$$h_2 = 2950.9 \frac{\text{kJ}}{\text{kg}};$$

From the energy balance equation

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

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

$$\Rightarrow \dot{W}_T = (10)(4145.9 - 2950.9);$$

$$\Rightarrow \dot{W}_T = 11950 \text{ kW} = 11.95 \text{ MW}$$

(b) PG model:

Given:

$$c_p = 1.8677 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.327;$$

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

State-2 (given $p_2, s_2 = s_1, \dot{m}_2 = \dot{m}_1$):

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}; \quad \Rightarrow T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = 1073\left(\frac{100}{3000}\right)^{\frac{0.327}{1.327}} = 464 \text{ K};$$

From the energy balance equation

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

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

$$\Rightarrow \dot{W}_T = \dot{m}c_p(T_1 - T_2);$$

$$\Rightarrow \dot{W}_T = (10)(1.8677)(1073 - 464);$$

$$\Rightarrow \dot{W}_T = 11374 \text{ kW} = 11.37 \text{ MW}$$

(c) IG model:
Using the IG tables:

Given:

$$R = 0.461 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\bar{M} = 18.015 \frac{\text{kg}}{\text{kmol}};$$

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

$$\bar{h}_1 \cong 39000 \frac{\text{kJ}}{\text{kmol}};$$

State-2 (given $p_2, s_2 = s_1, \dot{m}_2 = \dot{m}_1$):

$$\bar{h}_2 \cong 17200 \frac{\text{kJ}}{\text{kmol}};$$

From the energy balance equation

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

$$\Rightarrow \dot{W}_T = \frac{\dot{m}\left(\bar{h}_1 - \bar{h}_2\right)}{\bar{M}};$$

$$\Rightarrow \dot{W}_T = \frac{(10)(39000 - 17200)}{18.015};$$

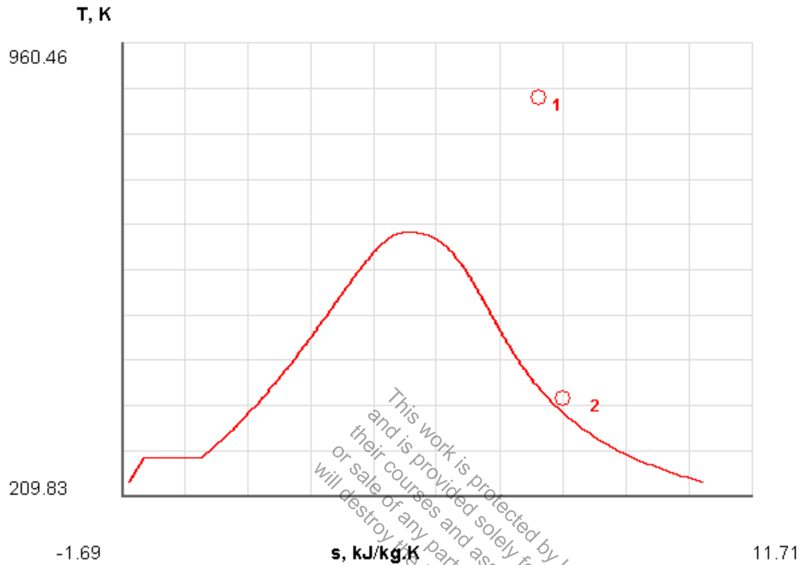
$$\Rightarrow \dot{W}_T = 12101\ \text{kW} = 12.10\ \text{MW}$$

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.

4-1-66 [ORV] Steam enters an adiabatic turbine steadily at 6 MPa, 600 oC, 50 m/s, and exits at 50 kPa, 100oC and 150 m/s. The turbine produces 5 MW. If the ambient condition is 100 kPa, 25oC. (a) Determine the entropy generation rate by the device and the surroundings (turbine's universe). (b) Draw an entropy flow diagram for the turbine.

SOLUTION



State-1 (given $p_1,\ T_1,\ V_1$):

$$h_1 = 3658.37\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 7.167\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 2682.36\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 7.688\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

From the energy balance equation on the steady turbine, we have

$$0 = \dot{m}(j_1 - j_2) + \cancel{\dot{Q}}^{0} - \dot{W}_T;$$

$$\Rightarrow \dot{W}_T = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right);\quad (\text{since } \Delta\text{pe} \cong 0,\ \dot{Q} = 0,\ \dot{m}_1 = \dot{m}_1)$$

$$\Rightarrow 5 = \dot{m}\left(3658.37 - 2682.36 + \frac{50^2 - 150^2}{2000}\right);$$

$$\Rightarrow \dot{m} = 0.005\ \frac{\text{kg}}{\text{s}};$$

(a) The entropy balance equation, applied on the turbine's universe produces

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_1 - s_2\right) + \frac{\cancel{\dot{Q}}^{0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = (0.005)(7.688 - 7.167);$$

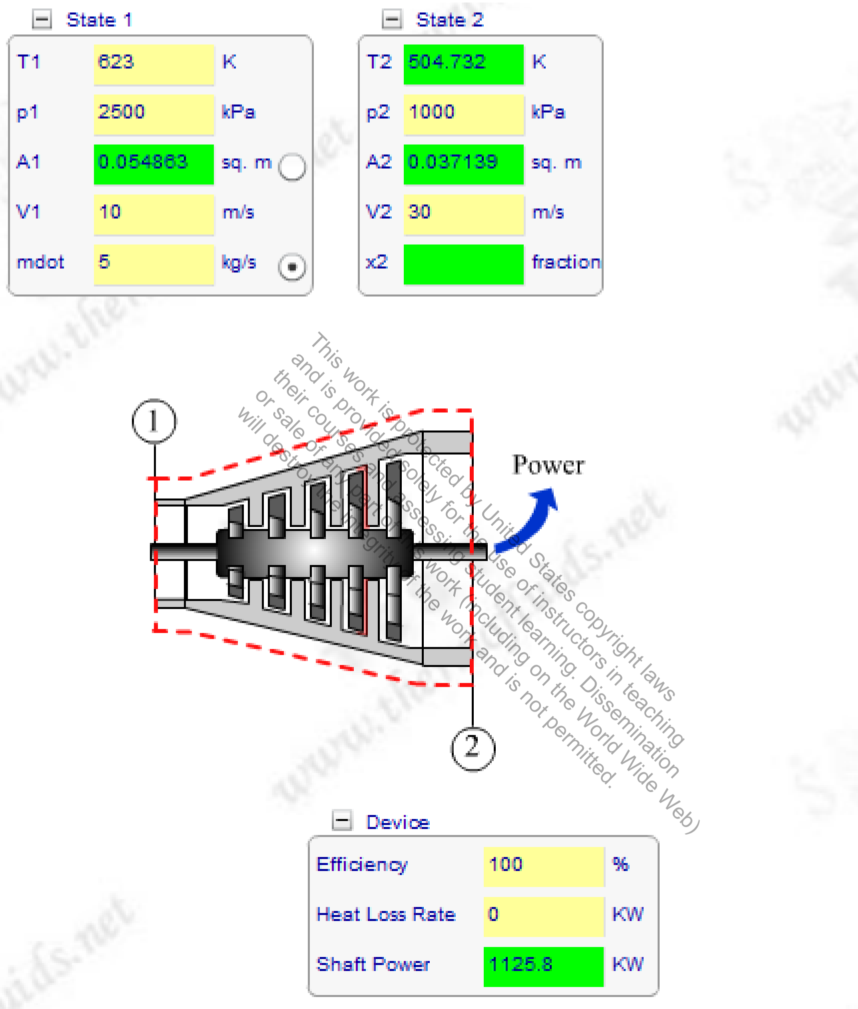
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.0026\ \frac{\text{kW}}{\text{K}}$$

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.

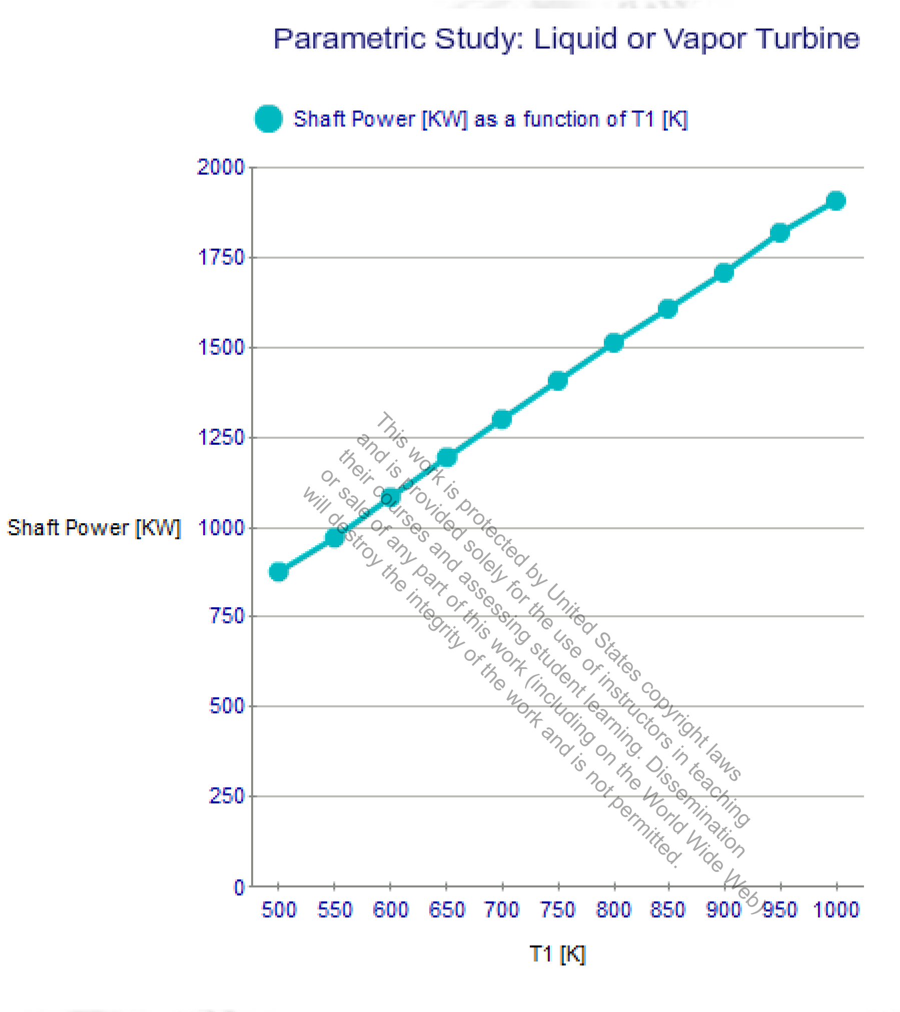
4-1-67 [BCN] Steam enters an adiabatic turbine steadily at 2.5 MPa, 350°C, 10 m/s and exits at 1 MPa, 30 m/s. The mass flow rate ($\dot{m}$) is 5 kg/s. Using the Turbine Simulator RIA (linked from the left margin), determine the shaft power ($\dot{W}_{sh}$).

SOLUTION



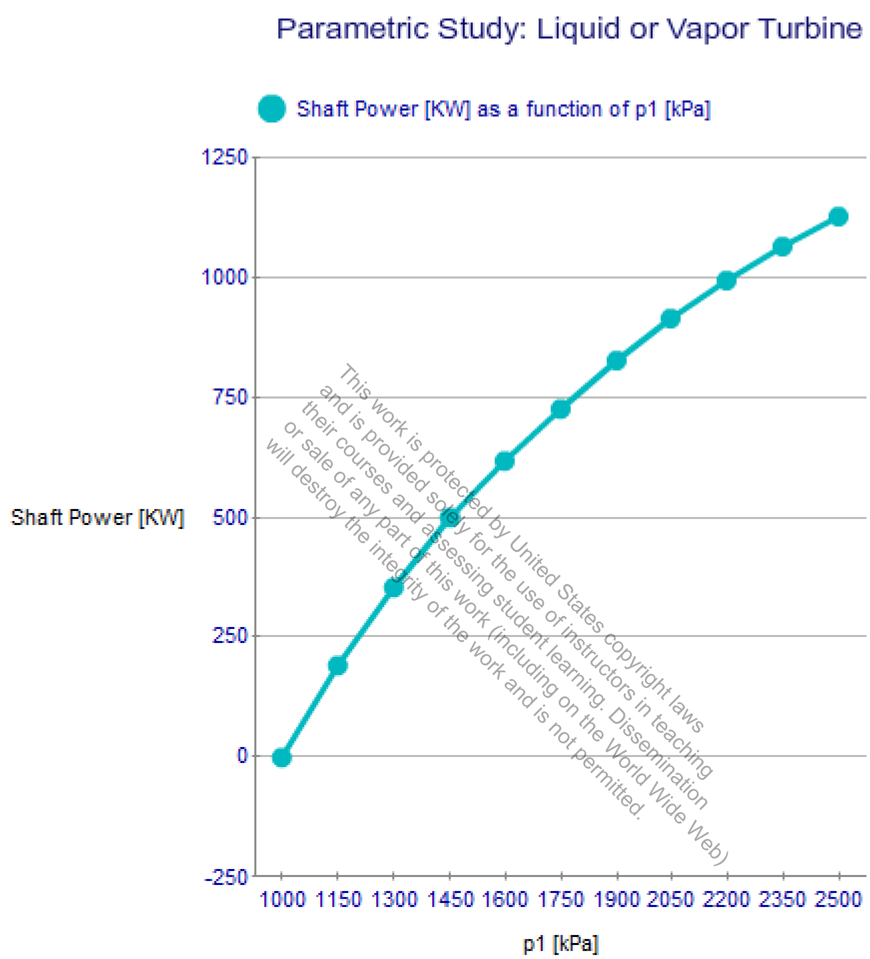
4-1-68 [BCR] Using the Steam turbine described in the previous problem, 4-1-75[BCN], plot how the shaft power ($\dot{W}_{sh}$) varies with input temperature (T_1) varying from 500 K to 1000 K, all other input parameters remaining unchanged.

SOLUTION



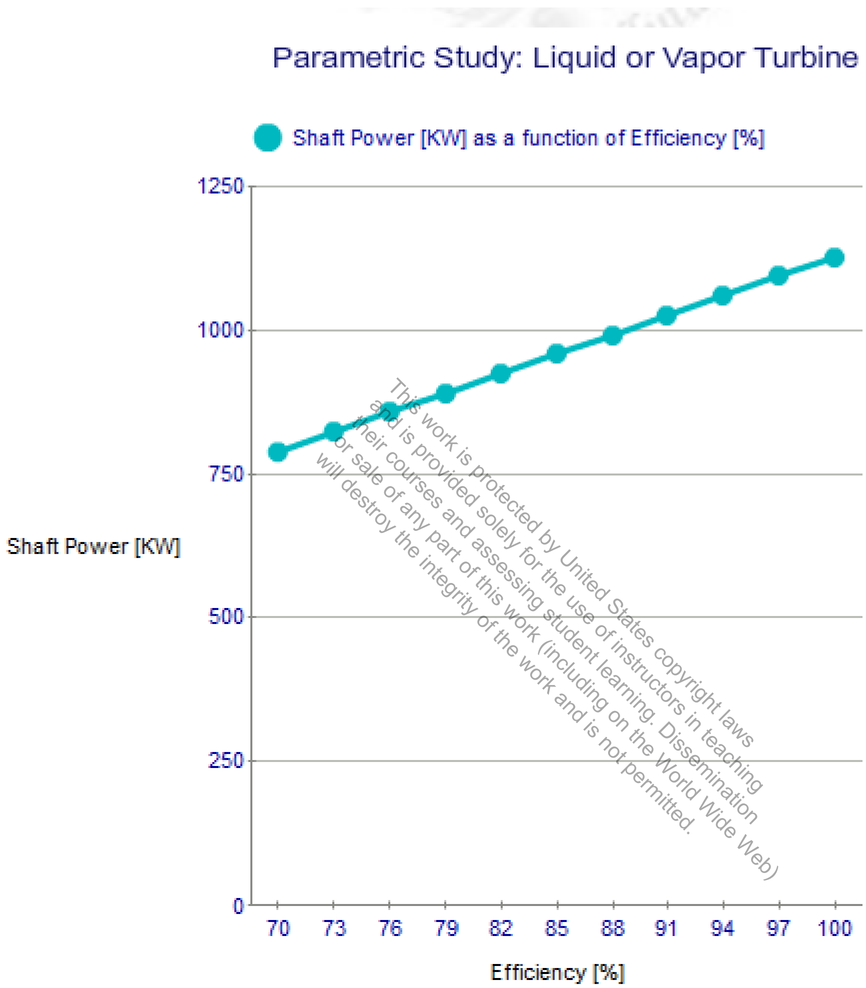
4-1-69 [BXW] Using the Steam turbine described in the previous problem, 4-1-75[BCN], plot how the shaft power ($\dot{W}_{sh}$) varies with input pressure (p_1) varying from 1 MPa to 2.5 MPa, all other input parameters remaining unchanged.

SOLUTION



4-1-70 [BCO] Using the Steam turbine described in previous problem, 4-1-75[BCN] plot how the shaft power ($\dot{W}_{sh}$) varies with isentropic efficiency of turbine varying from 70% to 100%, all input parameters remaining unchanged.

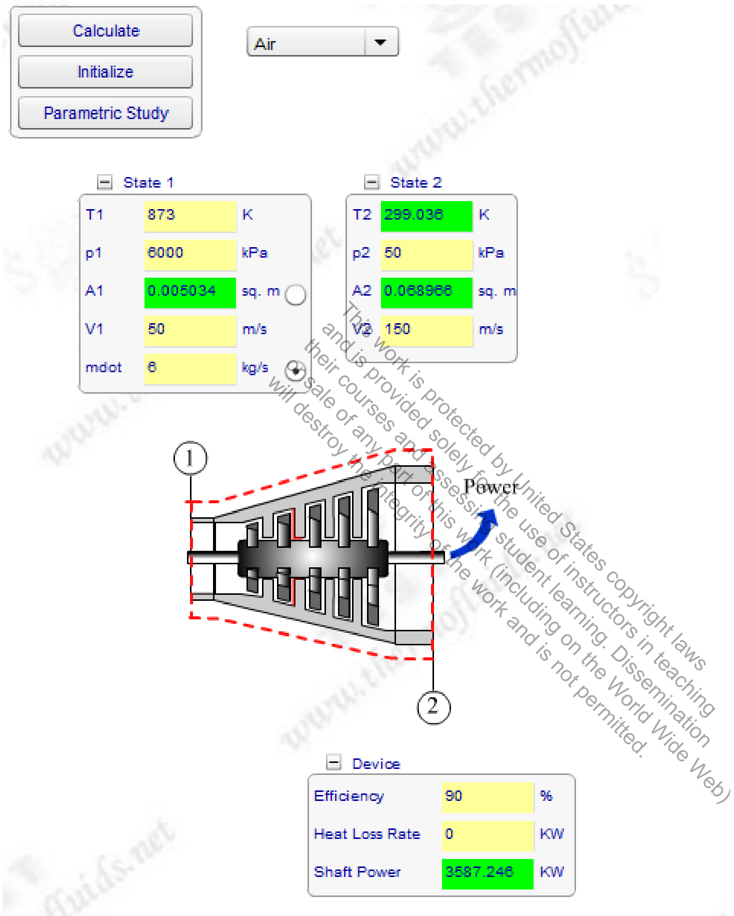
SOLUTION



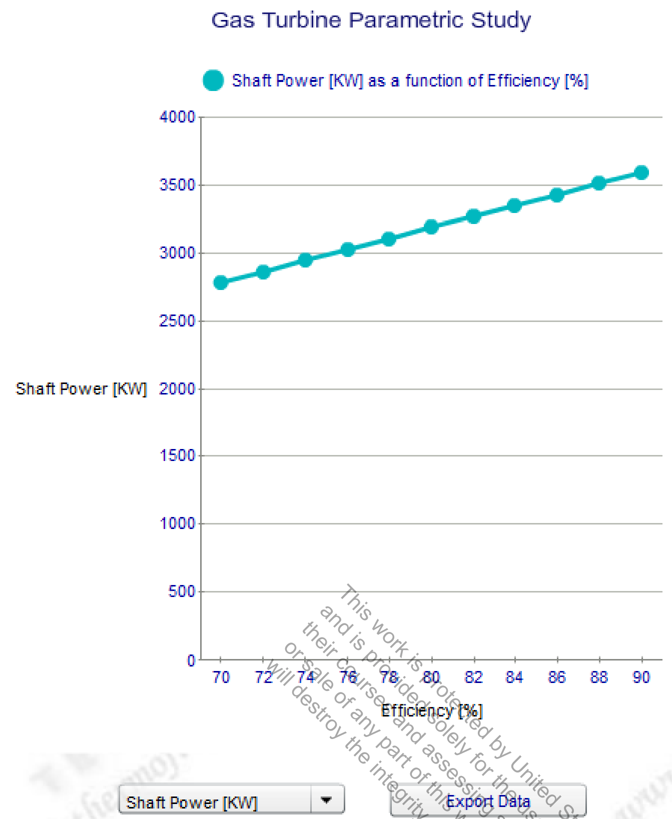
4-1-71 [BVN] Air enters an adiabatic turbine steadily at 6 MPa, 600°C, 50 m/s and exits at 50 kPa, 150 m/s with a mass flow rate ($\dot{m}$) of 6 kg/s.Assuming the turbine efficiency to be 90%, use Turbine Simulator RIA (linked from left margin) to (a) determine shaft power ($\dot{W}_{sh}$), (b) plot how shaft power ($\dot{W}_{sh}$) varies with turbine efficiency varying from 70% to 90%, all other input variables remaining unchanged.

SOLUTION

(a)

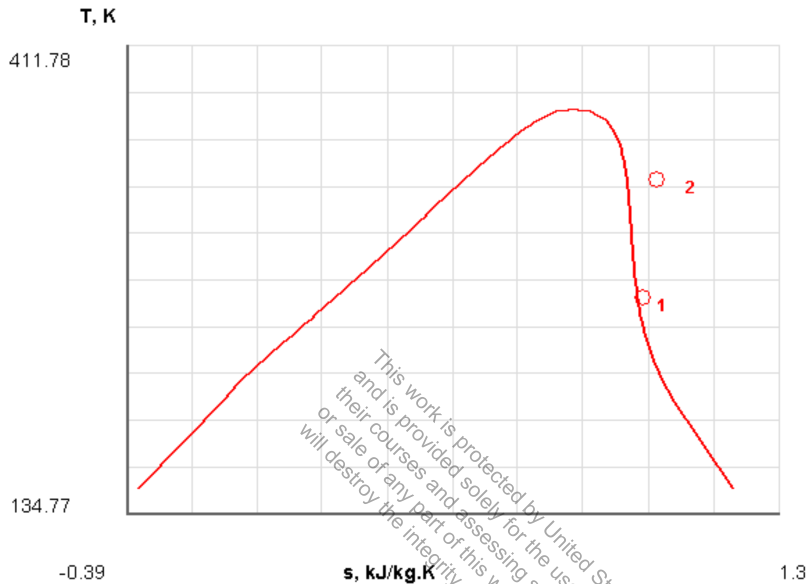


(b)


Gas Turbine Parametric Study
Shaft Power [KW] as a function of Efficiency [%]
Shaft Power [KW]
4000
3500
3000
2500
2000
1500
1000
500
0
70
72
74
76
78
80
82
84
86
88
90
Efficiency [%]
Shaft Power [KW]
Export Data

4-1-72 [ORY] Refrigerant R-134a enters an compressor at 175 kPa and -10oC and leaves at 1 MPa, 60oC. The mass flow rate is 0.02 kg/s and the power output to the compressor is 1.2 kW. Determine (a) the heat transfer rate from the compressor. (b) Draw an energy diagram for the device. Assume steady-state operation.

SOLUTION



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

$$h_1 = 244.11\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 0.946\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 292.89\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 0.982\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) From the energy balance equation on the steady state, we have

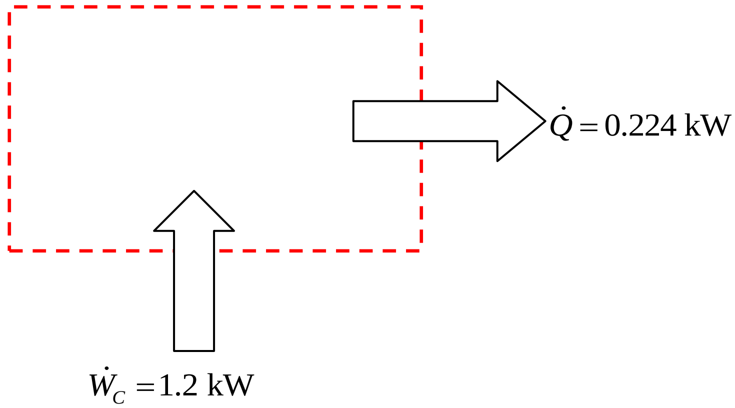
$$0 = \dot{m}\left(j_1 - j_2\right) + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow -\dot{Q} = \dot{m}(h_1 - h_2) - \dot{W}_{\text{ext}};\qquad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\Rightarrow -\dot{Q} = 0.02(244.11 - 292.89) + 1.2;$$

$$\Rightarrow \dot{Q} = -0.224\ \text{kW}$$

(b) Energy Diagram

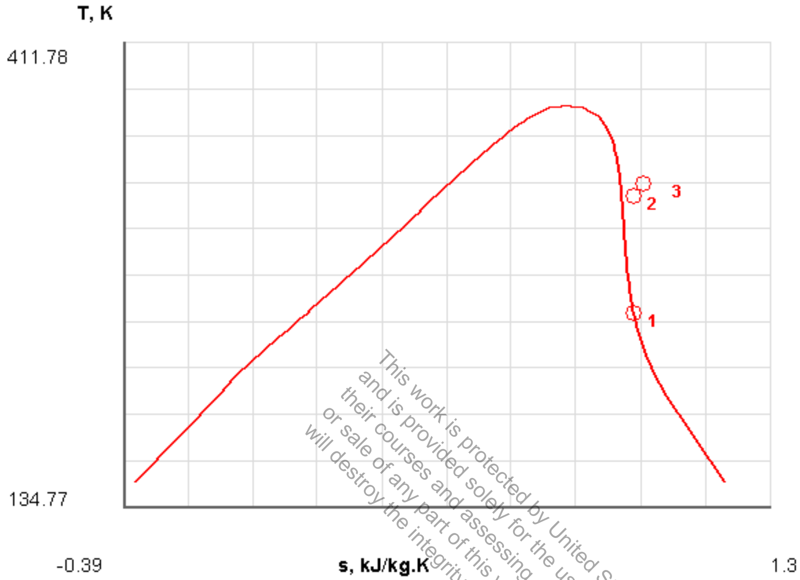


TEST Solution:

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.

4-1-73 [ORF] Refrigerant-134a enters an adiabatic compressor as saturated vapor at 120 kPa at a rate of 1 m3/min and exits at 1 MPa. The compressor has an adiabatic efficiency of 85%. Assuming the surrounding conditions to be 100 kPa and 25oC, determine (a) the actual power and (b) the rate of entropy generation. (c) ***What-if scenario:*** How would the conclusion in (b) change if the compressor had an adiabatic efficiency of 70%?

SOLUTION



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

$$h_1 = 235.5\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 0.943\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{0.0166}{0.162} = 0.1027\ \frac{\text{kg}}{\text{s}};$$

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

$$h_2 = 279.8\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_2$):

$$h_3 = \frac{h_1 - (h_1 - h_2)}{0.85} = 287.6\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 0.967\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) From the energy balance equation on the steady state, we have

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_2\right); \qquad (\text{since } \dot{Q} \cong 0,\ \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\Rightarrow \dot{W}_C = \dot{m}\left(h_2 - h_1\right);$$

$$\Rightarrow \dot{W}_C = 0.1027\left(287.6 - 235.5\right);$$

$$\Rightarrow \dot{W}_C = 5.35 \text{ kW}$$

(b) Using the entropy balance equation

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_1 - s_3\right) + \frac{\cancel{\dot{Q}}^{0}}{T_0} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_3 - s_1\right);$$

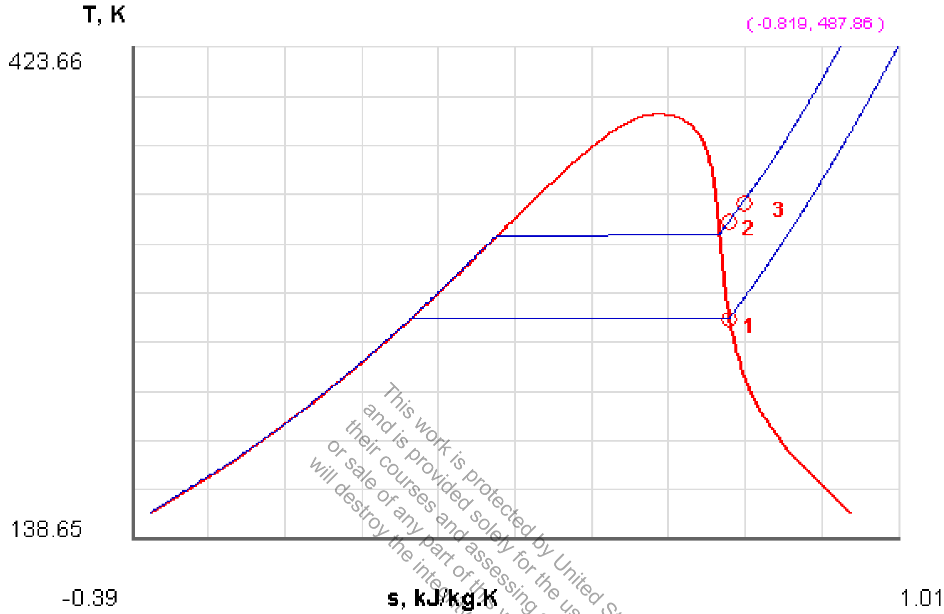
$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(0.1027\right)\left(0.967 - 0.943\right);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.00247 \ \frac{\text{kW}}{\text{K}}$$

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.

4-1-74 [ORW] Refrigerant-12 enters a compressor operating at steady state as saturated vapor at -7oC and exits at 1000 kPa. The compressor has an isentropic efficiency of 75%. Ignoring the heat transfer between the compressor and its surrounding as well as ke and pe, determine (a) the exit temperature. and (b) work input in kJ per kg of refrigerant flow.

SOLUTION



State-1 (given $T_1,\ x_1$):

$$h_1 = 184.5\ \frac{\text{kJ}}{\text{kg}}; \qquad s_1 = 0.7\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_2 = 209.8\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_2,\ \ \eta = 75\%$):

$$h_3 = h_1 + \frac{(h_2 - h_1)}{0.75} = 218.2\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 0.725\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $T_3 = 61^{\text{o}}\text{C}$

(b) From the energy balance equation on the steady state, we have

$$0 = \dot{m}\left(j_1 - j_3\right) + \cancel{\dot{Q}}^{0} - W_{\text{ext}};$$

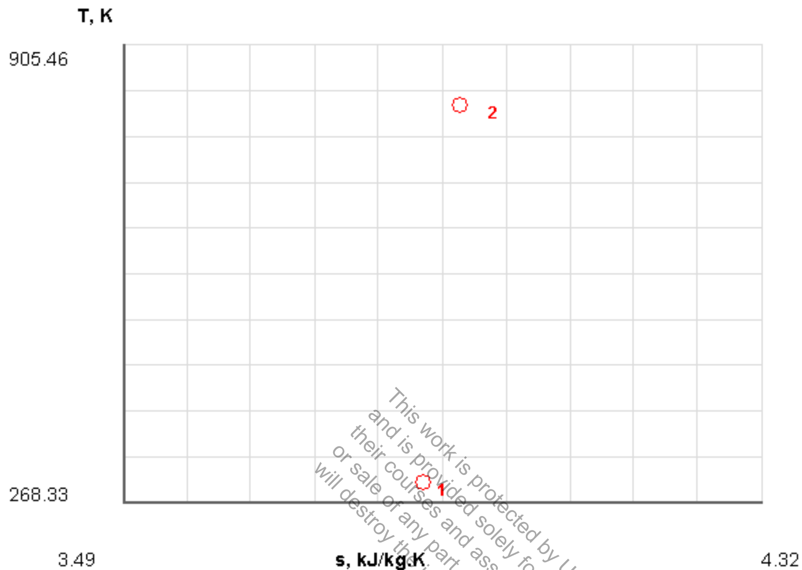
$$\Rightarrow w_{\text{ext}} = (h_1 - h_3); \qquad (\text{since } Q \cong 0,\ \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$
$$\Rightarrow w_C = (h_3 - h_1);$$
$$\Rightarrow w_C = (218.2 - 184.5);$$
$$\Rightarrow w_C = 33.7\ \frac{\text{kJ}}{\text{kg}}$$

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.

4-1-75 [ORT] Argon gas enters an adiabatic compressor at 100 kPa and 25oC with a velocity of 20 m/s and exits at 1 MPa, 550oC and 100 m/s. The inlet area of the compressor is 75 cm2. Determine (a) the power of the compressor, (b) ***What-if scenario:*** How would the conclusion change if the inlet area was 100 cm2?

SOLUTION



The specific heat ratio of hot gases $k = 1.6$. The constant pressure specific heat is

$$c_p = 0.5203 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

Let state-1 represent the inlet, state-2 the exit state.

State-1 (given p_1, T_1, A_1, V_1):

$$\dot{m}_1 = \frac{A_1 V_1}{v_1} = \frac{(0.0075)(20)}{0.6204} = 0.242 \ \frac{\text{kg}}{\text{s}};$$

State-2 (given p_2, T_2, V_2)

(a) Using the energy equation

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m} c_p (T_1 - T_2);$$

$$\Rightarrow \dot{W}_C = \dot{m} c_p (T_2 - T_1);$$

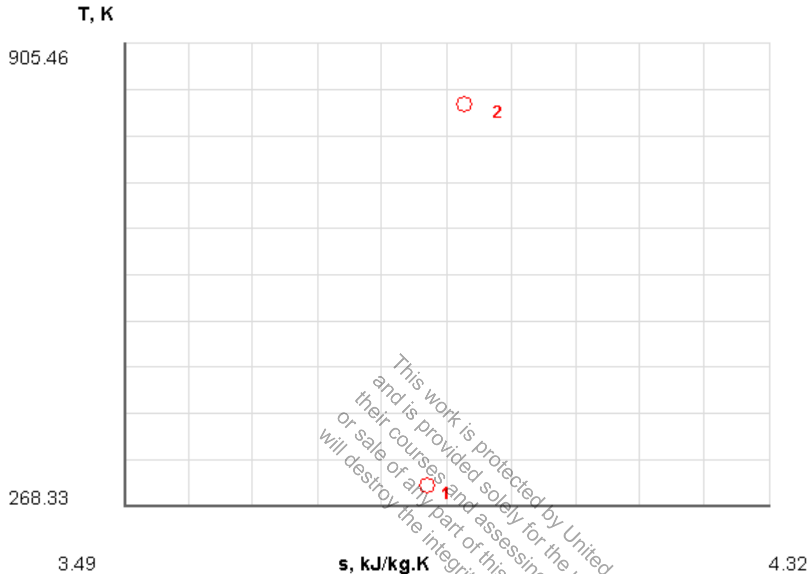
$$\Rightarrow \dot{W}_C = (0.242)(0.5203)(298 - 823);$$

$$\Rightarrow \dot{W}_C = 66.1 \text{ kW}$$

TEST Solution and What-if Scenario:
Launch the PG 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.

4-1-76 [ORQ] Argon gas enters an adiabatic compressor at 100 kPa and 25oC with a velocity of 20 m/s and exits at 1 MPa, 550oC and 100 m/s. The inlet area of the compressor is 75 cm2. Assuming the surroundings to be at 100 kPa and 25oC, determine (a) the internal entropy generation rate by this device, (b) the external entropy generation in the immediate surroundings, and (c) the entropy generation in the system's universe.

SOLUTION



The specific heat ratio of hot gases k = 1.6. The constant pressure specific heat is

$$c_p = 0.5203 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

Let state-1 represent the inlet, state-2 the exit state.

State-1 (given p_1, T_1, A_1, V_1):

$$\dot{m}_1 = \frac{A_1 V_1}{v_1} = \frac{(0.0075)(20)}{0.6204} = 0.242 \ \frac{\text{kg}}{\text{s}};$$

State-2 (given p_2, T_2, V_2)

(a) The entropy generated in the device

$$S_{\text{gen,system}} = \Delta S_{\text{system}} = \dot{m}(s_2 - s_1);$$

$$\Rightarrow S_{\text{gen,system}} = \dot{m}\left(s_2 - s_1\right);$$

$$\Rightarrow S_{\text{gen,system}} = \dot{m}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right);$$

$$\Rightarrow S_{\text{gen,system}} = 0.242\left(\left(0.5203\right)\ln\frac{823}{298} - \left(0.2081\right)\ln\frac{1000}{100}\right);$$

$$\Rightarrow S_{\text{gen,system}} = 0.012\ \frac{\text{kW}}{\text{K}}$$

(b) The entropy generated in the immediate surrounding

$$S_{\text{gen,surrounding}} = \Delta S_{\text{surrounding}} = \cancel{\frac{\dot{Q}}{T_B}}^{0} = 0\ \frac{\text{kW}}{\text{K}}$$

(c) The entropy generation in the systems universe

$$S_{\text{gen,univ}} = \Delta S_{\text{system}} + \Delta S_{\text{surrounding}};$$

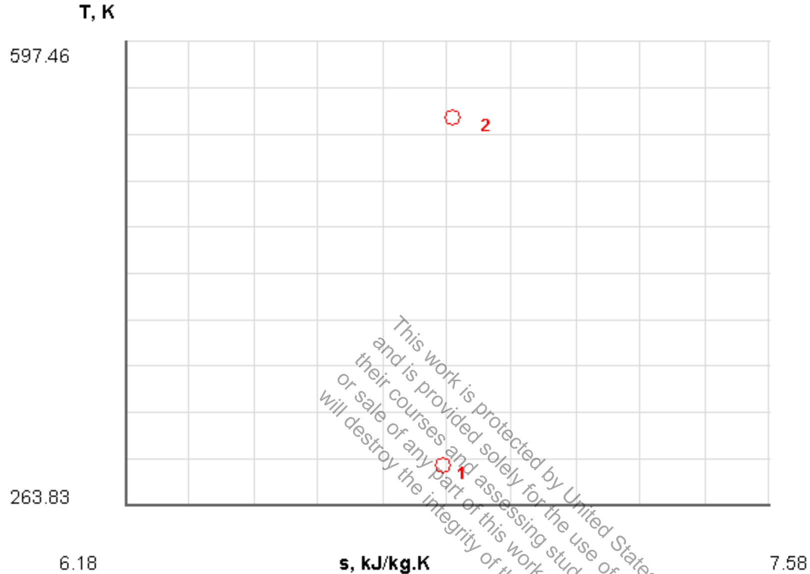
$$\Rightarrow S_{\text{gen,univ}} = 0.012 + 0 = 0.012\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:

Launch the PG 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.

4-1-77 [ORD] Air enters an adiabatic compressor at steady state at a pressure of 100 kPa, a temperature of 20oC, and a flow rate of 0.25 m3/s. Compressed air is discharged from the compressor at 800 kPa and 270oC. Given that the inlet and exit pipe diameters are 4 cm, determine (a) the exit velocity of air at the compressor outlet and (b) the compressor power. Use PG model for air. (c) ***What-if scenario:*** How would the compressor power change if the pipe diameters at the inlet and exit were 5 cm?

SOLUTION



The specific heat ratio of hot gases $k = 1.4$. The constant pressure specific heat is $c_p = 1.003\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$;

Let state-1 represent the inlet, state-2 the exit.

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

$$A_1 = 0.00126;$$

$$\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{0.25}{0.8413} = 0.297\ \frac{\text{kg}}{\text{s}};$$

$$V_1 = \frac{(0.297)(0.8413)}{0.00126} = 198.3\ \frac{\text{m}}{\text{s}};$$

State-2 (given $p_2, T_2, A_2 = A_1,\ \dot{m}_2 = \dot{m}_1$):

(a) $V_2 = \frac{\dot{m}_2 v_2}{A_2} = \frac{(0.297)(0.195)}{0.00126} = 45.9\ \frac{\text{m}}{\text{s}}$

(b) Using the energy equation

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(c(T_1 - T_2) + \frac{V_1^2 - V_2^2}{2000}\right);$$

$$\Rightarrow \dot{W}_C = \dot{m}\left(c(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2000}\right);$$

$$\Rightarrow \dot{W}_C = 0.297\left(1.003\left(543 - 293\right) + \frac{45.9^2 - 198.9^2}{2000}\right);$$

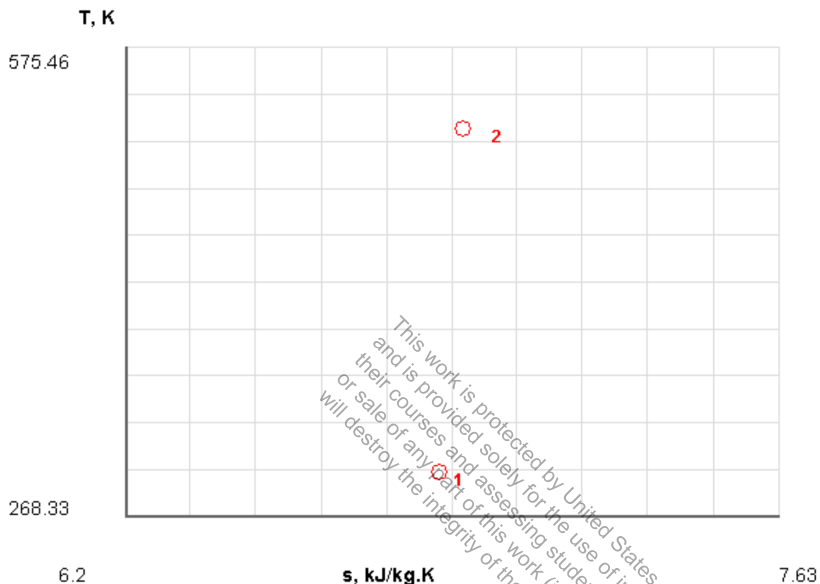
$$\Rightarrow \dot{W}_C = 68.9 \text{ kW}$$

TEST Solution and What-if Scenario:

Launch the PG 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.

4-1-78 [ORM] Air from the surrounding atmosphere at 100 kPa, 25oC enters a compressor with a velocity of 7 m/s through an inlet of area 0.1 m2. At the exit, the pressure is 600 kPa, the temperature is 150oC, and the velocity is 2m/s. Heat transfer from the compressor to its surrounding occurs at a rate of 3 kW. Determine (a) the power input to the compressor and (b) the rate of entropy generation. Use the PG model for air. (c) ***What-if scenario:*** How would the conclusion in (a) change if the IG model was used?

SOLUTION



The specific heat ratio of hot gases $k = 1.4$. The constant pressure specific heat is

$$c_p = 1.003 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Let state-1 represent the inlet, state-2 the exit state.

State-1 (given p_1, T_1, A_1, V_1):

$$\dot{m}_1 = \frac{A_1 V_1}{v_1} = \frac{(0.1)(7)}{0.856} = 0.818 \ \frac{\text{kg}}{\text{s}};$$

State-2 (given p_2, T_2, V_2)

(a) Using the energy equation

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right) + \dot{Q};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(c(T_1 - T_2) + \frac{V_1^2 - V_2^2}{2000}\right) + \dot{Q};$$

$$\Rightarrow \dot{W}_C = \dot{m}\left(c(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2000}\right) - \dot{Q};$$

$$\Rightarrow \dot{W}_C = 0.818\left(1.003(523 - 298) + \frac{2^2 - 7^2}{2000}\right) - (-3);$$

$$\Rightarrow \dot{W}_C = 187.6 \text{ kW}$$

(b) The entropy generation in the system's universe

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_1 - s_2\right) + \frac{\dot{Q}}{T_B} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow S_{\text{gen,univ}} = \dot{m}\left(s_2 - s_1\right) - \frac{\dot{Q}}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = \dot{m}\left(c \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1}\right) - \frac{-3}{298};$$

$$\Rightarrow S_{\text{gen,univ}} = 0.818\left((1.003)\ln\frac{523}{298} - (0.287)\ln\frac{600}{100}\right) + \frac{3}{298};$$

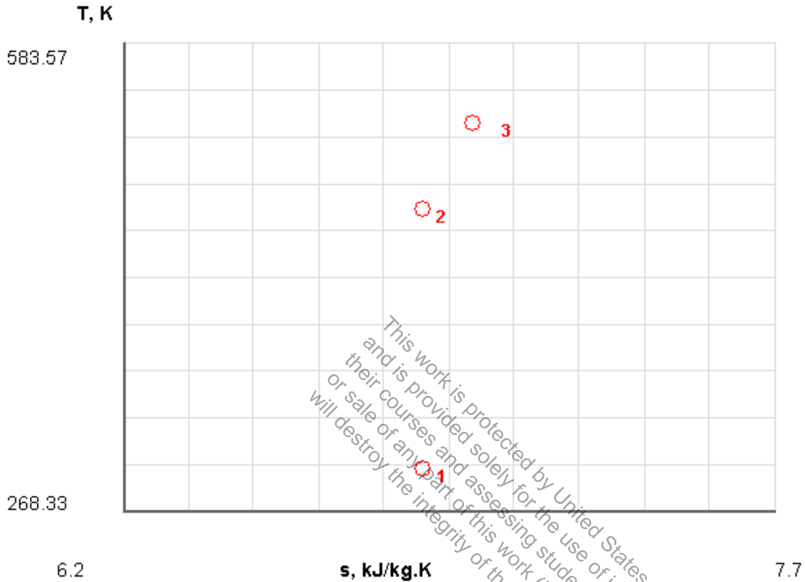
$$\Rightarrow S_{\text{gen,univ}} = 0.05 \ \frac{\text{kW}}{\text{K}}$$

TEST Solution and What-if Scenario:

Launch the PG 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.

4-1-79 [ORJ] An air compressor operating at steady state receives air at 100 kPa and 25oC. The ratio of pressure at the exit to that at inlet is 5. There is no significant heat transfer between the compressor and its surroundings. Also changes in ke and pe are negligible. If the isentropic compressor efficiency is 75 %, determine (a) the actual power and (b) temperature at the compressor exit. Use the PG model for air. (c) ***What-if scenario:*** How would the compressor power change if the IG model was used instead?

SOLUTION



The specific heat ratio of hot gases $k = 1.4$. The constant pressure specific heat is

$$c_p = 1.003 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

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

State-2 (given $p_2 = 5p_1, s_2 = s_1, \ \dot{m}_2 = \dot{m}_1$):

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{(k-1)}{k}} = (298)(5)^{\frac{(1.4-1)}{1.4}} = 472.4 \text{ K};$$

State-3 (given $p_3 = p_2, \ \eta$):

$$T_3 = \frac{T_1 - (T_1 - T_2)}{0.75} = 530.5 \text{ K} = 257.35°\text{C};$$

(a) Using the energy equation

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

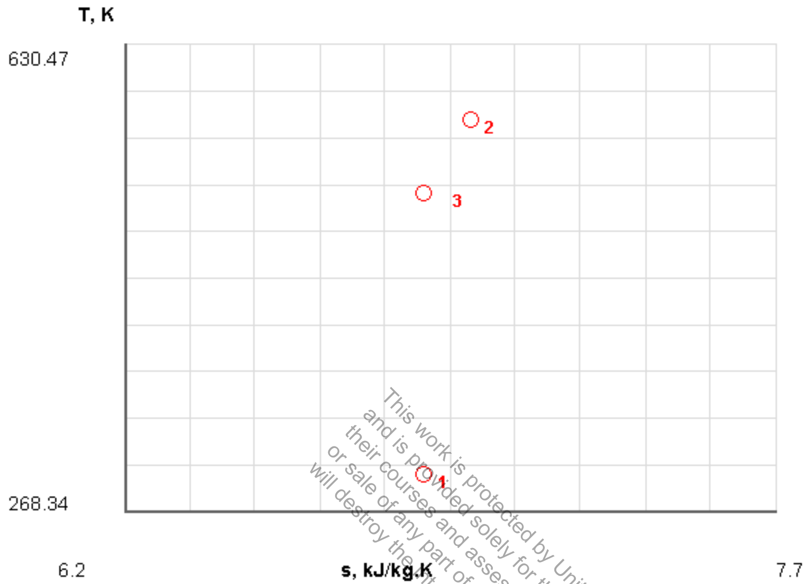
$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_3\right); \quad \left(\text{since } \dot{Q} \cong 0,\ \Delta\text{ke} \cong \Delta\text{pe} \cong 0\right)$$
$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(c\left(T_1 - T_3\right)\right);$$
$$\Rightarrow \dot{W}_C = \dot{m}\left(c\left(T_3 - T_1\right)\right);$$
$$\Rightarrow \dot{W}_C = 1.003(530.5 - 298);$$
$$\Rightarrow \dot{W}_C = 233.2 \text{ kW}$$

(b) $T_3 = 257.35°\text{C}$

TEST Solution and What-if Scenario:
Launch the PG 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.

4-1-80 [OOR] Air is compressed by an adiabatic compressor from 100 kPa and 25oC to 700 kPa and 300oC. Assuming variable specific heats and neglecting the changes in pe and ke, determine (a) the isentropic efficiency of the compressor, and (b) the exit temperature of air if the compressor was reversible.

SOLUTION



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

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

$$h_1 = 0.0159\ \frac{\text{kJ}}{\text{kg}};$$

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

$$h_2 = 282.2\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_2,\ s_3 = s_1$):

$$h_3 = 222.1\ \frac{\text{kJ}}{\text{kg}}; \qquad T_3 = 515.6\ \text{K};$$

(a) The isentropic efficiency of compressor is

$$\eta = \frac{h_1 - (h_1 - h_3)}{h_2};$$

$$\Rightarrow \eta = \frac{0.0159 - (0.0159 - 222.1)}{282.2} = 78.7\%$$

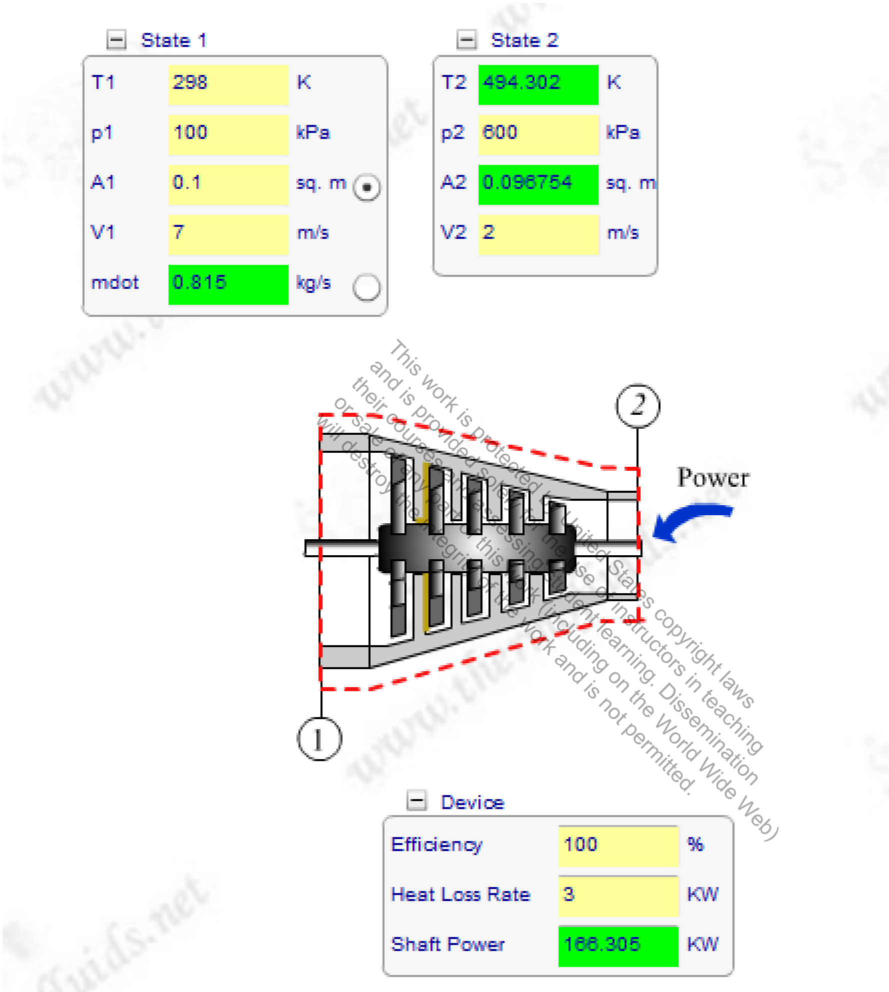
(b) $T_3 = 515.6\text{ K}$

TEST Solution:

Launch the IG 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.

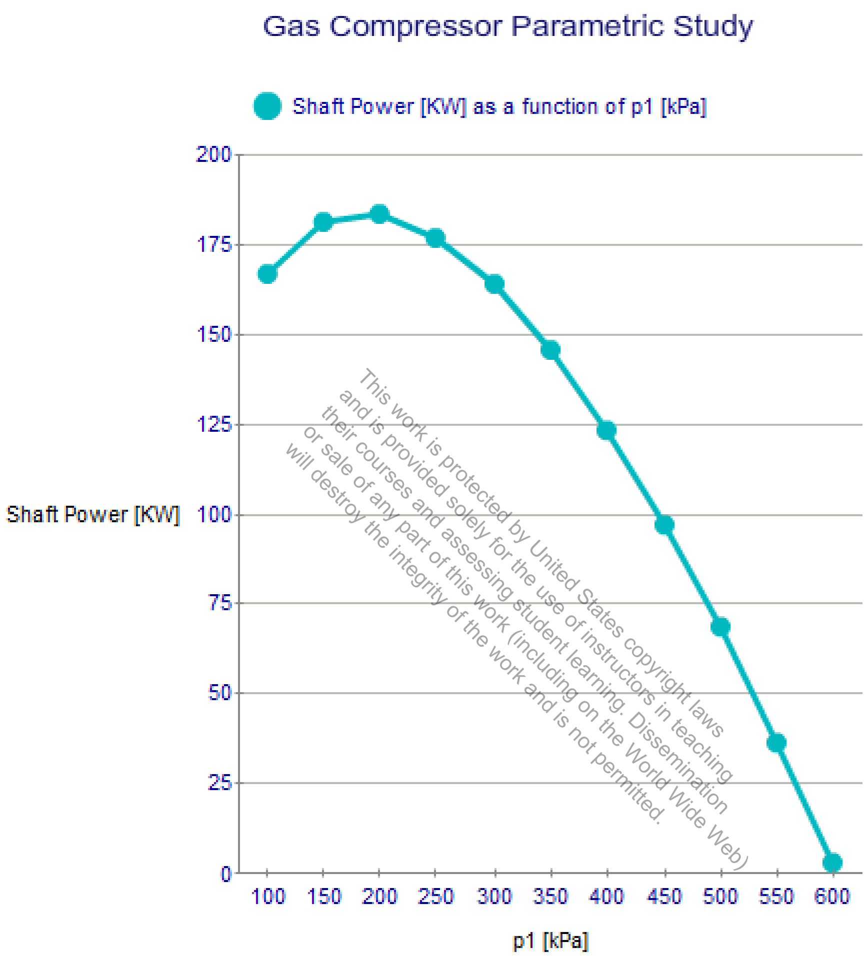
4-1-81 [BCG] Air from the surrounding atmosphere at 100 kPa, 25°C enters a compressor with a velocity of 7 m/s through an inlet of area 0.1 m^2. At the exit, the pressure is 600 kPa,and the velocity is 2 m/s. Heat transfer ($\dot{Q}$) from the compressor to its surrounding occurs at a rate of 3 kW. Using the Compressor Simulator RIA (linked from the left margin) determine the shaft power ($\dot{W}_{sh}$) of the compressor.

SOLUTION



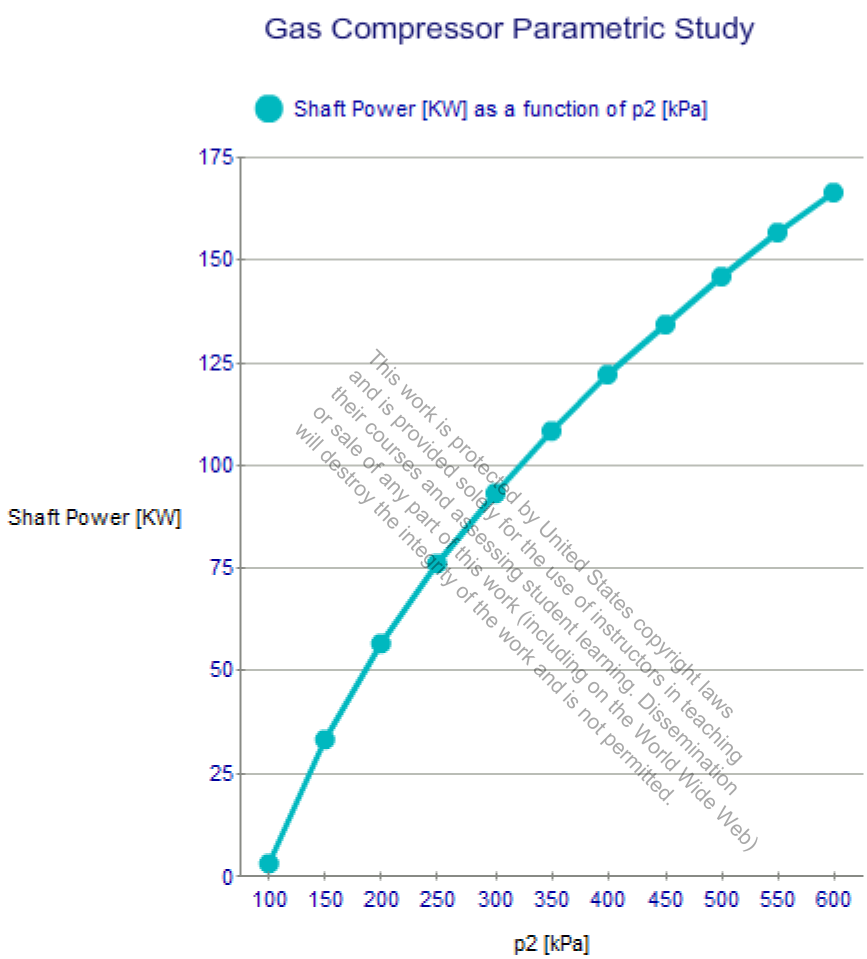
4-1-82 [BCZ] Using the compressor described in previous problem, 4-1-90[BCG], plot how the shaft power ($\dot{W}_{sh}$) varies with input pressure (p_1) varying from 100 kPa to 600 kPa, all other input parameters remaining unchanged.

SOLUTION



4-1-83 [BCK] Using the compressor described in previous problem, 4-1-90[BCG], plot how the shaft power ($\dot{W}_{sh}$) varies with exit pressure (p_2) varying from 100 kPa to 600 kPa, all other input parameters remaining unchanged.

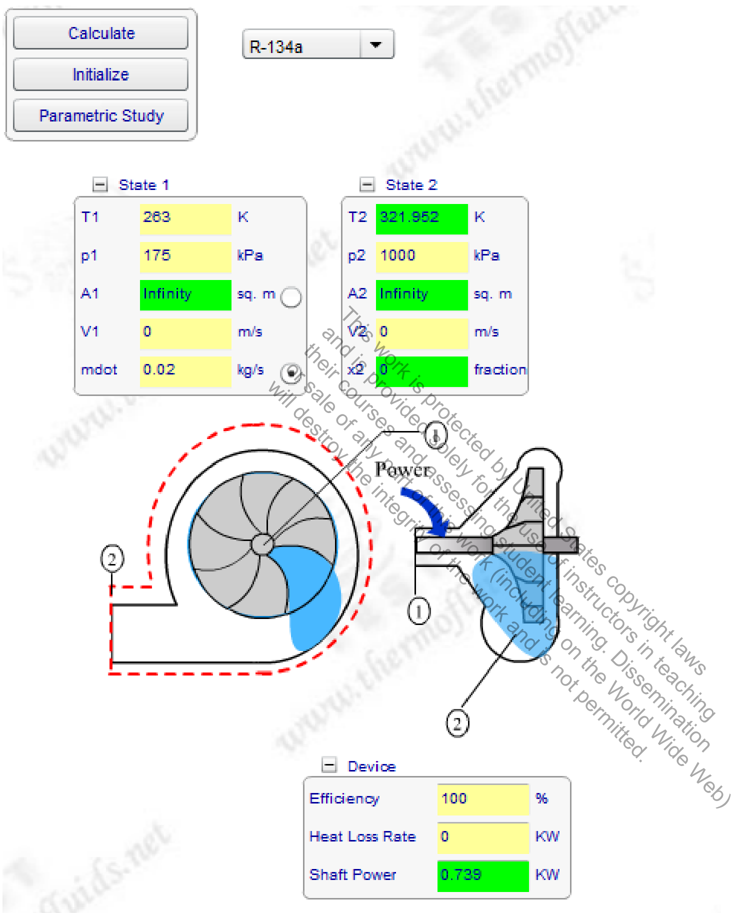
SOLUTION



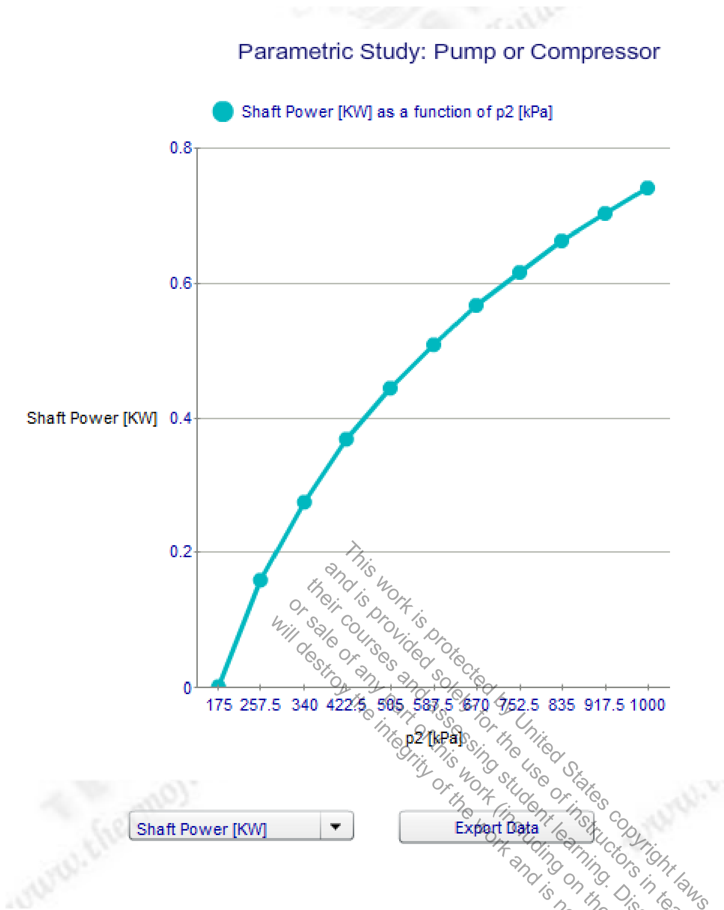
4-1-84 [BVE] Refrigerant R-134a enters an adiabetic compressor at 175 kPa, -10^{o}C and leaves at 1 MPa. The mass flow rate ($\dot{m}$) is 0.02 kg/s. Using the Compressor Simulator RIA (linked from left margin), (a) determine the shaft power ($\dot{W}_{sh}$) of the compressor, (b) plot how shaft power varies with exit pressure varying from 175 kPa to 1 MPa.

SOLUTION

(a)



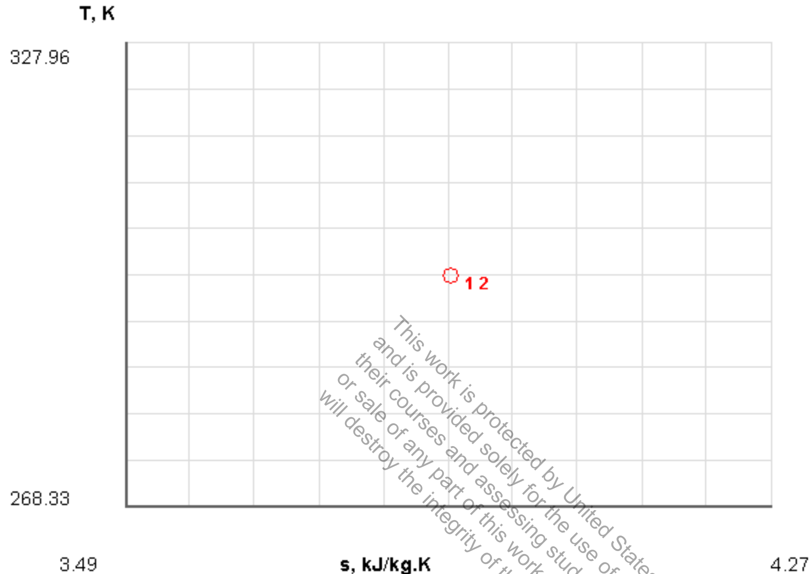
(b)



Parametric Study: Pump or Compressor
Shaft Power [KW] as a function of p2 [kPa]
0.8
0.6
Shaft Power [KW] 0.4
0.2
0
175 257.5 340 422.5 505 587.5 670 752.5 835 917.5 1000
p2 [kPa]
Shaft Power [KW]
Export Data

4-1-85 [OOB] The free surface of the water in the well is 15 m below ground level. This water is to be pumped steadily to an elevation of 20 m above the ground level. Assuming temperature to remain constant and neglecting heat transfer and change in ke, determine (a) power input to the pump required for steady flow of water at a rate of 2 m3/min. Use the SL model for water. (b) ***What-if scenario:*** How would the conclusion change if the flow rate was 1.5 m3/min?

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 $p_1, T_1, \dot{V}_1, z_1$):

$$v_1 = 0.0010 \frac{\text{m}^3}{\text{kg}};$$

$$\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{(0.0333)}{0.0010} = 33.3 \frac{\text{kg}}{\text{s}};$$

State-2 (given $p_2 = p_1,\ T_2 = T_1,\ \dot{m}_1 = \dot{m}_2,\ z_2$):

$$v_2 = 0.0010 \frac{\text{m}^3}{\text{kg}};$$

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

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

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

$$\Rightarrow \dot{W}_P = \dot{m}\left(\frac{g\left(z_2 - z_1\right)}{1000}\right);$$

$$\Rightarrow \dot{W}_P = \left(33.3\right)\left(\frac{9.81\left(20+15\right)}{1000}\right);$$

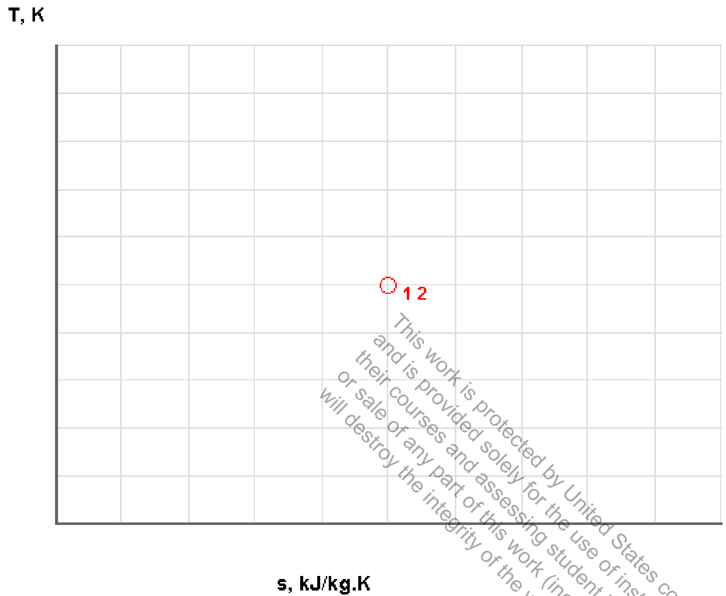
$$\Rightarrow \dot{W}_P = 11.4 \text{ kW}$$

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.

4-1-86 [OOS] Oil with a density of 800 kg/m3 is pumped from a pressure of 0.6 bar to a pressure of 1.4 bar, and the outlet is 3 m above the inlet. The flow rate is 0.2 m3/s, and the inlet and exit areas are 0.06 m2 and 0.03 m3 respectively. (a) Assuming the temperature to remain constant and neglecting any heat transfer, determine the power input to the pump in kW. (b) ***What-if scenario:*** How would the answer change if the change in ke was neglected in the analysis?

SOLUTION



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

The specific heat $c = 4.2 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$;

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

State-1 (given $p_1, T_1, \ \dot{V}_1, \ \rho_1, \ A_1$):

$$\dot{m}_1 = \rho_1 \dot{V}_1 = 800(0.2) = 160 \ \frac{\text{kg}}{\text{s}};$$

$$V_1 = \frac{\dot{m}_1}{\rho_1 A_1} = \frac{160}{800(0.06)} = 3.33 \ \frac{\text{m}}{\text{s}};$$

State-2 (given $p_2, \ T_2 = T_1, \ \dot{m}_1 = \dot{m}_2, \ z_2, \ \rho_2 = \rho_1, \ A_2$):

$$V_2 = \frac{\dot{m}_2}{\rho_2 A_2} = \frac{160}{800(0.03)} = 6.66 \ \frac{\text{m}}{\text{s}};$$

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

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

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

$$\Rightarrow \dot{W}_P = \dot{m}\left(v\left(p_2 - p_1\right) + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g\left(z_2 - z_1\right)}{1000}\right);$$

$$\Rightarrow \dot{W}_P = (160)\left(\frac{(140 - 60)}{800} + \frac{\left(6.66^2 - 3.33^2\right)}{2000} + \frac{9.81(3 - 0)}{1000}\right);$$

$$\Rightarrow \dot{W}_P = 23.4 \text{ kW}$$

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.

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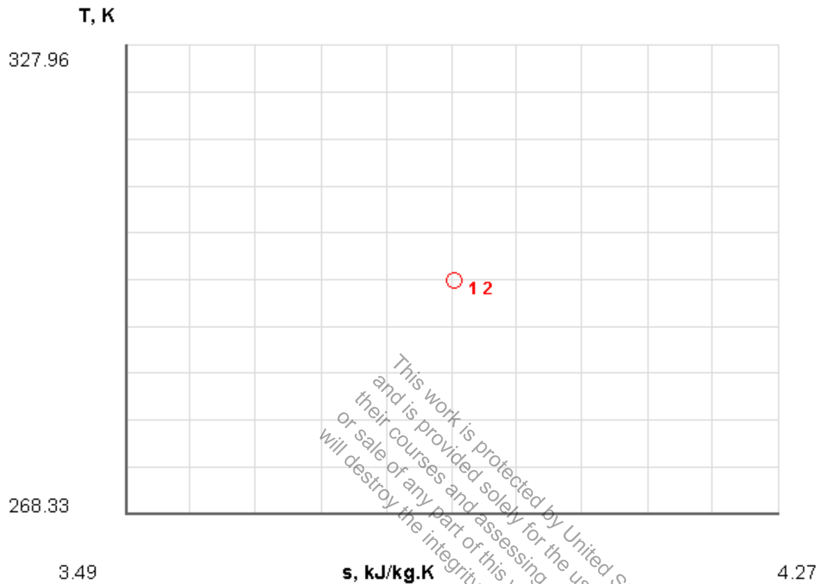
4-1-87 [OOA] A pump raises the pressure of water, flowing at a rate of 0.1 m3/s, from 70 kPa to a pressure of 150 kPa. The inlet and exit areas are 0.05 m2 and 0.02 m2 respectively. Assuming the pump to be isentropic and neglecting any change in pe, determine (a) the power input to the pump in kW. (b) ***What-if scenario:*** How would the answer change if the exit area was 0.01 m2 instead?

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 $p_1, \dot{V}_1, A_1$):

$$\dot{m}_1 = \frac{\dot{V}}{v_1} = \frac{(0.1)}{.001} = 100 \ \frac{\text{kg}}{\text{s}};$$

$$V_1 = \frac{v_1 \dot{m}_1}{A_1} = \frac{(0.001)(100)}{(0.05)} = 2 \ \frac{\text{m}}{\text{s}};$$

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

$$V_2 = \frac{v_2 \dot{m}_2}{A_2} = \frac{(0.001)(100)}{(0.02)} = 5 \ \frac{\text{m}}{\text{s}};$$

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

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

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

$$\Rightarrow \dot{W}_P = \dot{m}\left(v\left(p_2 - p_1\right) + \frac{V_2^2 - V_1^2}{2000}\right);$$

$$\Rightarrow \dot{W}_P = (100)\left(0.001(150 - 70) + \frac{\left(5^2 - 2^2\right)}{2000}\right);$$

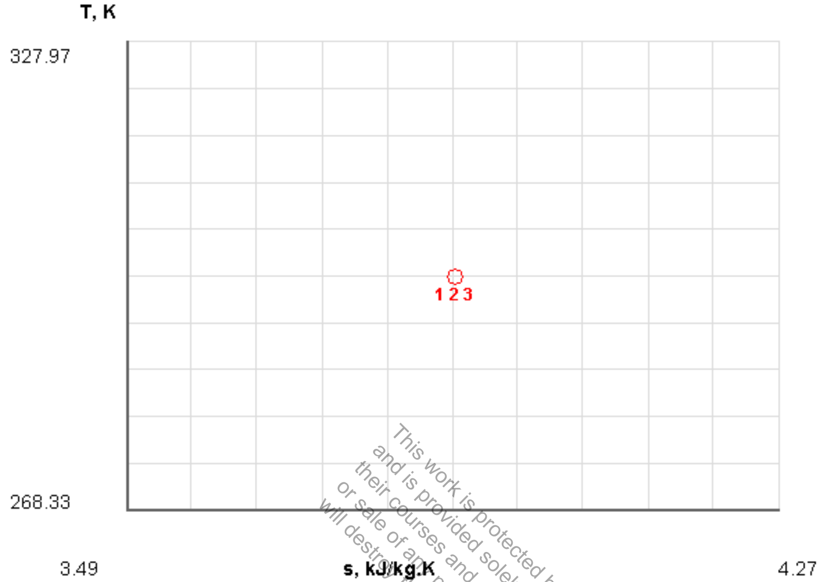
$$\Rightarrow \dot{W}_P = 9.05 \text{ kW}$$

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.

4-1-88 [OOH] If the pump above has an adiabatic efficiency of 75%, determine (a) the power input, (b) the exit temperature, and (c) the rate of entropy generation in the pump. Assume the inlet and surroundings temperature to be 25oC.

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 $p_1, T_1, \dot{V}_1, A_1$):

$$\dot{m}_1 = \frac{\dot{V}}{v_1} = \frac{(0.1)}{.001} = 100 \ \frac{\text{kg}}{\text{s}};$$

$$V_1 = \frac{v_1\dot{m}_1}{A_1} = \frac{(0.001)(100)}{(0.05)} = 2 \ \frac{\text{m}}{\text{s}};$$

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

$$V_2 = \frac{v_2\dot{m}_2}{A_2} = \frac{(0.001)(100)}{(0.02)} = 5 \ \frac{\text{m}}{\text{s}};$$

State-3 (given $p_3 = p_2, \dot{m}_3 = \dot{m}_1, A_3 = A_2, \ \eta$):

$$V_3 = \frac{v_3\dot{m}_3}{A_3} = \frac{(0.001)(100)}{(0.02)} = 5 \ \frac{\text{m}}{\text{s}};$$

(a) The energy balance equation gives

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

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

$$\Rightarrow \dot{W}_P = \dot{m}\frac{\left(v\left(p_2 - p_1\right) + \frac{V_2^2 - V_1^2}{2000}\right)}{\eta};$$

$$\Rightarrow \dot{W}_P = \frac{(100)\left(0.001(150-70) + \frac{\left(5^2 - 2^2\right)}{2000}\right)}{0.75};$$

$$\Rightarrow \dot{W}_P = 12.07\ \text{kW}$$

Alternatively:

$$\eta = \frac{\dot{W}_{P,s}}{\dot{W}_P};$$

$$\Rightarrow \dot{W}_P = \frac{\dot{W}_{P,s}}{\eta};$$

$$\Rightarrow \dot{W}_P = \frac{9.05}{0.75};$$

$$\Rightarrow \dot{W}_P = 12.07\ \text{kW}$$

(b) From this information:

$$-12.07 = \dot{m}\left(j_1 - j_3\right);$$

$$\Rightarrow j_1 - j_3 = -\frac{12.07}{\dot{m}};$$

$$\Rightarrow c\left(T_1 - T_3\right) + v\left(p_1 - p_3\right) + \frac{V_1^2 - V_3^2}{2000} = -\frac{12.07}{\dot{m}};$$

$$\Rightarrow T_3 = T_1 - \frac{v\left(p_3 - p_1\right) + \frac{V_3^2 - V_1^2}{2000} - \frac{12.07}{\dot{m}}}{c};$$

$$\Rightarrow T_3 = 25 - \frac{(0.001)(150-70) + \frac{5^2 - 2^2}{2000} - \frac{12.07}{100}}{4.184};$$

$$\Rightarrow T_3 = 25.007°\text{C}$$

(c) From the entropy balance equation

$$\frac{\cancel{dS}^{\,0}}{\cancel{dt}} = \dot{m}\left(s_1 - s_3\right) + \frac{\cancel{\dot{Q}}^{\,0}}{\cancel{T_B}} + \dot{S}_{\text{gen,univ}};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}\left(s_3 - s_1\right);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}c\ln\frac{T_3}{T_1};$$

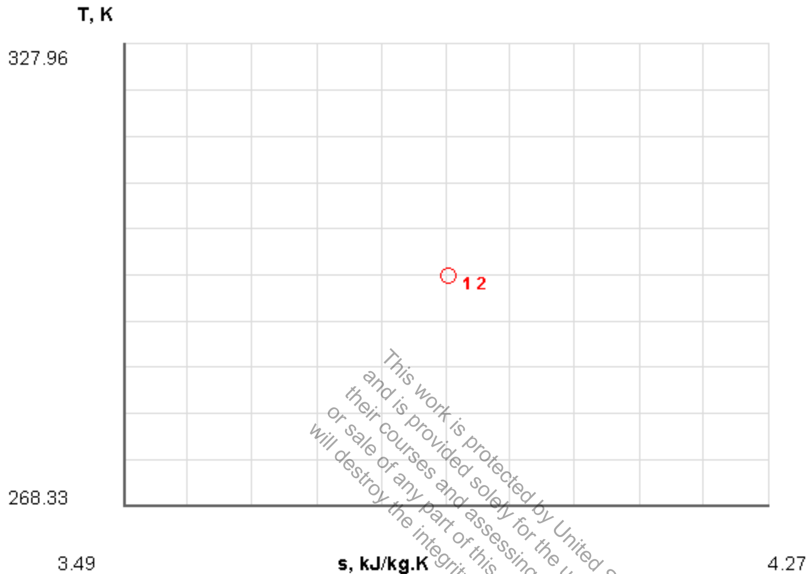
$$\Rightarrow \dot{S}_{\text{gen,univ}} = (100)(4.184)\ln\left(\frac{298.007}{298}\right);$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.01\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-89 [OON] Water at 25oC is being pumped at 1.5 kg/s from an open reservoir through a 10-cm pipe. The open end of the 5-cm discharge pipe is 15 m above the top of the water surface in the reservoir. (a) Neglecting any losses, determine the power required in kW. Assume the temperature to remain unchanged and use the SL model for water. (b) ***What-if scenario:*** How would the answer change if the PC model was used?

SOLUTION



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

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

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

State-1 (given $p_1, T_1, \dot{m}_1, A_1$):

$$V_1 = \frac{v_1 \dot{m}_1}{A_1} = \frac{(0.001)(1.5)}{(0.00785)} = 0.191 \ \frac{\text{m}}{\text{s}};$$

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

$$V_2 = \frac{v_2 \dot{m}_2}{A_2} = \frac{(0.001)(1.5)}{(0.00196)} = 0.765 \ \frac{\text{m}}{\text{s}};$$

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

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

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

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

$$\Rightarrow \dot{W}_P = (1.5)\left(\frac{\left(0.765^2 - 0.191^2\right)}{2000} + \frac{9.81(15-0)}{1000} \right);$$

$$\Rightarrow \dot{W}_P = 0.221 \text{ kW}$$

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.

4-1-90 [OOE] In the above problem, (a) determine the pumping power if the water temperature is 60oC throughout. (b) How high above the free surface of the storage tank the pump can be placed without vapor starting to form at the pump inlet?

SOLUTION

(a) To take into account the temperature effect, we must use the PC model. Using Table B-2

$$v_1 = v_2 = v_{f@60^\circ\mathrm{C}} = 0.001017\ \frac{\mathrm{m}^3}{\mathrm{s}}$$

as opposed to $0.001\frac{\mathrm{m}^3}{\mathrm{s}}$ used in the SL model (problem 4-1-89).

Therefore, V_1 and V_2 are practically unchanged. Also, with the pressure and temperature unchanged between the inlet and exit states, $h_1 = h_2$

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

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(\cancel{(h_1 - h_2)}^{0} + \frac{V_1^2 - V_2^2}{2000} + \frac{g(z_1 - z_2)}{1000}\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = (1.5)\left(\frac{(0.191^2 - 0.765^2)}{2000} + \frac{9.81(0-15)}{1000}\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = -0.221\ \mathrm{kW}$$

Therefore, the power input to the pump is 0.221 kW

(b) From Table B-2, $p_{\text{sat}@60^\circ\mathrm{C}} = 19.94\ \mathrm{kPa}$

Water would start boiling if the inlet pressure is lower than 19.94 kPa. If the pump is housed at an elevation z above the free surface,

$$p_0 = p_1 + \frac{z_1 \rho_1 g}{1000}$$

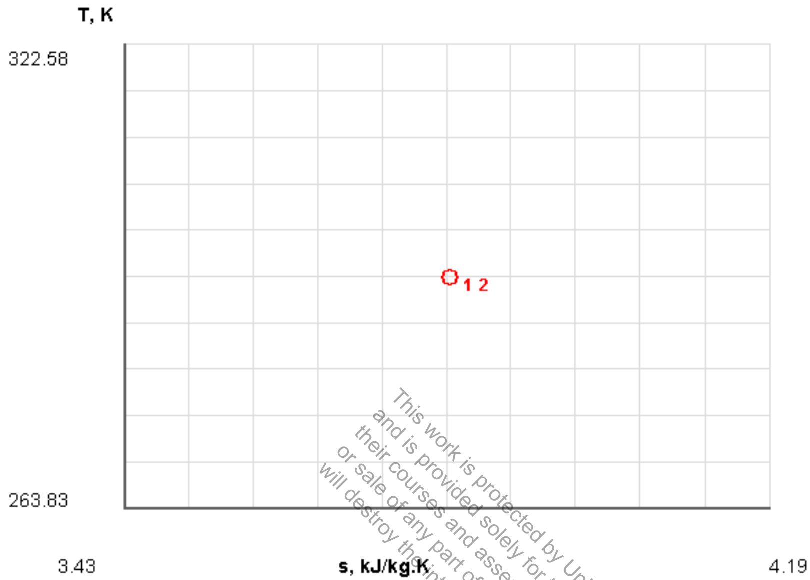
$$\Rightarrow z_1 = \frac{1000(p_0 - p_1)}{\rho_1 g} = \frac{1000 v_1 (p_0 - p_1)}{g} = \frac{1000(0.001)(100 - 19.94)}{9.81} = 8.16\ \mathrm{m}$$

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.

4-1-91 [OOG] A 5 kW pump is raising water to an elevation of 25 m from the free surface of a lake. The temperature of water increases by 0.1oC. Neglecting heat transfer and any change in ke, determine (a) the mass flow rate and (b) the entropy generated in the system.

SOLUTION



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

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

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, $T_2 = T_1 + 0.1$, $\dot{m}_2 = \dot{m}_1$)

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

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

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

$$\Rightarrow \dot{W}_P = \dot{m}\left(c\left(T_2 - T_1\right) + \frac{g\left(z_2 - z_1\right)}{1000} \right);$$

$$\Rightarrow \dot{m} = \frac{\dot{W}_P}{c\left(T_2 - T_1\right) + \frac{g\left(z_2 - z_1\right)}{1000}};$$

$$\Rightarrow \dot{m} = \frac{5}{4.184\left(0.1\right) + \frac{9.81\left(25 - 0\right)}{1000}};$$

$$\Rightarrow \dot{m} = 7.5\ \frac{\text{kg}}{\text{s}}$$

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

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_2 - s_1\right) + \cancel{\frac{\dot{Q}}{T_B}}^{0} + \dot{S}_{\text{gen,univ}};$$

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

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \dot{m}c\ln\frac{T_2}{T_1};$$

$$\Rightarrow \dot{S}_{\text{gen,univ}} = \left(7.5\right)\left(4.184\right)\ln\frac{298.25}{298.15};$$

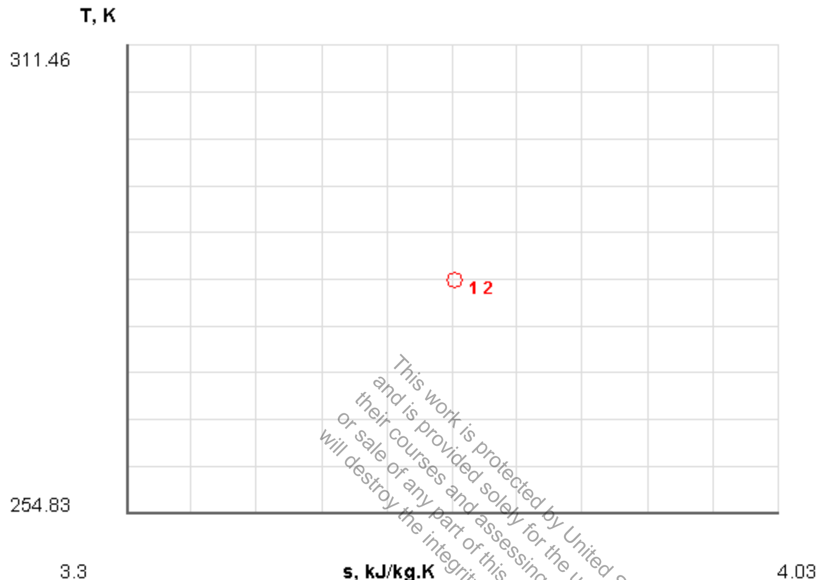
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.01\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-92 [OOL] A small water pump is used in an irrigation system. The pump takes water in from a river at 10oC, 100 kPa at a rate of 4.5 kg/s. The exit line enters a pipe that goes up to an elevation 18 m above the pump and river, where water runs into open channel. Assume the process is adiabatic and that the water stays at 10oC. Determine (a) the required pump power.

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 $p_1, T_1, \dot{m}_1$)

State-2 (given $p_2 = p_1, T_2 = T_1, \dot{m}_2 = \dot{m}_1, z_2$)

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

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

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

$$\Rightarrow \dot{W}_P = \frac{\dot{m}g\left(z_2 - z_1\right)}{1000};$$

$$\Rightarrow \dot{W}_P = \frac{(4.5)(9.81)(18-0)}{1000};$$

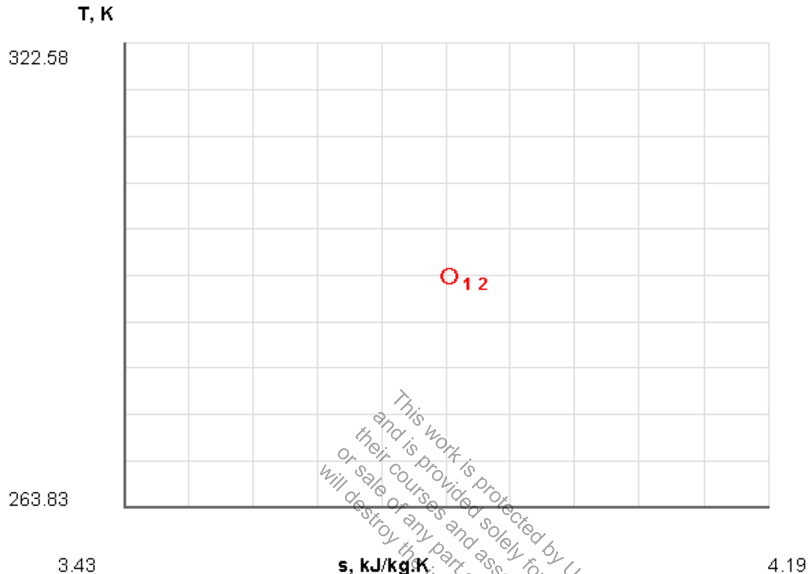
$$\Rightarrow \dot{W}_P = 0.794 \text{ kW}$$

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.

4-1-93 [OOI] A 5 kW pump is raising water to an elevation of 25 m from the free surface of a lake. The temperature of water increases by 0.1oC. Neglecting any change in ke, determine (a) the mass flow rate. (b) ***What-if scenario:*** How would the conclusion change if the pumping power was 10 kW?

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 $p_2,\ T_2 = T_1 + 0.1,\ \dot{m}_2 = \dot{m}_1$)

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

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

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

$$\Rightarrow \dot{W}_P = \dot{m}\left(c\left(T_2 - T_1\right) + \frac{g\left(z_2 - z_1\right)}{1000} \right);$$

$$\Rightarrow \dot{m} = \frac{\dot{W}_P}{c\left(T_2 - T_1\right) + \frac{g\left(z_2 - z_1\right)}{1000}};$$

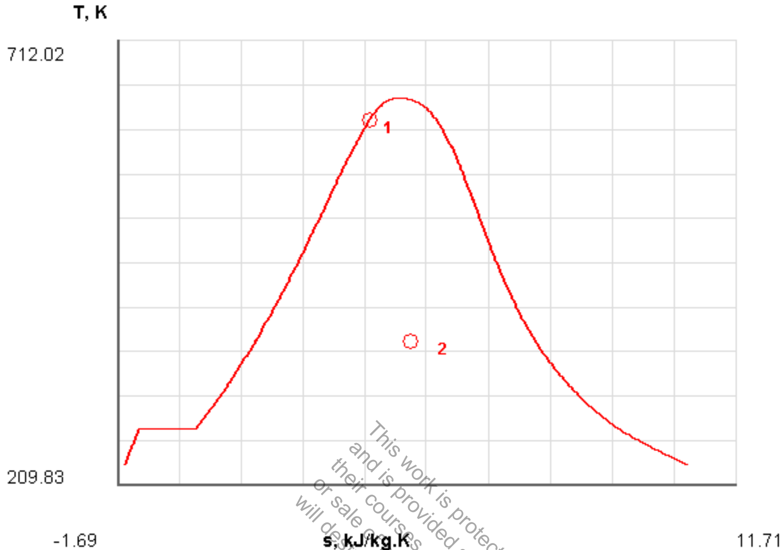
$$\Rightarrow \dot{m} = \frac{5}{4.184\left(0.1\right) + \frac{9.81\left(25 - 0\right)}{1000}};$$

$$\Rightarrow \dot{m} = 7.5\ \frac{\text{kg}}{\text{s}}$$

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.

4-1-94 [OOZ] Saturated liquid water at 350oC is throttled to a pressure of 100 kPa at a flow rate of 10 kg/s. Neglecting change in ke, determine (a) the exit temperature, and (b) the amount of saturated vapor produced by the throttling process.

SOLUTION



State-1 (given $x_1,\ T_1$):

$$p_1 = 16529 \text{ kPa}; \quad h_1 = 1671 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 3.778 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$h_f = 416.51 \ \frac{\text{kJ}}{\text{kg}}; \quad h_{fg} = 2257.5 \ \frac{\text{kJ}}{\text{kg}};$$

$$x_2 = \frac{h_2 - h_f}{h_{fg}} = 0.55;$$

(a) $T_2 = 99.16^{\circ}\text{C}$

(b) The amount of saturated vapor produced

$$\dot{m}_v = x_2 \dot{m}_1;$$

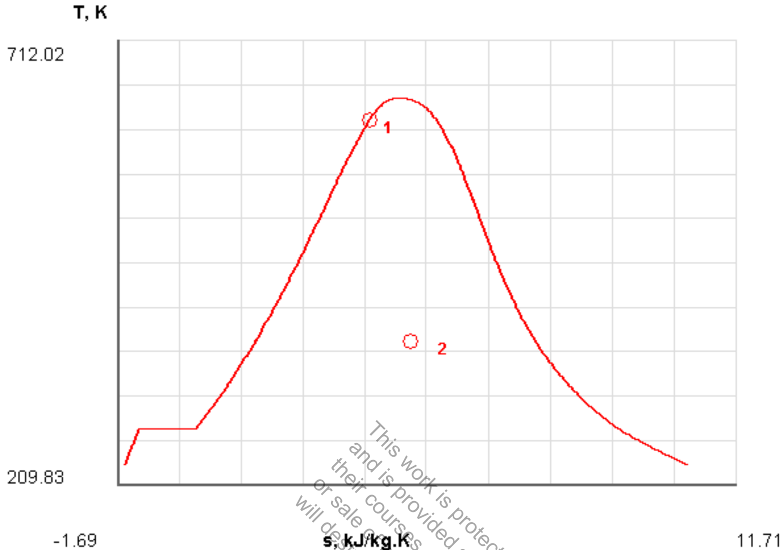
$$\Rightarrow \dot{m}_v = (0.55)(10) = 5.5 \ \frac{\text{kg}}{\text{s}}$$

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.

4-1-95 [OOK] In the above problem, steam enters the throttling valve with a velocity of 10 m/s. If the exit area is 15 times as large as the area of the inlet, determine (a) the exit velocity and (b) the vapor production rate.

SOLUTION



State-1 (given $x_1,\ T_1,\ V_1$):

$p_1 = 16529$ kPa;

$$h_1 = 1671\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 3.778\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad v_1 = 0.001741\ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $p_2,\ \dot{m}_2 = \dot{m}_1,\ A_2 = 15A_1$):

$T_2 = 99.16^{\circ}$C;

From energy equation simplifications

$j_1 = j_2$;

$$V_2 = \frac{\dot{m}}{\rho_2 A_2};$$

$$h_2 + \left(\frac{10}{0.0261\rho_2}\right)^2 = 1671.0043\ \frac{\text{kJ}}{\text{kg}};$$

Therefore by iteration of values of

$$h_2 \le 1671.0043\ \frac{\text{kJ}}{\text{kg}};\qquad \rho_2 \ge 0.590319\ \frac{\text{kg}}{\text{m}^3};$$

From steam table at saturated gas @ 100 kPa

$$h_2 = 1612.0834 \ \frac{\text{kJ}}{\text{kg}}; \qquad \rho_2 = 1.11457 \ \frac{\text{kg}}{\text{m}^3};$$

Therefore

(a) $$V_2 = \left(\frac{10}{(0.0261)(1.11457)} \right) = 343.24 \ \frac{\text{m}}{\text{s}}$$

(b) The vapor production

$$x_2 = \frac{h_2 - h_f}{h_g - h_f};$$

$$x_2 = \frac{1612.0834 - 417.46}{2675.5\text{-}417.46} = 0.52907;$$

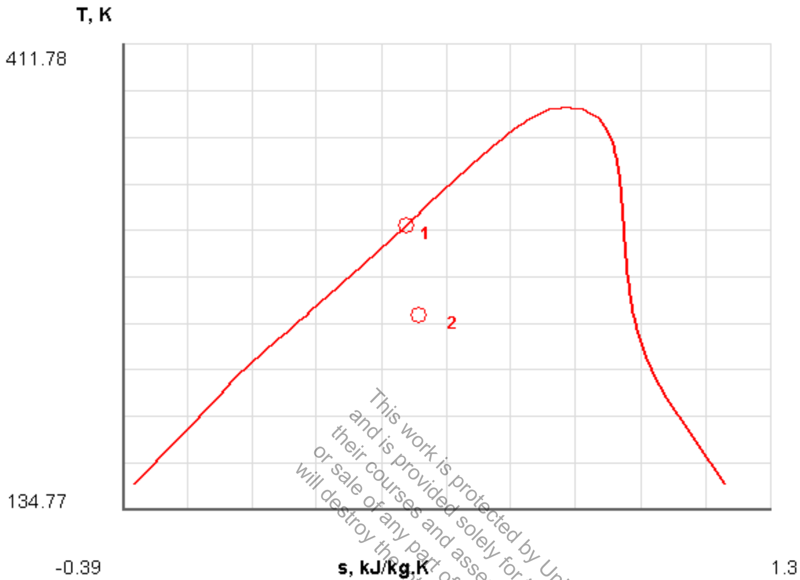
$$\dot{m}_v = \dot{m} x_2 = 5.29 \ \frac{\text{kg}}{\text{s}}$$

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.

4-1-96 [OOP] Refrigerant-134a enters an insulated capillary tube of a refrigerator as saturated liquid at 0.8 MPa and is throttled to a pressure of 0.12 MPa. Determine (a) the quality of refrigerant at the final state (b) and the temperature drop during this process.

SOLUTION



State-1 (given $p_1,\ x_1$):

$$T_1 = 304.4\text{ K};\quad h_1 = 94.7\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2,\ h_2 = h_1$):

$$T_2 = 250.6\text{ K} = -22.4^{\circ}\text{C};$$

(a) $x_2 = \dfrac{h_2 - h_f}{h_{fg}} = 0.341$

(b) The temperature drop during the process

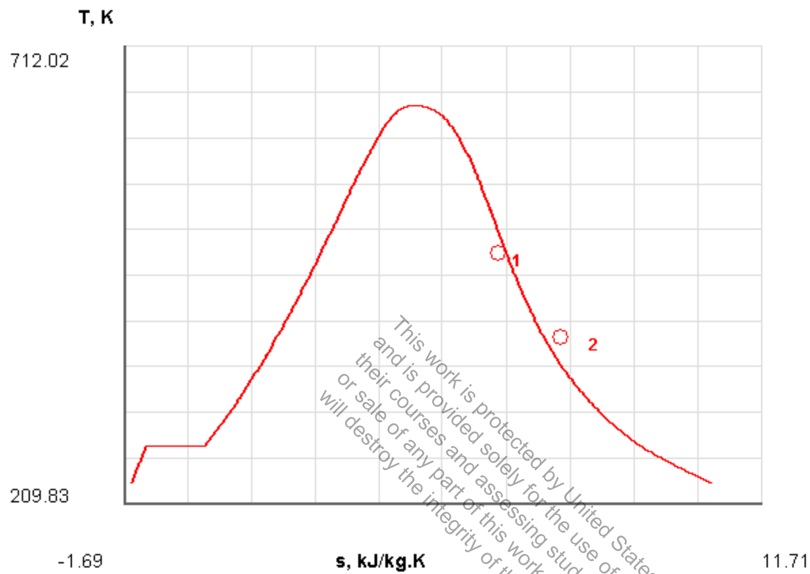
$$\Delta T = 53.8^{\circ}\text{C}$$

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.

4-1-97 [OOU] A pipe carries steam as a two phase liquid vapor mixture at 2.0 MPa. A small quantity is withdrawn through a throttling calorimeter, where it undergoes a throttling process to an exit pressure of 0.1 MPa. The temperature at the exit of the calorimeter is observed to be 120oC. Determine (a) the quality of the steam in the pipeline. (b) ***What-if scenario:*** How would the result change if the exit temperature was measured as 150^{o}C?

SOLUTION



State-1 (given p_1):

$$T_1 = 304.4 \text{ K}; \quad h_1 = 94.7 \frac{\text{kJ}}{\text{kg}};$$

State-2 (given p_2, T_2):

$$h_2 = 2716.27 \frac{\text{kJ}}{\text{kg}};$$

(a) From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}(h_1 - h_2);$$

$$\Rightarrow h_1 = h_2 = 2716.27 \frac{\text{kJ}}{\text{K}};$$

The quality of the steam in the pipe is

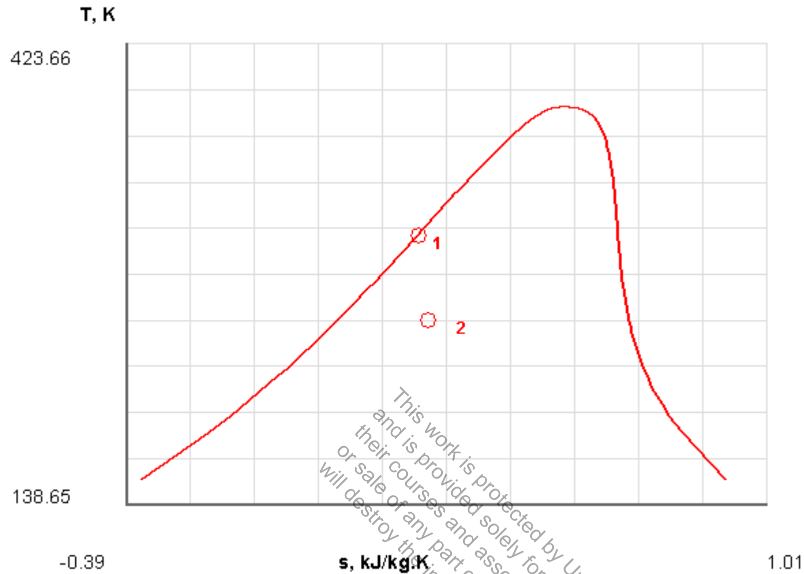
$$x_1 = \frac{h_1 - h_f}{h_{fg}} = 0.956$$

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.

4-1-98 [OOX] Refrigerant-12 is throttled by a valve from the saturated liquid state at 800 kPa to a pressure of 150 kPa at a flow rate of 0.5 kg/s. Determine (a) the temperature after throttling. (b) ***What-if scenario:*** How would the temperature change if the Refrigerant-12 was throttled down to 100 kPa?

SOLUTION



State-1 (given $p_1,\ x_1,\ \dot{m}_1$):

$$T_1 = 305.8 \text{ K};\quad h_1 = 67.3\ \frac{\text{kJ}}{\text{kg}};$$

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

From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}\left(h_1 - h_2\right);$$

$$\Rightarrow h_1 = h_2 = 67.3\ \frac{\text{kJ}}{\text{K}};$$

(a) Therefore, the temperature after throttling is

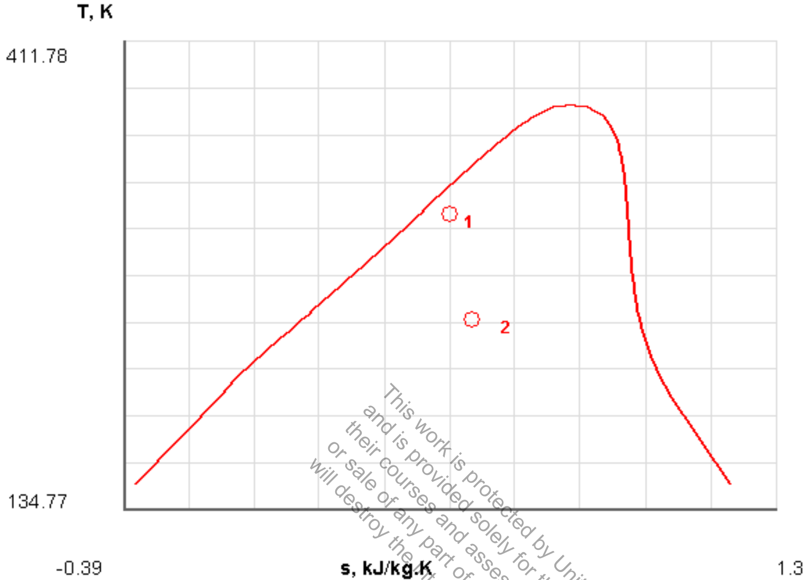
$$T_2 = 252.9 \text{ K} = -20.15^{\circ}\text{C}$$

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.

4-1-99 [OOC] Refrigerant-134a at 950 kPa is throttled to a temperature of -25oC and a quality of 0.5. If the velocity at the inlet and outlet remains constant at 10 m/s, determine (a) the quality at the inlet, (b) the ratio of exit-to-inlet area. (c) ***What-if scenario:*** How would the answers change if the velocity was 20 m/s?

SOLUTION



State-1 (given $p_1,\ V_1,\ \dot{m}_1$)

State-2 (given $T_2,\ x_2,\ \dot{m}_2 = \dot{m}_1,\ V_2 = V_1$):

$$h_2 = 126.18\ \frac{\text{kJ}}{\text{K}}; \qquad \rho_2 = 11.04\ \frac{\text{kg}}{\text{m}^3};$$

From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}\left(h_1 - h_2 + \frac{V_1 - \cancel{V_2}^{0}}{\cancel{2000}}\right);$$

$$\Rightarrow h_1 = h_2 = 126.18\ \frac{\text{kJ}}{\text{K}};$$

(a) The quality at the inlet is

$$x_1 = \frac{h_1 - h_f}{h_{fg}} = 0.134$$

$$\rho_1 = 273.9\ \frac{\text{kg}}{\text{m}^3};$$

(b) The ratio of exit-to-inlet area is

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

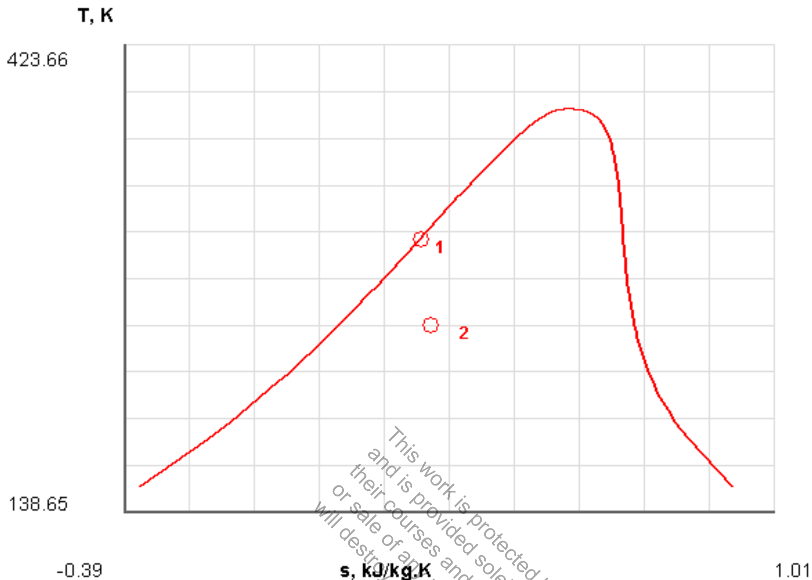
$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2;$$

$$\Rightarrow \frac{A_2}{A_1} = \frac{\rho_1}{\rho_2} = \frac{273.9}{11.04} = 24.8$$

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.

4-1-100 [OOV] Refrigerant-12 is throttled by a valve from the saturated liquid state at 800 kPa to a pressure of 150 kPa at a flow rate of 0.5 kg/s. Assuming the surrounding conditions to be 100 kPa, 25°C, determine the rate of entropy generation.

SOLUTION



State-1 (given $p_1,\ x_1,\ \dot{m}_1$):

$$T_1 = 305.8\ \text{K};\quad h_1 = 67.3\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 0.248\frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}\left(h_1 - h_2\right);$$

$$\Rightarrow h_1 = h_2 = 67.3\ \frac{\text{kJ}}{\text{K}};$$

$$\therefore T_2 = 252.9\ \text{K};\quad s_2 = 0.268\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

The entropy equation, applied to the overall system produces

$$\cancel{\frac{dS}{dt}}^{0} = \dot{m}\left(s_2 - s_1\right) + \cancel{\frac{\dot{Q}}{T_B}}^{0} + \dot{S}_{\text{gen,univ}};$$

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

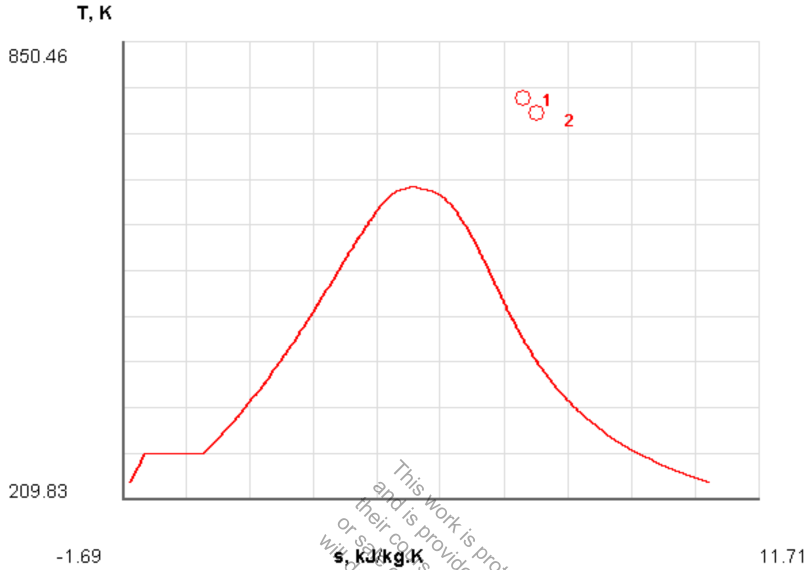
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 0.5\left(0.268 - 0.248\right) = 0.01\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-101 [OOQ] Steam at 8 MPa and 500oC is throttled by a valve to a pressure of 4 MPa at a flow rate of 7 kg/s. Determine the rate of entropy generation.

SOLUTION



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

$$h_1 = 3398.2\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.7\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

From the energy balance equation, we have

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

$$\Rightarrow 0 = \dot{m}(h_1 - h_2);$$

$$\Rightarrow h_1 = h_2 = 3398.2\ \frac{\text{kJ}}{\text{K}};$$

$$\therefore T_2 = 752.7\ \text{K}; \quad s_2 = 7.0\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

The entropy equation, applied to the overall system produces

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

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

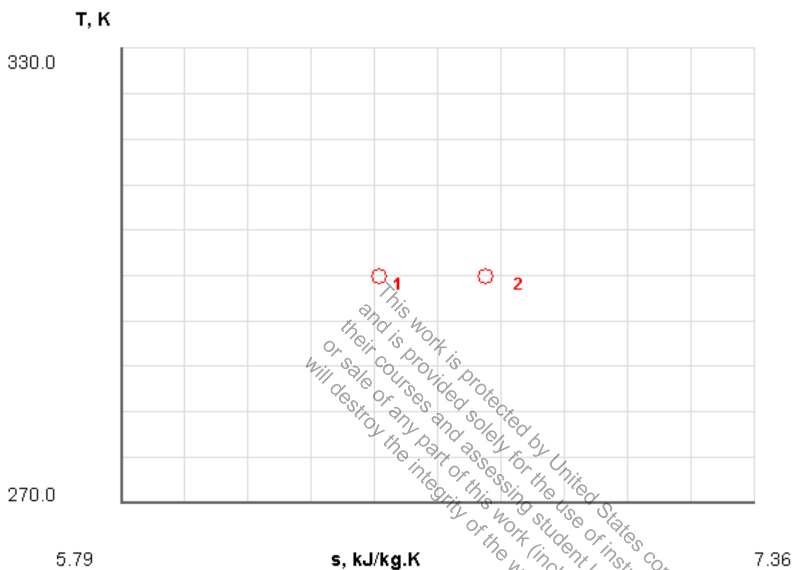
$$\Rightarrow \dot{S}_{\text{gen,univ}} = 7(7.0 - 6.7) = 2.1\ \frac{\text{kW}}{\text{K}}$$

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.

4-1-102 [OOT] Oxygen (model it as a perfect gas) is throttled by an insulated valve. At the inlet, the conditions are: 500 kPa, 300 K, 10 m/s, 1 kg/s. At the exit the conditions are: 200 kPa, 30 m/s. Determine (a) the exit area, and (b) the temperature at the exit. Assume steady state with no heat or external work transfer, and constant specific heats. Neglect any change in ke or pe. (c) ***What-if Scenario:*** What would the exit temperature be if the change in ke were not neglected. (d) Discuss if the use of IG model will affect your answers.

SOLUTION



Given:

$$c_p = 0.918 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$R = 0.2598 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

State-1 (given $p_1,\ T_1,\ \dot{m}_1, V_1$):

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.2598)(300)}{500} = 0.1559 \ \frac{\text{m}^3}{\text{kg}};$$

$$A_1 = \frac{\dot{m}_1 v_1}{V_1} = \frac{(1)(0.1559)}{10} = 0.01559 \ \text{m}^2 = 155.9 \ \text{cm}^2;$$

State-2 (given $p_2, h_2 = h_1, \dot{m}_2 = \dot{m}_1, V_2$)

(a) Since the throttling is isenthalpic

$$h_2 - h_1 = c_p (T_2 - T_1);$$

$$\Rightarrow 0 = c_p (T_2 - T_1);$$

$T_2 = T_1 = 300\ \text{K}$

(b) The exit area follows as

$$v_2 = \frac{RT_2}{p_2} = \frac{(0.2598)(300)}{200} = 0.3897\,\frac{\text{m}^3}{\text{kg}};$$

$$A_2 = \frac{\dot{m}_2 v_2}{V_2} = \frac{(1)(0.3897)}{30} = 0.01299\ \text{m}^2 = 129.9\ \text{cm}^2$$

TEST Solution and What-if Scenario:

Launch the PG 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.