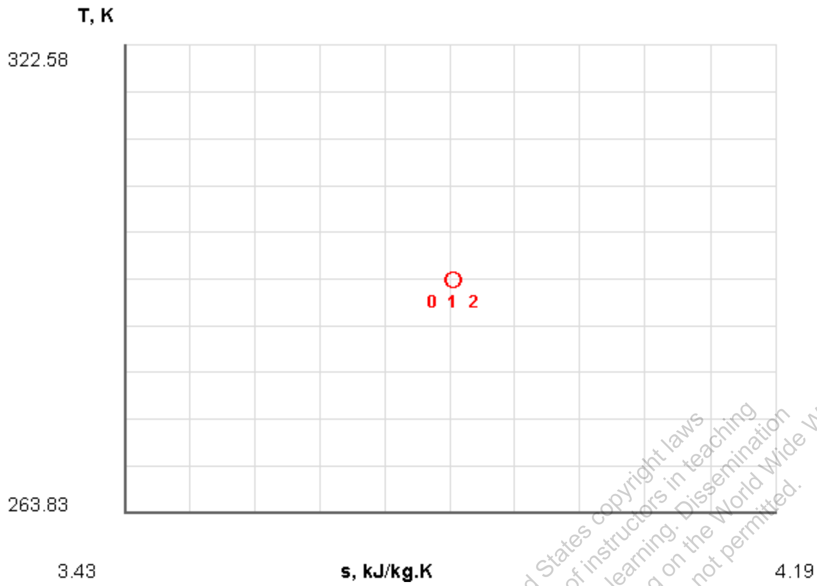
6-3-1 [OEY] A 5 kW pump is raising water to an elevation of 25 m from the free surface of a lake. The temperature of water increases by 0.1ºC. Neglecting the KE, determine (a) the mass flow rate, (b) the minimum power (magnitude only) required and (c) the exergetic (second-law) efficiency of the system. Assume the ambient temperature to be 20ºC.

SOLUTION



From Table A-1 or the SL open-steady single-flow TESTcalc, obtain $c_v = 4.182 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ for water.

(a) The energy equation for the open-steady system yields:

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

$$\Rightarrow \dot{W}_P = -\dot{W}_{\text{ext}} = \dot{m}\left(j_2 - j_1\right) = \dot{m}\left[(h_2 + \cancel{\text{ke}_2}^{\,0} + \text{pe}_2) - (h_1 + \cancel{\text{ke}_1}^{\,0} + \text{pe}_1)\right];$$

$$\Rightarrow \dot{W}_P = \dot{m}\left[(u_2 - u_1) + (p_2 v_2 - p_1 v_1) + (\text{pe}_2 - \text{pe}_1)\right] = \dot{m}\left[c_v \Delta T + v(p_0 - p_0) + (\text{pe}_2 - \text{pe}_1)\right];$$

$$\Rightarrow \dot{m} = \frac{\dot{W}_P}{c_v \Delta T + \left(g \Delta z / 1000\right)} = \frac{5}{0.418 + 0.245} = 7.53 \ \frac{\text{kg}}{\text{s}}$$

(b) The minimum power required is the reversible power. Simplifying the exergy balance equation for the open-steady system, we obtain:

$$\frac{d\cancel{\Phi}^{\,0}}{\cancel{dt}} = \dot{m}\left(\psi_1 - \psi_2\right) + \sum_k \cancel{\dot{Q}_k}^{\,0}\left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{P,\min} = -\dot{W}_{\text{rev}} = \dot{m}(\psi_2 - \psi_1) = \dot{m}\left[(h_2 - h_1) - T_0(s_2 - s_1) + \Delta\text{ke} + \Delta\text{pe}\right];$$

$$\Rightarrow \dot{W}_{P,\min} = \dot{m}\left[c_v \Delta T + v\,\cancel{\Delta p}^{\,0} - T_0 \Delta s + \cancel{\Delta\text{ke}}^{\,0} + \Delta\text{pe}\right] = \dot{m}\left[c_v \Delta T - T_0 c_v \ln\frac{T_2}{T_1} + \Delta\text{pe}\right];$$

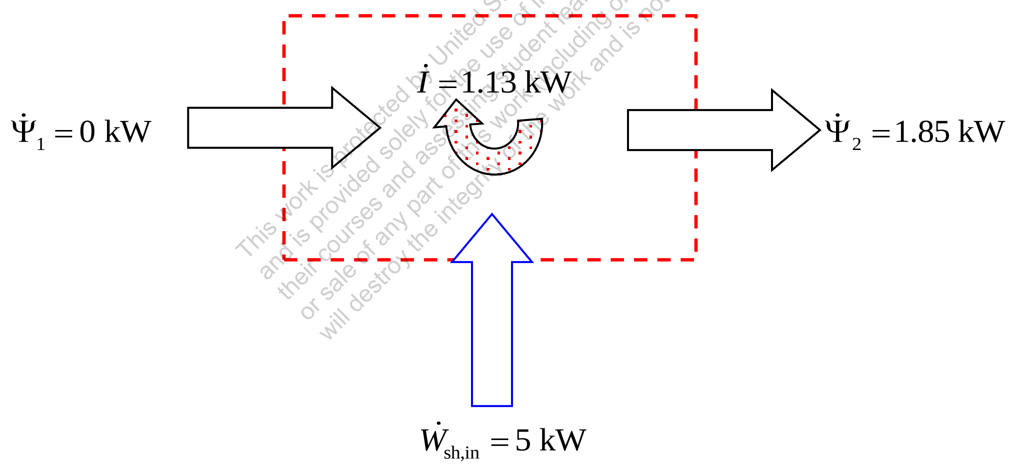
$$\Rightarrow \dot{W}_{P,\min} = (7.53)\left[0.418 - (293)(0.00143) + 0.245\right] = 1.84\ \text{kW}$$

(c) The exergetic efficiency.

$$\eta_{II} = \frac{\dot{W}_{P,\min}}{\dot{W}_P} = \frac{1.84}{5.0} = 0.368 = 36.8\%$$

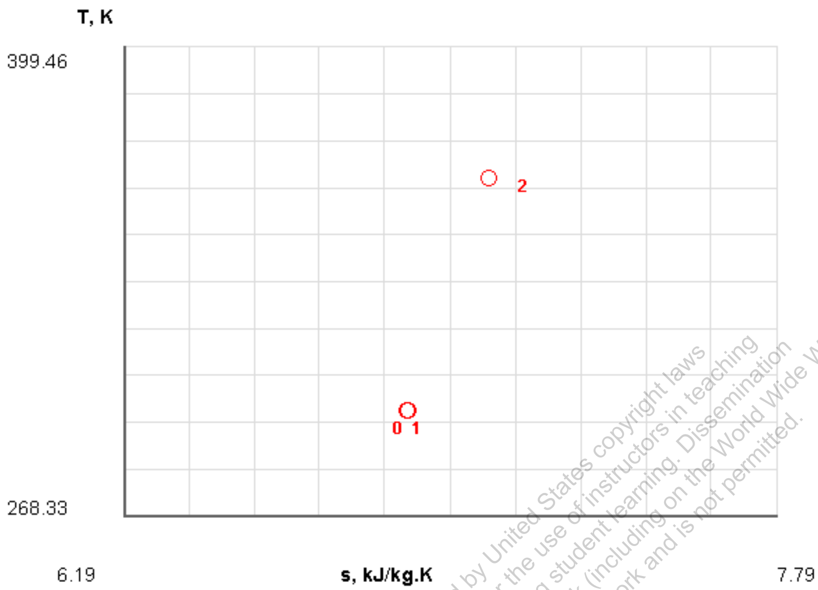
TEST Solution:

Launch the SL open-steady single flow TESTcalc and select Water(L). Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and exit states, enter Wdot_ext, Qdot and T_B, and click Calculate to determine the mass flow rate (posted on the state panel) and exergy variables in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.



6-3-2 [OEF] Measurements during steady state operation indicate that warm air exits a hand held hair dryer at a temperature of 90°C with a velocity of 10 m/s through an area of 20 cm^3. Air enters the dryer at 25°C, 100 kPa with a velocity of 3 m/s. No significant change in pressure is observed. Also, no significant heat transfer between the dryer and its surroundings occurs. Determine (a) the external power and (b) the exergetic efficiency. Let T_0 = 25°, p_0 = 1 atm. Use the PG model.

SOLUTION



From Table C-1 or the PG open-steady TESTcalc, obtain $R = 0.2870\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ and $c_p = 1.005\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ for air.

State-1 $\left(\text{given } p_1 = 100 \text{ kPa},\ T_1 = 25^\circ\text{C},\ \text{and } V_1 = 3\ \dfrac{\text{m}}{\text{s}}\right)$:

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.287)(298)}{100} = 0.855\ \frac{\text{m}^3}{\text{kg}};$$

State-2 $\left(\text{given } p_2 = p_1,\ T_2 = 90^\circ\text{C},\ A_2 = 20 \text{ cm}^2 \text{ and } V_2 = 10\ \dfrac{\text{m}}{\text{s}}\right)$:

$$v_2 = \frac{RT_2}{p_2} = \frac{(0.287)(363)}{100} = 1.042\ \frac{\text{m}^3}{\text{kg}};$$

$$\dot{m} = \frac{A_2 V_2}{v_2} = \frac{(.002)(10)}{1.042} = 0.0192\ \frac{\text{kg}}{\text{s}};$$

(a) The energy equation for the open-steady system yields:

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

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}\left(j_1 - j_2\right) = \dot{m}\left(h_1 - h_2\right) = \dot{m}c_p\left(T_1 - T_2\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = (0.0192)(1.005)(298 - 363) = -1.25 \text{ kW}$$

(b) The reversible power can be obtained from the exergy balance equation.

$$\frac{\cancel{d\Phi}^{0}}{\cancel{dt}} = \dot{m}\left(\psi_1 - \psi_2\right) + \sum_k \cancel{\dot{Q}_k}^{0}\left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left(\psi_2 - \psi_1\right) = -\dot{m}\left[(h_2 - h_1) - T_0(s_2 - s_1) + \Delta\text{ke} + \cancel{\Delta\text{pe}}^{0}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left[c_p\left(T_2 - T_1\right) - T_0\left(C_p \ln\frac{T_2}{T_1} - \cancel{R\ln\frac{p_2}{p_1}}^{0}\right) + \frac{V_2^2 - V_1^2}{2000}\right];$$

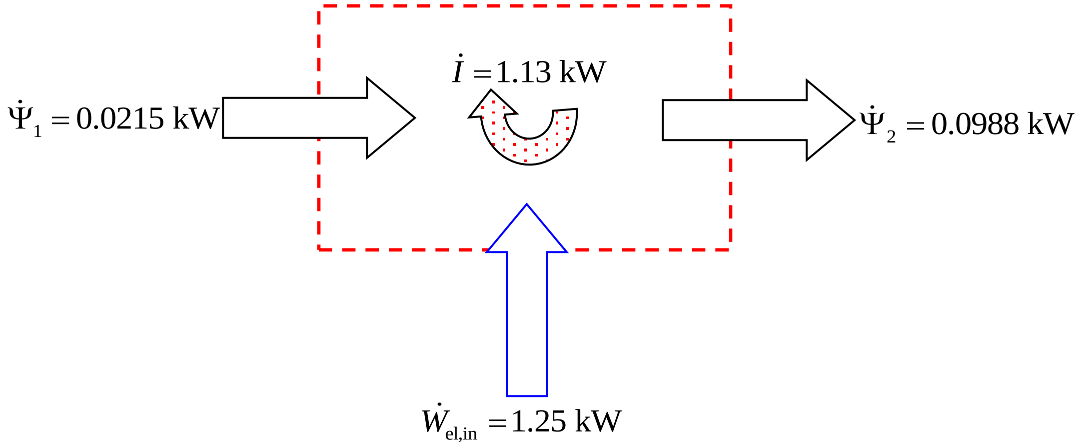
$$\Rightarrow \dot{W}_{\text{rev}} = -0.0192\left[1.005(363 - 298) - 298\left(1.005\ln\frac{363}{298}\right) + \frac{10^2 - 3^2}{2000}\right] = -0.121 \text{ kW};$$

The exergetic efficiency is

$$\eta_{II} = \frac{\dot{W}_{\text{rev}}}{\dot{W}_{\text{ext}}} = \frac{-0.121}{-1.25} = 9.68\%$$

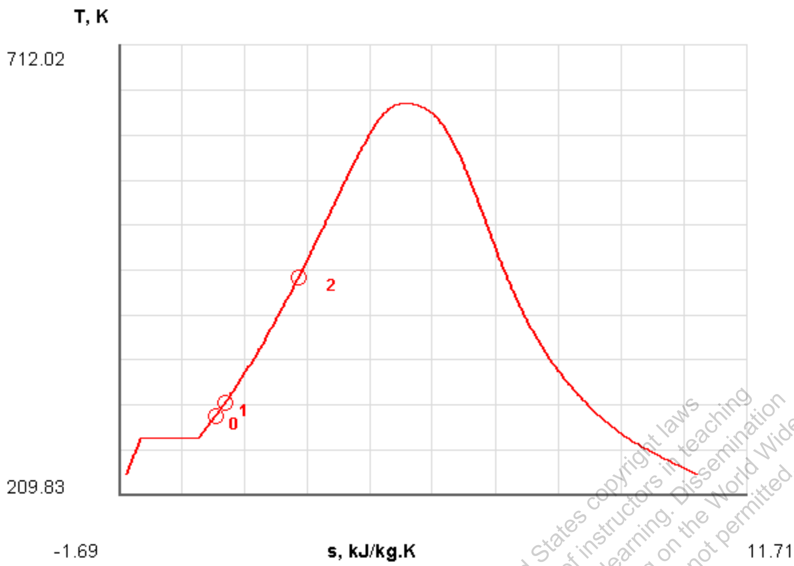
TESTSolution:

Launch the PG open-steady single flow TESTcalc and select Water(L). Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and exit states, enter Qdot, T_B, and click Calculate to determine Wdot_ext. The exergy variables are calculated in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.


$\dot{I} = 1.13$ kW
$\dot{\Psi}_1 = 0.0215$ kW
$\dot{\Psi}_2 = 0.0988$ kW
$\dot{W}_{el,in} = 1.25$ kW

6-3-3 [OED] A feedwater heater has water at a mass flow rate of 5 kg/s at 5 MPa, 40°C flowing through it, being heated from two sources. One source adds 900 kW from a 100°C reservoir and the other source adds heat from a 200°C reservoir such that the water exit conditions are 5 MPa and 180°C. (a) Determine the exergetic efficiency of the device. Let T_0 = 25°, p_0 = 1 atm.

SOLUTION



Use the manual approach or the PC single-flow open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 1$ atm and $T_0 = 25^{\circ}\text{C}$):

$$h_0 = 104.878\ \frac{\text{kJ}}{\text{kg}};\quad s_0 = 0.36732\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 $\left(\text{given } p_1 = 5\text{ MPa},\ T_1 = 40^{\circ}\text{C, and } \dot{m}_1 = 5\ \frac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 172.599\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 0.57247\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 6.454\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = p_1$, $T_2 = 180^{\circ}\text{C}$ and $\dot{m}_2 = \dot{m}_1$):

$$h_2 = 767.726\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 2.1396\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 134.34\ \frac{\text{kJ}}{\text{kg}};$$

The energy equation for this open-steady system simplifies as:

$$\cancel{\frac{dE}{dt}}^{0} = \dot{m}\left(j_1 - j_2\right) + \dot{Q} - \cancel{\dot{W}_{\text{ext}}}^{0} = \dot{m}\left(h_1 - h_2\right) + \dot{Q}_{\text{in},1} + \dot{Q}_{\text{in},2};$$

$$\Rightarrow \dot{Q}_{\text{in},1} + \dot{Q}_{\text{in},2} = \dot{m}\left(h_2 - h_1\right) = 2973\ \text{kW};$$

Given $\dot{Q}_{\text{in},1} = 900\ \text{kW}; \quad \Rightarrow \dot{Q}_{\text{in},2} = 2073\ \text{kW};$

The exergy equation for this open-steady system simplifies as:

$$\cancel{\frac{d\Phi}{dt}}^{0} = \dot{m}\left(\psi_1 - \psi_2\right) + \sum_k \dot{Q}_k\left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left(\psi_2 - \psi_1\right) + \dot{Q}_{\text{in},1}\left[1 - \frac{T_0}{T_1}\right] + \dot{Q}_{\text{in},2}\left[1 - \frac{T_0}{T_2}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = -639.4 + (900)\left[1 - \frac{298}{373}\right] + (2073)\left[1 - \frac{298}{473}\right] = 308.6\ \text{kW};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -639.4 + 181 + 767 = 308.6\ \text{kW};$$

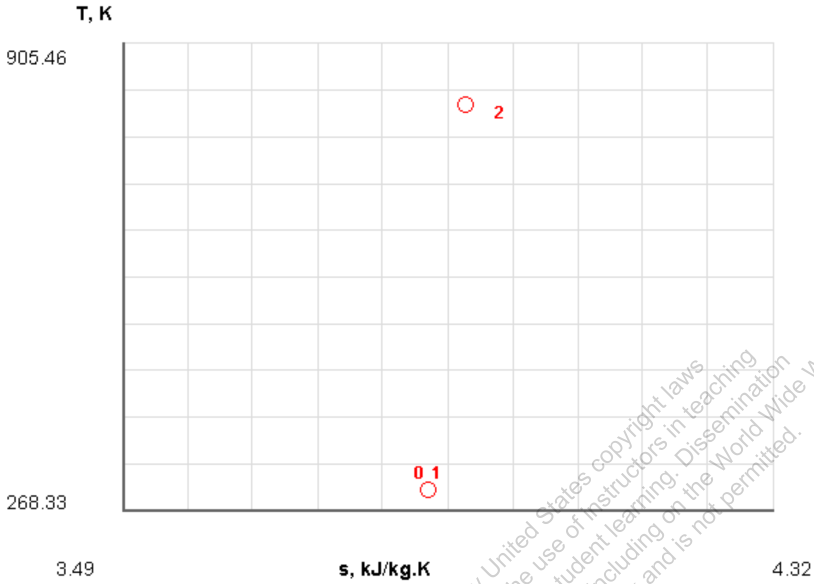
$$\eta_{\text{II}} = \frac{\text{Desired exergy}}{\text{Required input}} = \frac{\text{Exergy gained}}{\text{Exergy supplied}} = \frac{639.4}{181 + 767} = 67.45\%$$

TESTSolution:

Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and exit states, enter Wdot_ext, T_B, and click Calculate to determine Qdot. Because the TESTcalc allows only one external thermal reservoir, use the I/O panel to calculate the second law efficiency. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-4 [OEW] Argon gas enters an adiabatic compressor at 100 kPa, 25°C, 20 m/s and exits at 1 MPa, 550°C, 100 m/s. The inlet area of the compressor is 75 cm^2. Assuming the surroundings to be at 100 kPa and 25°C, determine (a) the reversible power, (b) irreversibility for this device and (c) the exergetic efficiency. (d) What-if Scenario: What would the answers be if the compressor lost 5 kW of heat to the atmosphere due to poor insulation?

SOLUTION



From Table C-1 or the PG single-flow open-steady TESTcalc, obtain $R = 0.208\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ and $c_p = 0.5203\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ for argon.

State-1 $\left(\text{given } p_1 = 100\text{ kPa},\ T_1 = 25^\circ\text{C},\ A_1 = 75\text{ cm}^2,\ \text{and } V_1 = 20\ \dfrac{\text{m}}{\text{s}}\right)$:

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.208)(298)}{100} = 0.619\ \frac{\text{m}^3}{\text{kg}};$$

$$\dot{m} = \frac{A_1V_1}{v_1} = \frac{(0.0075)(20)}{0.619} = 0.242\ \frac{\text{kg}}{\text{s}};$$

State-2 $\left(\text{given } p_2 = 1\text{ MPa},\ T_2 = 550^\circ\text{C},\ V_2 = 100\ \dfrac{\text{m}}{\text{s}}\ \text{and } \dot{m}_2 = \dot{m}_1\right)$

The energy equation for the open-steady system yields:

$$\frac{d\cancel{E}^{\,0}}{\cancel{dt}} = \dot{m}\left(j_i - j_e\right) + \cancel{\dot{Q}}^{\,0} - \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_2\right) + \dot{m}\left(\text{ke}_1 - \text{ke}_2\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}c_p\left(T_1 - T_2\right) - \dot{m}\frac{V_1^2 - V_2^2}{2000} = (0.242)(0.5203)(298 - 823) - 1.2;$$

$$\Rightarrow \dot{W}_{\text{ext}} = -67.3 \text{ kW};$$

(a) Using the exergy balance equation for this single-flow open-steady system

$$\dot{W}_{\text{rev}} = \dot{m}\left(\psi_2 - \psi_1\right) = -\dot{m}\left[\left(h_2 - h_1\right) - T_0\left(s_2 - s_1\right) + \Delta ke + \cancel{\Delta pe}^{\,0}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left[c_p\left(T_2 - T_1\right) - T_0\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right) + \frac{V_2^2 - V_1^2}{2000}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = -(0.242)\left[(0.5203)(823 - 298) - (298)\left(0.5203\ln\frac{823}{298} - 0.208\ln\frac{1000}{100}\right) + \frac{100^2 - 20^2}{2000}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = -63.7 \text{ kW}$$

(b) The exergy destroyed is given by

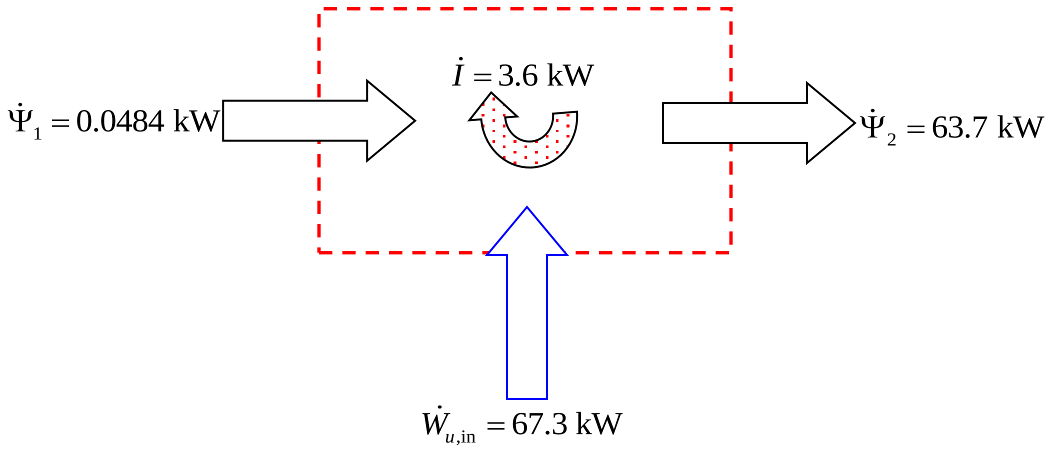
$$\dot{I} = \dot{W}_{\text{rev}} - \dot{W}_u = (-63.7) - (-67.3) = 3.6 \text{ kW}$$

(c) The exergetic efficiency is

$$\eta_{II} = \frac{\dot{W}_{\text{rev}}}{\dot{W}_u} = \frac{-63.7}{-67.3} = 94.6\%$$

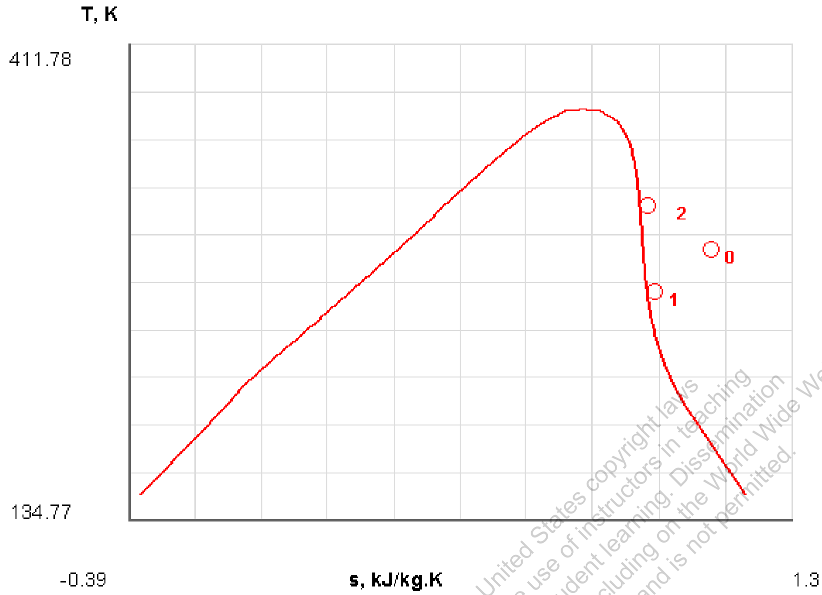
TEST Solution:
Launch the PG open-steady single flow TESTcalc and select Argon. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel, load the inlet and exit states, enter Qdot, T_B, and click Calculate to determine Wdot_ext. The exergy variables are calculated in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

(d) **What-if Scenario:** Modify Qdot in the device panel and click Super-Calculate to update all solutions. The updated results are: (a) -63.7 kW, (b) 8.6 kW, (c) 88%


$\dot{I} = 3.6$ kW
$\dot{\Psi}_1 = 0.0484$ kW
$\dot{\Psi}_2 = 63.7$ kW
$\dot{W}_{u,\text{in}} = 67.3$ kW

6-3-5 [OEM] Refrigerant-134a is to be compressed from 0.2 MPa and -5°C to 1 MPa and 50°C steadily by an adiabatic compressor. Taking the environment conditions to be 20°C and 95 kPa, determine (a) the specific exergy change of the refrigerant and (b) the minimum work input (magnitude only) that needs to be supplied to the compressor per unit mass of the refrigerant

SOLUTION



Use the manual approach or the PC single-flow open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 95$ kPa and $T_0 = 20^{\circ}$C):

$$h_0 = 271.15 \ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 1.09 \ \frac{\text{kJ}}{\text{kg.K}};$$

State-1 $\left(\text{given } p_1 = 0.2 \text{ MPa}, \ T_1 = -5^{\circ}\text{C, and } \dot{m}_1 = 1 \ \frac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 247.64 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.949 \ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_1 = (h_1 - h_0) - T_0 (s_1 - s_0) + \cancel{ke_1}^0 + \cancel{pe_1}^0 = 18.34 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = 1$ MPa, $T_2 = 50^{\circ}$C and $\dot{m}_2 = \dot{m}_1$):

$$h_2 = 276.7 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 0.933 \ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_2 = (h_2 - h_0) - T_0 (s_2 - s_0) + \cancel{ke_2}^0 + \cancel{pe_2}^0 = 52.26 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $\Delta\psi = \psi_2 - \psi_1 = 52.26 - 18.34 = 33.92 \ \frac{\text{kJ}}{\text{kg}}$

(b) The exergy balance equation for this open-steady system simplifies as:

$$\cancel{\frac{d\Phi}{dt}}^0 = \dot{m}(\psi_1 - \psi_2) + \sum_k \cancel{\dot{Q}_k}^0 \left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}(\psi_2 - \psi_1);$$

$$\Rightarrow \frac{\dot{W}_{\text{rev}}}{\dot{m}} = -(\psi_2 - \psi_1) = -\Delta\psi = -33.92 \ \frac{\text{kJ}}{\text{kg}};$$

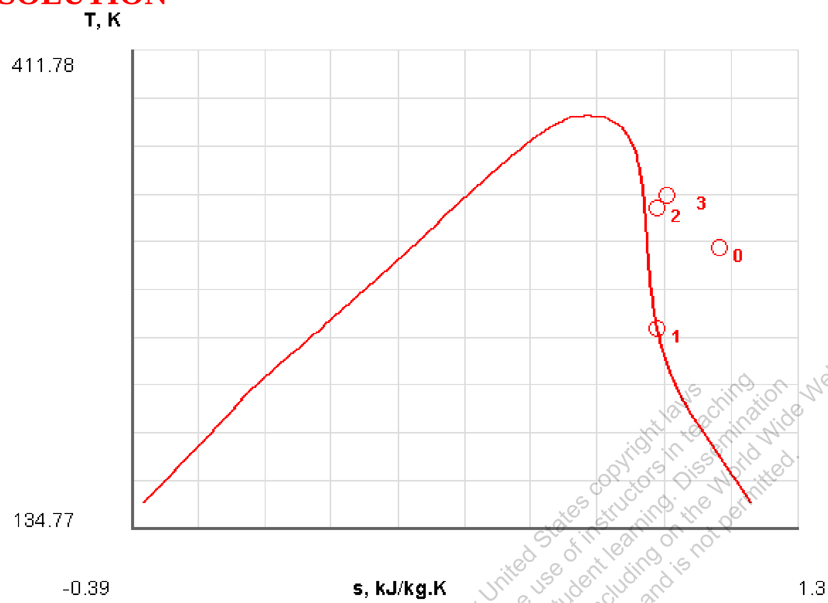
$$\Rightarrow \frac{\dot{W}_{\text{in,min}}}{\dot{m}} = \frac{-\dot{W}_{\text{rev}}}{\dot{m}} = 33.92 \ \frac{\text{kJ}}{\text{kg}}$$

TESTSolution:

Launch the PC open-steady single flow TESTcalc and select R-134a. Evaluate the dead, inlet, and exit states from the given conditions (with a mass flow rate of 1 kg/s). In the device panel load the inlet and exit states, enter Qdot, T_B, and click Calculate to determine Wdot_ext. Find the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-6 [OEJ] Refrigerant-134a enters an adiabatic compressor as saturated vapor at 120 kPa at a rate of 1 m^3/min and exits at 1 MPa. The compressor has an adiabatic efficiency of 85%. Assuming the surrounding conditions to be 100 kPa and 25°C. Determine (a) the actual power (W_{rev}) and (b) the second-law efficiency of the compressor. (c) What-if Scenario: What would the actual power be if the compressor had an adiabatic efficiency of 70%?

SOLUTION



Use the manual approach or the PC single-flow open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 25^\circ\text{C}$)

State-1 $\left(\text{given } p_1 = 120\ \text{kPa},\ x_1 = 1,\ \dot{V}_1 = 1\ \dfrac{\text{m}^3}{\text{min}}\right)$:

$$h_1 = 235.5\ \frac{\text{kJ}}{\text{kg}};\quad v_1 = 0.1622\ \frac{\text{m}^3}{\text{kg}};\quad s_1 = 0.943\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{0.0166}{0.1622} = 0.1023\ \frac{\text{kg}}{\text{s}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 7.76\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = 1$ MPa and $s_2 = s_1$):

$$h_2 = 279.8\ \frac{\text{kJ}}{\text{kg}};\qquad v_2 = 0.0216\ \frac{\text{m}^3}{\text{kg}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^0 + \cancel{pe_2}^0 = 52.0\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_2$ and $\eta_c = 85\%$) :

$$s_3 = 0.9667\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$h_3 = h_1 + \frac{(h_2 - h_1)}{\eta_c} = 287.65\ \frac{\text{kJ}}{\text{kg}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \cancel{ke_3}^0 + \cancel{pe_3}^0 = 52.7\ \frac{\text{kJ}}{\text{kg}};$$

(a) Using the energy balance equation we obtain

$$\cancel{\frac{dE}{dt}}^0 = \dot{m}(j_i - j_e) + \cancel{\dot{Q}}^0 - \dot{W}_{\text{ext}} = \dot{m}(h_1 - h_3);$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{m}(h_3 - h_1) = -5.35\ \text{kW};$$

$$\Rightarrow \dot{W}_{\text{in}} = -\dot{W}_{\text{ext}} = 5.35\ \text{kW}$$

(b) The exergy balance equation for this open-steady system simplifies as:

$$\cancel{\frac{d\Phi}{dt}}^0 = \dot{m}(\psi_1 - \psi_2) + \sum_k \cancel{\dot{Q}_k}^0\left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = \dot{m}_1(\psi_1 - \psi_3) = \dot{m}_1\left[(h_1 - h_3) - T_0(s_1 - s_3) - \cancel{\Delta ke}^0 - \cancel{\Delta pe}^0\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = (0.1027)[7.76 - 52.7] = -4.6\ \text{kW};$$

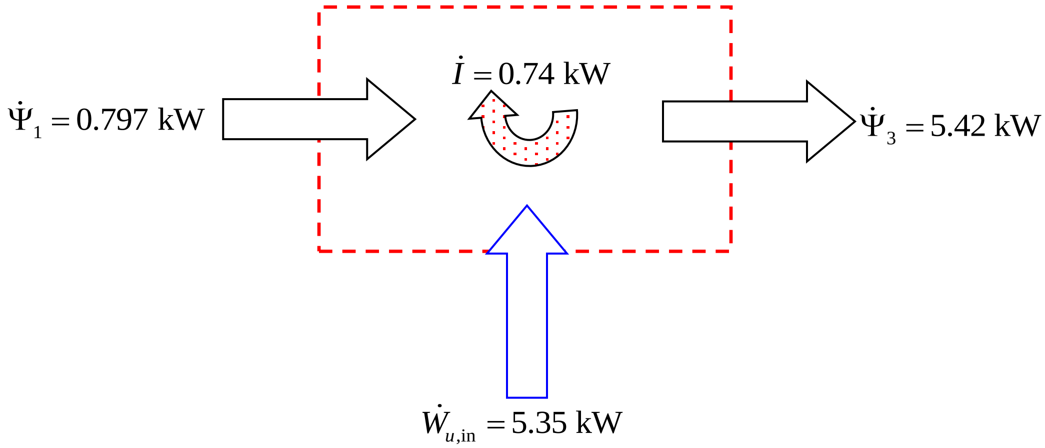
The second law efficiency

$$\eta_{II} = \frac{\dot{W}_{rev}}{\dot{W}_u} = \frac{-4.6\ \text{kW}}{-5.35\ \text{kW}} = 0.86 = 86\%$$

TEST Solution:

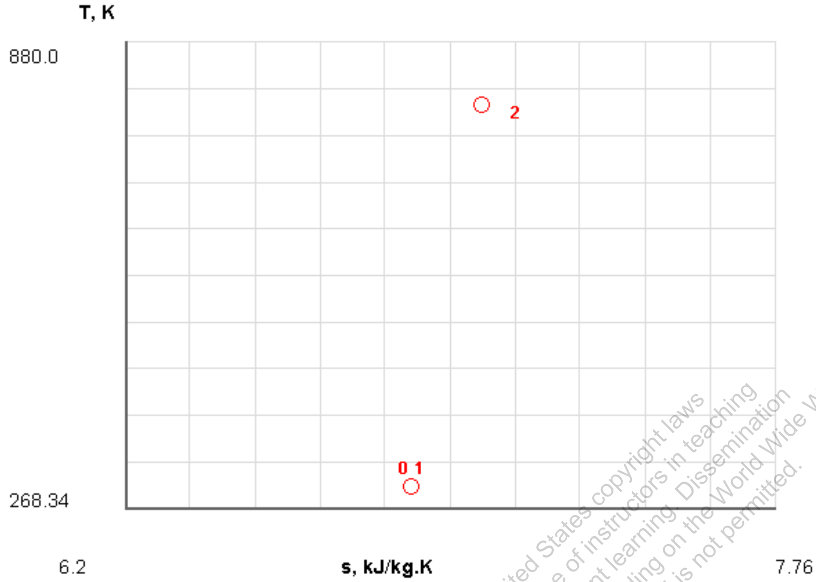
Launch the PC open-steady single flow TESTcalc and select R-134a. Evaluate the dead, inlet, actual exit and isentropic exit states from the given conditions. In the device panel load the inlet and actual exit states, enter Qdot, T_B, and click Calculate to determine Wdot_ext. Find the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

(c) Change the adiabatic efficiency in the expression for j3 and Super-Calculate to obtain the new power to be 6.5 kW.



6-3-7 [OIR] Consider an air compressor that receives ambient air at 100 kPa and 25°C. It compresses the air to a pressure of 2 MPa, where it exits at a temperature of 800 K. Since the air and compressor housing are both hotter than the ambient temperature, the compressor loses 80 kJ per kilogram air flowing through the compressor. Determine (a) the reversible work (w_{rev}) and (b) the irreversibility in the process. Use the IG model for air.

SOLUTION



Use the manual approach or the IG single-flow open-steady TESTcalc to determine the states.

The gas constant for air is $R = 0.28699\ \dfrac{\text{kJ}}{\text{kg.K}}$;

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 25^\circ\text{C}$):

$$h_0 = 298\ \frac{\text{kJ}}{\text{kg}}; \qquad s_0 = 6.886\ \frac{\text{kJ}}{\text{kg.K}};$$

State-1 $\left(\text{given } p_1 = 100 \text{ kPa}, T_1 = 25^\circ\text{C and } \dot{m} = 1\ \dfrac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 298\ \frac{\text{kJ}}{\text{kg}}; \qquad s_1^0 = 1.695\ \frac{\text{kJ}}{\text{kg.K}}; \qquad s_1 = 6.886\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{\,0} + \cancel{pe_1}^{\,0} = 0\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (Given $p_2 = 2$ MPa, $T_2 = 800$ K):

$$h_2 = 821.95\ \frac{\text{kJ}}{\text{kg}};\quad s_2^0 = 2.718\ \frac{\text{kJ}}{\text{kg.K}};\quad s_2 = 7.053\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{\,0} + \cancel{pe_2}^{\,0} = 476\ \frac{\text{kJ}}{\text{kg}};$$

(a) The exergy balance equation for this open-steady system simplifies as:

$$\cancel{\frac{d\Phi}{dt}}^{\,0} = \dot{m}(\psi_1 - \psi_2) + \sum_k \cancel{\dot{Q}_k}^{\,0}\left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}(\psi_2 - \psi_1);$$

$$\Rightarrow \frac{\dot{W}_{\text{rev}}}{\dot{m}} = -(\psi_2 - \psi_1) = -\Delta\psi = -476\ \frac{\text{kJ}}{\text{kg}}$$

(b) Using the energy equation

$$0 = \dot{m}(h_1 - h_2) + \dot{Q} - \dot{W}_{ext};$$

$$\Rightarrow \frac{\dot{W}_{\text{ext}}}{\dot{m}} = (h_1 - h_2) + \frac{\dot{Q}}{\dot{m}};$$

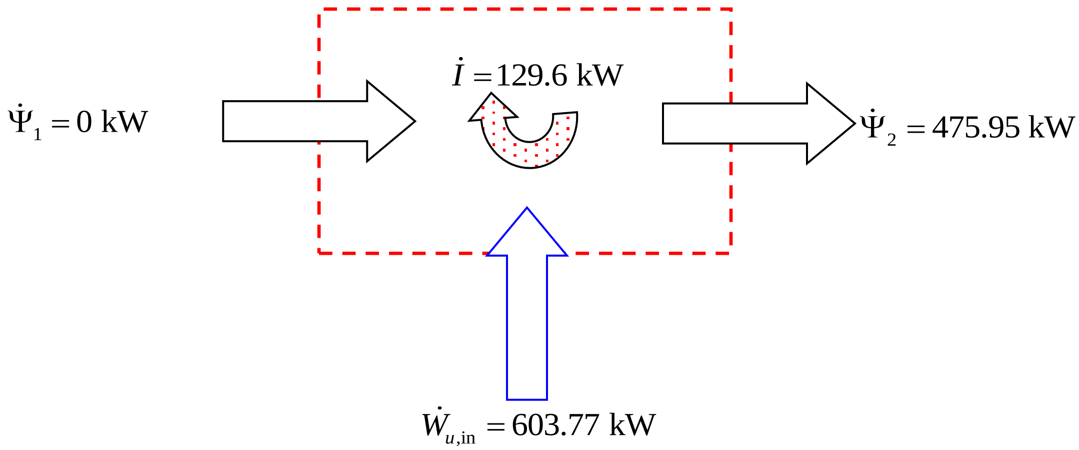
$$\Rightarrow \frac{\dot{W}_{\text{ext}}}{\dot{m}} = \; = (298.18 - 821.95) - 80 = -605.7\ \text{kW};$$

The exergy destroyed per unit mass is given by

$$\frac{\dot{I}}{\dot{m}} = \frac{\dot{W}_{\text{rev}} - \dot{W}_u}{\dot{m}} = \frac{\dot{W}_{\text{rev}} - \dot{W}_{\text{ext}}}{\dot{m}} = 129.7\ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

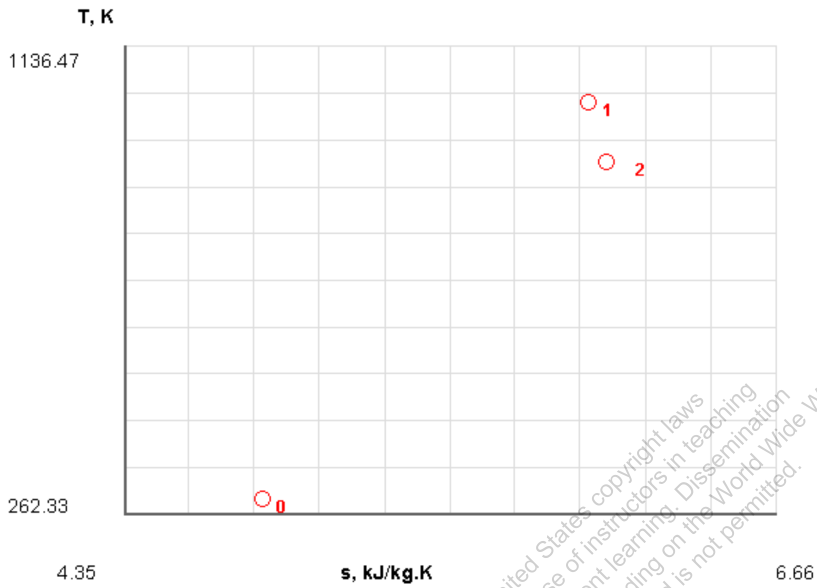
Launch the IG open-steady single flow TESTcalc and select Air*. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and actual exit states, enter Qdot, T_B, and click Calculate to determine Wdot_ext. Find the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.



$\dot{\Psi}_1 = 0$ kW
$\dot{I} = 129.6$ kW
$\dot{\Psi}_2 = 475.95$ kW
$\dot{W}_{u,\text{in}} = 603.77$ kW

6-3-8 [OIO] Carbon dioxide (CO_2) enters a nozzle at 35 psia, 1400°F, 250 ft/s and exits at 12 psia, 1200°F. Assuming the nozzle to be adiabatic and the surroundings to be at 14.7 psia and 65°F. Determine (a) the exit velocity (V_2) and (b) the availability drop between the inlet and the exit. (c) What-if Scenario: What would the exit velocity be if carbon dioxide entered the nozzle at 500 ft/s?

SOLUTION



Use the manual approach or the IG single-flow open-steady TESTcalc to determine the states.

The gas constant of $R = 0.18891\ \frac{\text{kJ}}{\text{kg.K}}$;

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 15^\circ\text{C}$):

$h_0 = -8947.3\ \frac{\text{kJ}}{\text{kg}}$; $\quad s_0 = 4.838\ \frac{\text{kJ}}{\text{kg.K}}$;

State-1 $\left(\text{given } p_1 = 35 \text{ psia, } T_1 = 1400^\circ\text{ F, and } V_1 = 250\ \frac{\text{ft}}{\text{s}}\right)$:

$h_1 = -8141.7\ \frac{\text{kJ}}{\text{kg}}$; $\quad s_1^0 = 6.16\ \frac{\text{kJ}}{\text{kg.K}}$; $\quad s_1 = 6.00\ \frac{\text{kJ}}{\text{kg.K}}$;

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 471.3\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = 12$ psia, $T_2 = 1200^\circ$ F):

$$h_2 = -8278.1\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 6.058\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^0 + \cancel{pe_2}^0 = 453.1\ \frac{\text{kJ}}{\text{kg}};$$

(a) Using the energy equation

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

$$\Rightarrow V_2 = \sqrt{2000\left(h_1 - h_2 + \frac{V_1^2}{2000}\right)} = \sqrt{2000\left(-8142 + 8278 + \frac{76.2^2}{2000}\right)};$$

$$\Rightarrow V_2 = 527.6\ \frac{\text{m}}{\text{s}} = 1731.64\ \frac{\text{ft}}{\text{s}}$$

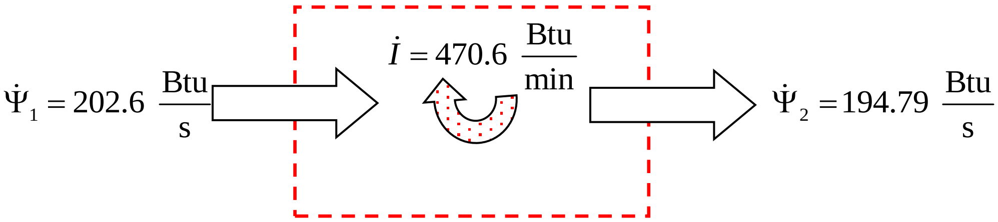
(b) The availability drop is given by

$$\dot{m}(\psi_1 - \psi_2) = 8.28\ \text{kW} = 471\ \frac{\text{Btu}}{\text{min}}$$

TESTSolution:

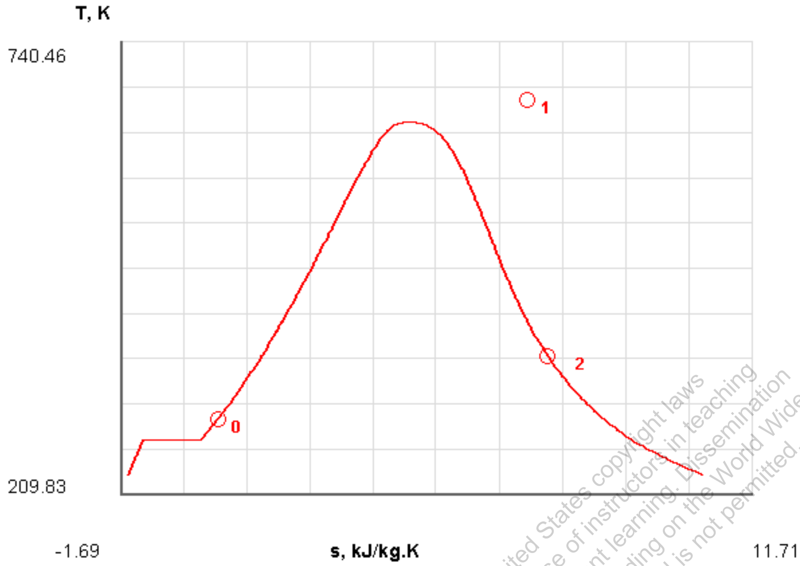
Launch the IG open-steady single flow TESTcalc and select CO2. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and actual exit states, enter Qdot, T_B, and click Calculate to determine Wdot_ext. Find the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

(c) **What-if Scenario:** Change Vel1 to the new value and click the Super-Calculate button to obtain Vel2 as 544 m/s or 1785 ft/s.


$\dot{\Psi}_1 = 202.6\ \frac{\text{Btu}}{\text{s}}$
$\dot{I} = 470.6\ \frac{\text{Btu}}{\text{min}}$
$\dot{\Psi}_2 = 194.79\ \frac{\text{Btu}}{\text{s}}$

6-3-9 [OIB] Steam enters a turbine with a pressure of 3 MPa, a temperature of 400°C and a velocity of 140 m/s. Steam exits as saturated vapor at 100°C with a velocity of 105 m/s. At steady state, the turbine develops work at a rate of 500 kJ per kg of steam flowing through the turbine. Heat transfer between the turbine and its surroundings occurs at an average outer surface temperature of 450 K. Determine the irreversibility per unit mass of steam flowing through the turbine in kJ/kg. Neglect PE.

SOLUTION



Use the manual approach or the PC single-flow open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100$ kPa and $T_0 = 25^\circ$C):

$$h_0 = 104.98 \ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 0.367 \ \frac{\text{kJ}}{\text{kg K}};$$

State-1 $\left(\text{given } p_1 = 3 \text{ MPa}, T_1 = 400^\circ\text{C, and } V_1 = 140 \ \frac{\text{m}}{\text{s}}\right)$:

$$\dot{m}_1 = 1 \ \frac{\text{kg}}{\text{s}}; \quad h_1 = 3230.79 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.92 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_1 = (h_1 - h_0) - T_0 (s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 1181.6 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 $\left(\text{given } T_2 = 100^\circ\text{C}, V_2 = 105 \ \frac{\text{m}}{\text{s}}, \text{ and } x_2 = 1\right)$:

$$\dot{m}_2 = \dot{m}_1 = 1\ \frac{\text{kg}}{\text{s}};$$

$$h_2 = 2676.1\ \frac{\text{kJ}}{\text{kg}}; \qquad s_2 = 7.35\ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{\,0} + \cancel{pe_2}^{\,0} = 493.2\ \frac{\text{kJ}}{\text{kg}};$$

(a) The exergy balance equation for this open-steady system simplifies as:

$$\cancel{\frac{d\Phi}{dt}}^{\,0} = \dot{m}(\psi_1 - \psi_2) + \sum_k \dot{Q}_k \left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}(\psi_2 - \psi_1) + \dot{Q}\cancel{\left[1 - \frac{T_0}{T_0}\right]}^{\,0};$$

$$\Rightarrow \frac{\dot{W}_{\text{rev}}}{\dot{m}} = -(\psi_2 - \psi_1) = -\Delta\psi = 688.3\ \frac{\text{kJ}}{\text{kg}}$$

(b) The exergy destroyed per unit mass is given by

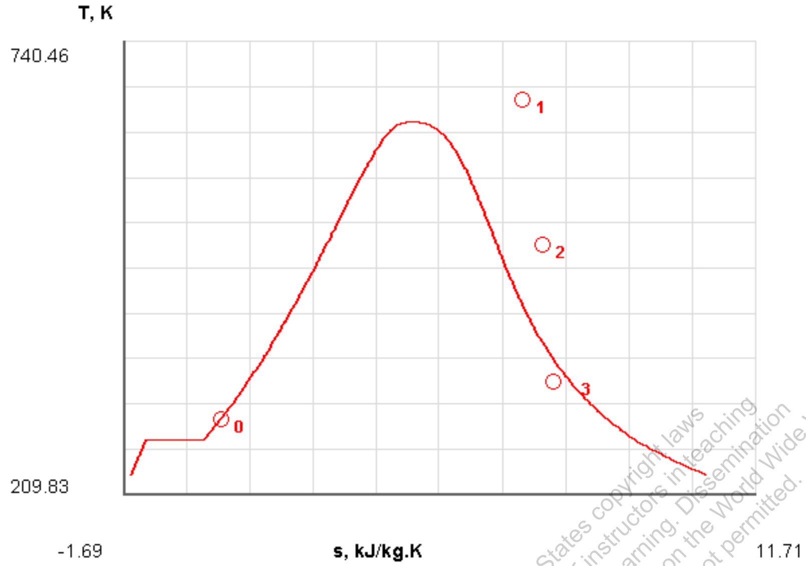
$$\frac{\dot{I}}{\dot{m}} = \frac{\dot{W}_{\text{rev}} - \dot{W}_u}{\dot{m}} = \frac{\dot{W}_{\text{rev}} - \dot{W}_{\text{ext}}}{\dot{m}} = 688.3 - 500 = 188.3\ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and exit states (use a mass flow rate of 1 kg/s), enter Qdot, T_B, and click Calculate to determine Wdot_ext. Find the answer in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-10 [OIH] An insulated steam turbine, receives 25 kg of steam per second at 4 MPa and 400°C. At the point in the turbine where the pressure is 0.5 MPa, steam is bled off for processing equipment at a rate of 10 kg/s. The temperature of this steam is 230°C. The balance of steam leaves the turbine at 30 kPa, 95% quality. Determine (a) the specific flow exergy (ψ) at each port and (b) the exergetic efficiency of the turbine.

SOLUTION



Use the manual approach or the PC multi-flow mixing open-steady TESTcalc to determine the states.

(a) The specific flow exergy at each state is obtained using:

$$\psi = (j - T_0 s) - (j - T_0 s)_0 = (h - h_0) - T_0 (s - s_0).$$

	State-0	State-1	State-2	State-3
p (MPa)	0.100	4	0.5	0.030
T (°C)	25	400	230	69.08
v (m^3/kg)	0.0010	0.0734	0.4546	4.980
u (kJ/kg)	104.878	2919.852	2691.248	2359.405
h (kJ/kg)	104.979	3213.486	2918.535	2508.427
s (kJ/kg.K)	0.3673	6.7689	7.186	7.428
ψ (kJ/kg)	0	1200	780.5	298.3

(b) The exergy balance equation for this open-steady system simplifies as:

$$\frac{d\cancel{\Phi}^{\,0}}{\cancel{dt}} = \dot{m}_1\psi_1 - \dot{m}_2\psi_2 - \dot{m}_3\psi_3 + \sum_k \dot{Q}_k\left[1-\frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left(\psi_2-\psi_1\right)+\dot{Q}\cancel{\left[1-\frac{T_0}{T_0}\right]}^{\,0};$$

$$\Rightarrow \dot{W}_{\text{rev}} = (25)(1200)-(10)(780.5)-(15)(298.3)=17717 \text{ kW};$$

Using the energy balance equation we obtain

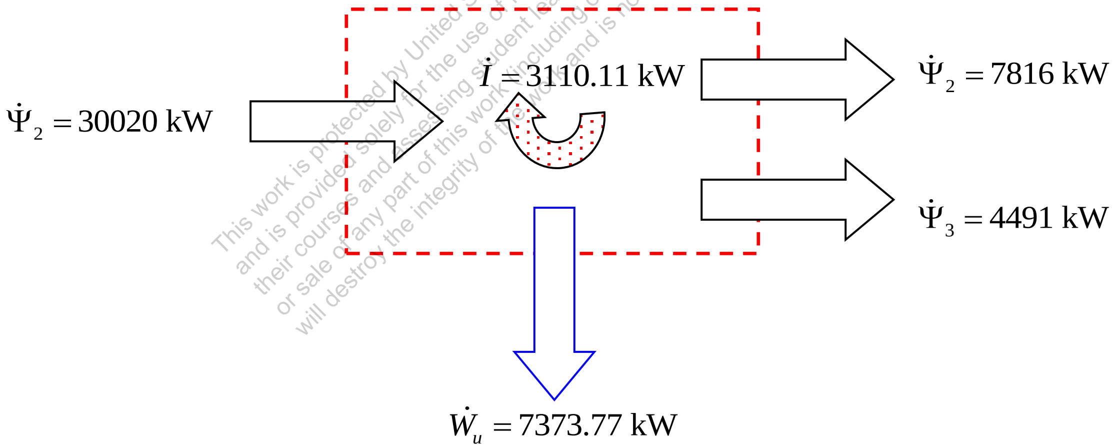
$$\frac{d\cancel{E}^{\,0}}{\cancel{dt}} = \dot{m}_1 j_1 - \dot{m}_2 j_2 - \dot{m}_3 j_3 + \cancel{\dot{Q}}^{\,0} - \dot{W}_{\text{ext}} = \dot{m}\left(h_1-h_3\right);$$

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

$$\Rightarrow \dot{W}_{\text{ext}} = (25)(3213.5)-(10)(2918.5)-(15)(2508.4)=13525 \text{ kW};$$

Exergetic efficiency is:

$$\eta_{II} = \frac{\dot{W}_u}{\dot{W}_{\text{rev}}} = \frac{\dot{W}_{\text{ext}}}{\dot{W}_{\text{rev}}} = \frac{13525}{17717} = 76.36\%$$

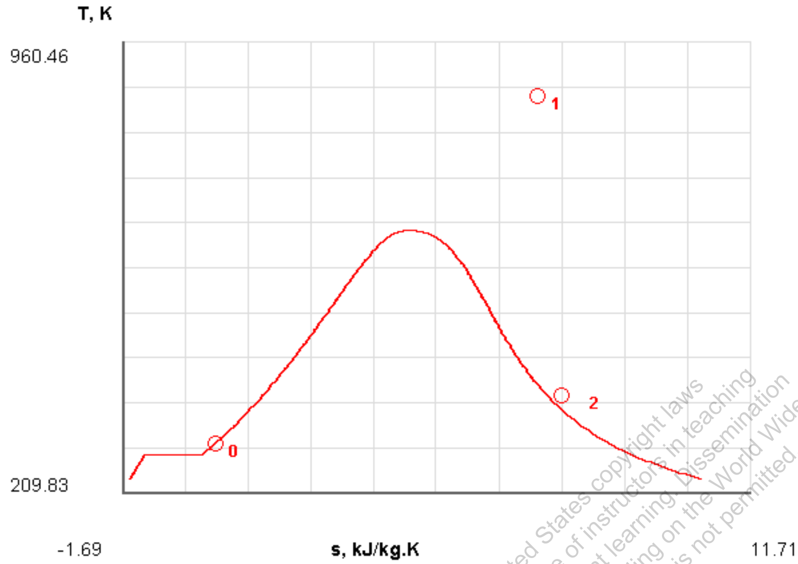


TEST Solution:

Launch the PC multi-flow mixing TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and the two exit states, enter Qdot and T_B, and click Calculate to determine Wdot_ext. Evaluate =mdot1*psi1-mdot2*psi2-mdot3*psi3 in the I/O panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-11 [OIS] Steam enters an adiabatic turbine steadily at 6 MPa, 600°C, 50 m/s, and exits at 50 kPa, 100°C, 150 m/s. The turbine produces 5 MW. If the ambient conditions are 100 kPa and 20°C, determine (a) the maximum possible power output, (b) the second-law (exergetic) efficiency and (c) the irreversibility. (d) What-if Scenario: What would the irreversibility be if the ambient temperature were at 40°C?

SOLUTION



Use the manual approach or the PC open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100$ kPa and $T_0 = 20^\circ\text{C}$):

$$h_0 = 84.1 \ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 0.297 \ \frac{\text{kJ}}{\text{kg K}};$$

State-1 $\left(\text{given } p_1 = 6 \text{ MPa, } T_1 = 600^\circ\text{C, and } V_1 = 50 \ \frac{\text{m}}{\text{s}}\right)$:

$$h_1 = 3658.4 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.17 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 1561.3 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 $\left(\text{given } p_2 = 50 \text{ kPa, } T_2 = 100^\circ\text{C, } V_2 = 150 \ \frac{\text{m}}{\text{s}} \text{ and } \dot{m}_2 = \dot{m}_1 \ \frac{\text{kg}}{\text{s}}\right)$:

$$h_2 = 2682.4 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 7.69 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 442.6 \ \frac{\text{kJ}}{\text{kg}};$$

The energy equation simplifies as:

$$0 = \dot{m}(j_1 - j_2) + \cancel{\dot{Q}}^0 - \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_2 + \frac{V_1^2 - V_2^2}{2000}\right) - \dot{W}_{\text{ext}};$$

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

$$\Rightarrow 5000 = \dot{m}\left(3658.4 - 2682.4 + \frac{50^2 - 150^2}{2000}\right);$$

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

(a) The exergy balance applied on the turbine and setting the exergy destruction term equal to zero gives

$$\dot{W}_{\text{rev}} = \dot{m}_1(\psi_1 - \psi_2) = \dot{m}_1\left[(h_1 - h_2) - T_0(s_1 - s_2) - \Delta ke - \cancel{\Delta pe}^0\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = 5.17\left[(3658.4 - 2682.4) - 293(7.17 - 7.69) - \frac{150^2 - 50^2}{2000}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = 5.78\ \text{MW}$$

(b) The exergetic efficiency is

$$\eta_{II} = \frac{\dot{W}_u}{\dot{W}_{\text{rev}}} = \frac{\dot{W}_{\text{ext}}}{\dot{W}_{\text{rev}}} = \frac{5}{5.78} = 86.5\%$$

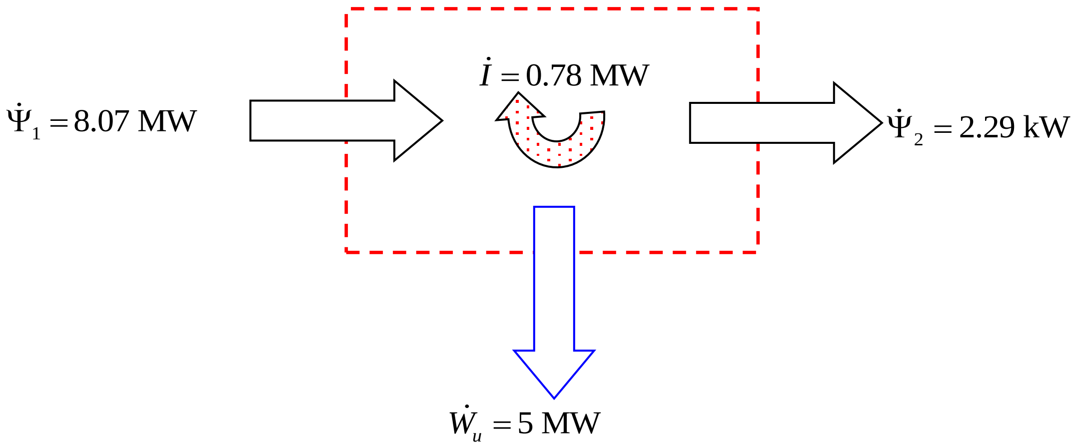
(c) The rate of exergy destruction in the turbine's universe is

$$\dot{I} = W_{rev} - W_u = 5782 - 5000 = 782\ \text{kW}$$

TEST Solution:

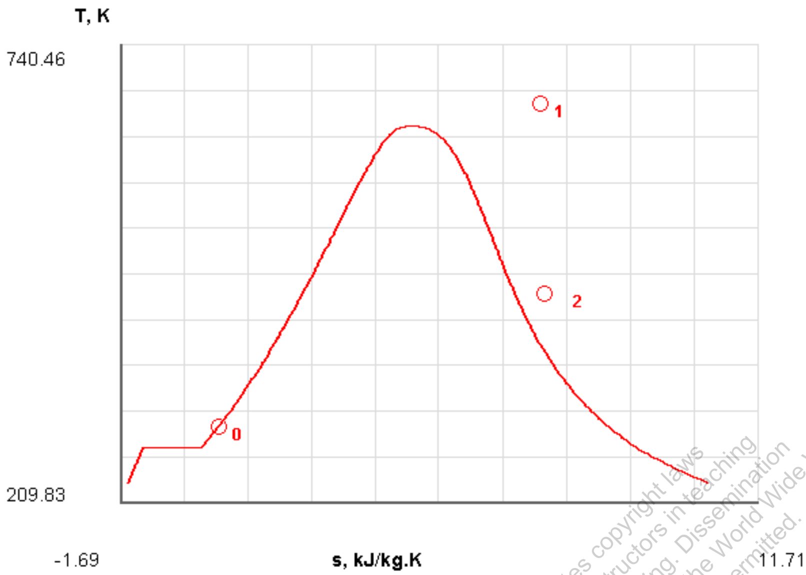
Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and the two exit states, enter Qdot and T_B, and click Calculate to determine Wdot_ext. Obtain the answers in the exergy panel The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

(d) Change T0 and press the Super-Calculate button to update all values. The new value of irreversibilites can be found in the exergy panel as 844.4 kW.


$\dot{\Psi}_1 = 8.07$ MW
$\dot{I} = 0.78$ MW
$\dot{\Psi}_2 = 2.29$ kW
$\dot{W}_u = 5$ MW

6-3-12 [OIA] Steam enters a turbine steadily at 2 MPa, 400°C, 6 kg/s and exits at 0.3 MPa, 150°C. Steam is losing heat to the surrounding air at 100 kPa and 25°C at a rate of 200 kW. Determine (a) the actual power output (W_{ext}), (b) the maximum possible power output (W_{ext}), (c) the second law efficiency and (d) the exergy destroyed (I).

SOLUTION



Use the manual approach or the PC open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100\text{ kPa}$ and $T_0 = 25^\circ\text{C}$):

$$h_0 = 104.98\ \frac{\text{kJ}}{\text{kg}};\qquad s_0 = 0.367\ \frac{\text{kJ}}{\text{kg K}};$$

State-1 (given $p_1 = 2\text{ MPa}$, $T_1 = 400^\circ\text{C}$):

$$\dot{m}_1 = 6\ \frac{\text{kg}}{\text{s}};\qquad h_1 = 3247.58\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 7.13\ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^0 + \cancel{pe_1}^0 = 1127.2\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = 0.3\text{ MPa}$, $T_2 = 150^\circ\text{C}$):

$$\dot{m}_2 = \dot{m}_1 = 6\ \frac{\text{kg}}{\text{s}};$$

$$h_2 = 2823.7\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 7.22\frac{\text{kJ}}{\text{kg K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^0 + \cancel{pe_2}^0 = 676.2\ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy equation simplifies as:

$$0 = \dot{m}\left(j_i - j_e\right) + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow 0 = \dot{m}\left(h_1 - h_2\right) + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{ext}} = 6\left(3247.58 - 2823.7\right) - 200;$$

$$\Rightarrow \dot{W}_{\text{ext}} = 2343.3 \text{ kW}$$

(b) The exergy equation simplifies as:

$$\dot{W}_{\text{rev}} = \dot{m}_1(\psi_1 - \psi_2) = \dot{m}_1\left[\left(h_1 - h_2\right) - T_0\left(s_1 - s_2\right) - \Delta ke - \cancel{\Delta pe}^{\,0}\right];$$

$$\Rightarrow \dot{W}_{\text{rev}} = 6\left[(3247.58 - 2823.7) - 298\left(7.13 - 7.22\right)\right] = 2704.2 \text{ kW}$$

(c) The second law efficiency is

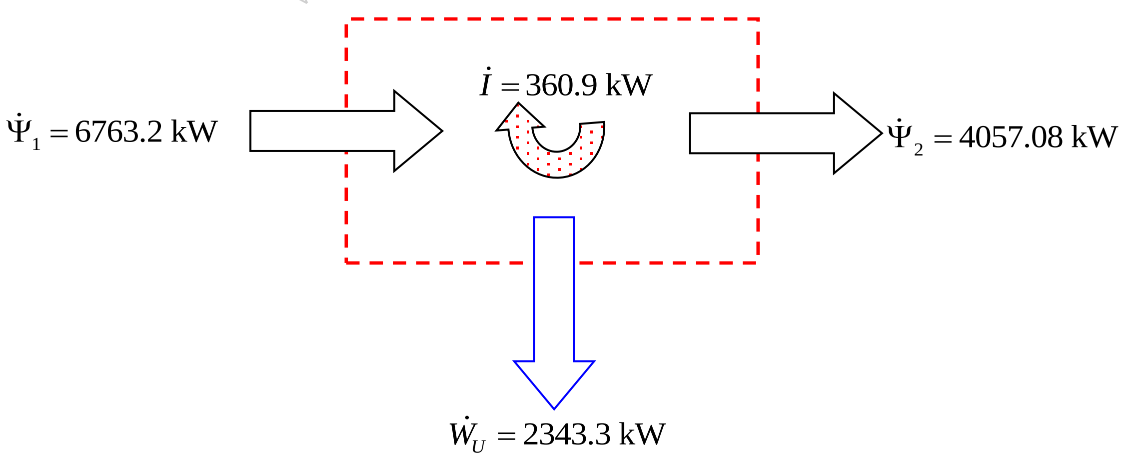
$$\eta_{II} = \frac{\dot{W}_u}{\dot{W}_{\text{rev}}} = \frac{\dot{W}_{\text{ext}}}{\dot{W}_{\text{rev}}} = \frac{2343.3}{2704.2} = 0.87 = 87\ \%$$

(d) The exergy destroyed is

$$\dot{I} = \dot{W}_{\text{rev}} - \dot{W}_u = 2704.2 - 2343.3 = 360.9 \text{ kW}$$

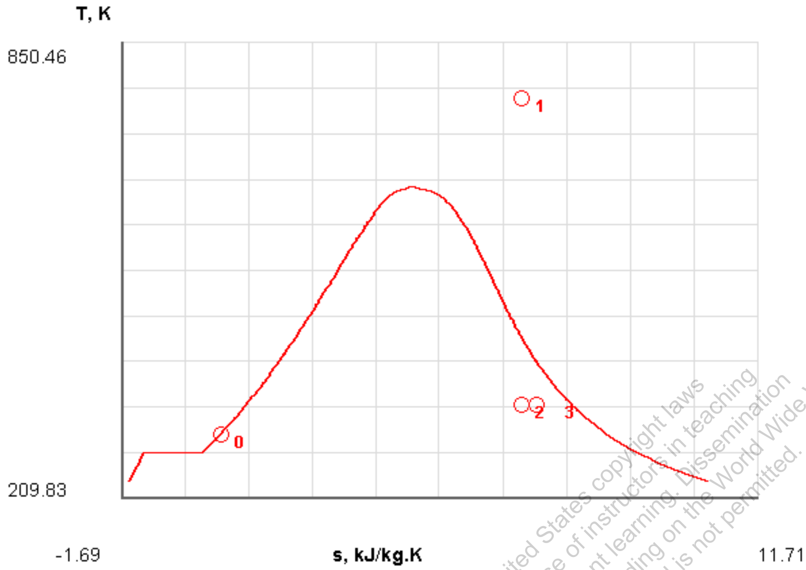
TEST Solution:

Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and the two exit states, enter Qdot and T_B, and click Calculate to determine Wdot_ext. Obtain the answers in the exergy panel The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.



6-3-13 [OIN] Steam enters an adiabatic turbine steadily at 8 MPa, 500°C, 50 m/s, and exits at 30 kPa, 150 m/s. The mass flow rate is 1 kg/s, the adiabatic efficiency is 90%, and the ambient temperature is 300 K. Determine (a) the second-law efficiency of the turbine. (b) What-if Scenario: What would the second law efficiency be if the adiabatic efficiency were 85%?

SOLUTION



Use the manual approach or the PC open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 300\text{ K}$)

State-1 $\left(\text{given } p_1 = 8\text{ MPa}, T_1 = 500^{\circ}\text{C}, V_1 = 50\ \dfrac{\text{m}}{\text{s}}, \text{ and assume: } \dot{m}_1 = 1\ \dfrac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 3398.24\ \frac{\text{kJ}}{\text{kg}}; \quad v_1 = 0.04175\ \frac{\text{m}^3}{\text{kg}}; \quad s_1 = 6.724\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \text{ke}_1 + \cancelto{0}{\text{pe}_1} = 1387.5\ \frac{\text{kJ}}{\text{kg}};$$

State-2 $\left(\text{given } p_2 = 30\text{ kPa}, s_2 = s_1 \text{ and } V_2 = 150\ \dfrac{\text{m}}{\text{s}}, A_2 = A_3, \dot{m}_2 = \dot{m}_1\right)$:

$$h_1 = 2267.44\ \frac{\text{kJ}}{\text{kg}}; \quad v_2 = 4.44\ \frac{\text{m}^3}{\text{kg}};$$

$$V_2 = \frac{v_2}{v_3} V_2 = 142\ \frac{\text{m}}{\text{s}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \text{ke}_2 + \cancel{\text{pe}_2}^{\,0} = 255.4\ \frac{\text{kJ}}{\text{kg}};$$

State-3 $\left(\text{given } p_3 = p_2,\ \eta_{turb} = 0.9 \text{ and } V_3 = 150\ \frac{\text{m}}{\text{s}},\ \dot{m}_3 = \dot{m}_1\right)$:

$$h_3 = h_1 - \eta_c(h_1 - h_2) = 2380.5\ \frac{\text{kJ}}{\text{kg}};$$

$$v_3 = 4.693\ \frac{\text{m}^3}{\text{kg}}; \quad s_3 = 7.054\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \text{ke}_3 + \cancel{\text{pe}_3}^{\,0} = 280.7\ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy equation simplifies as:

$$0 = \dot{m}(j_1 - j_3) + \cancel{\dot{Q}}^{\,0} - \dot{W}_{\text{ext}} = \dot{m}\left(h_1 - h_3 + \frac{V_1^2 - V_3^2}{2000}\right) - \dot{W}_{\text{ext}};$$

$$\Rightarrow \dot{W}_{\text{ext}} = \dot{W}_u = \dot{m}\left(h_1 - h_3 + \frac{V_1^2 - V_3^2}{2000}\right) = 1007.8\ \text{kW};$$

The exergy equation simplifies as:

$$\dot{W}_{\text{rev}} = \dot{m}(\psi_1 - \psi_3) = 1106.74\ \text{kW};$$

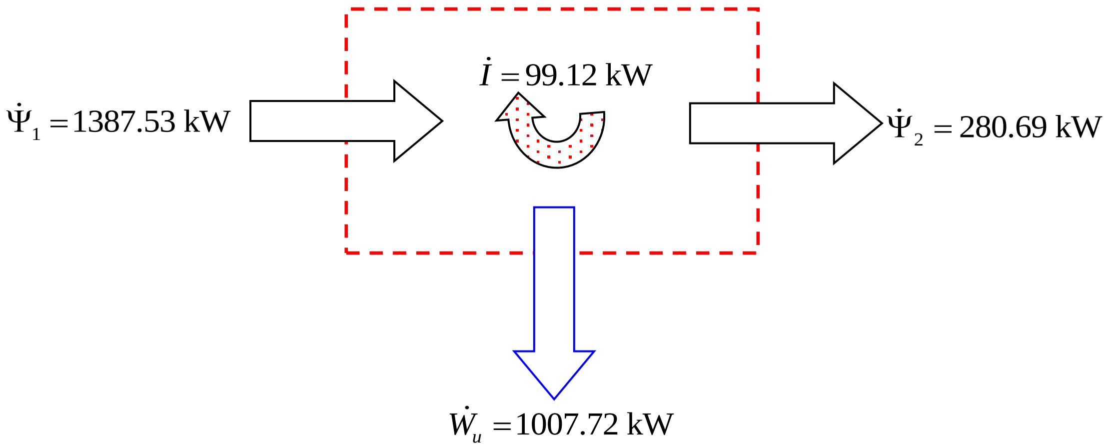
The second law efficiency is

$$\eta_{II} = \frac{\dot{W}_u}{\dot{W}_{\text{rev}}} = \frac{\dot{W}_{\text{ext}}}{\dot{W}_{\text{rev}}} = \frac{1007.8}{1106.74} = 91\%$$

TEST Solution:

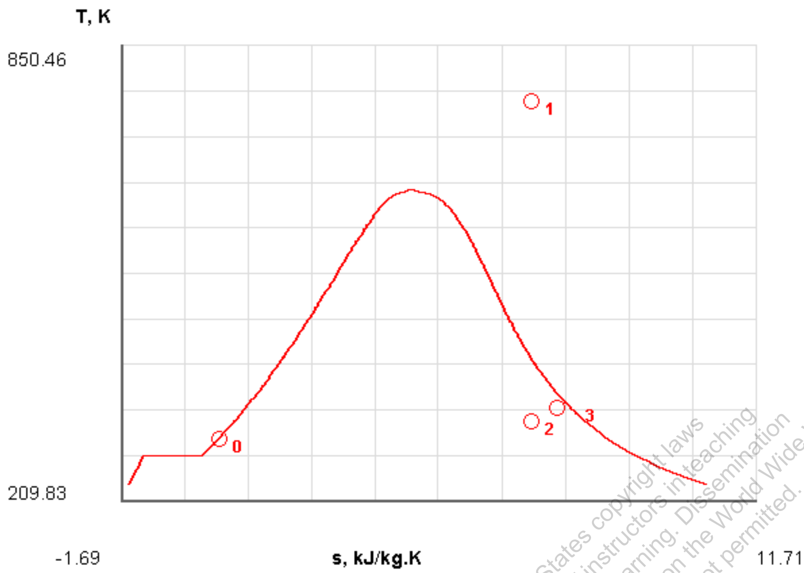
Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, ideal and actual exit states from the given conditions. Note how A2 is set equal to A3 so that Vel2 can be evaluated (need to use the Super-Calculate button). In the device panel load the inlet and the actual exit states, enter Qdot and T_B, and click Calculate to determine Wdot_ext. In the exergy panel find the answers. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

(b) Change the efficiency in the expression for h3 to 0.85 and click Super-Calculate. The new second-law efficiency can be calculated as 951/1100 = 86.4%.



6-3-14 [OIE] A steam turbine has the inlet conditions of 5 MPa, 500°C and an exit pressure of 12 kPa. Assuming the atmospheric conditions to be 100 kPa and 25°C, plot how the exergetic efficiency of the turbine changes as the isentropic efficiency decreases from 100% to 75%.

SOLUTION



Use the manual approach or the PC open-steady TESTcalc to determine the states.

State-0 $\left(\text{given } p_0 = 100 \text{ kPa and } T_0 = 25^\circ\text{C}\right)$:

$$h_0 = 104.97 \ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 0.367 \ \frac{\text{kJ}}{\text{kg K}};$$

State-1 $\left(\text{given } p_1 = 5 \text{ MPa, } T_1 = 500^\circ\text{C, and assume: } \dot{m}_1 = 1 \ \frac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 3433.7 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.975 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 1358.5 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = 12$ kPa, $\dot{m}_2 = \dot{m}_1$):

$$h_2 = 2232.63 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = s_1 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 157.3 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (Given $p_3 = p_2,\ \eta_T = 0.75$):

$$h_3 = h_1 - \eta_T\left(h_1 - h_2\right) = 2533\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = 7.91\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_3 = \left(h_3 - h_0\right) - T_0\left(s_3 - s_0\right) + \cancel{ke_3}^{0} + \cancel{pe_3}^{0} = 180.1\ \frac{\text{kJ}}{\text{kg}};$$

The energy equation simplifies as:

$$\dot{W}_{\text{ext}} = \dot{W}_u = \dot{m}\left(h_1 - h_3\right);$$

$$\Rightarrow \dot{W}_{\text{ext}} = (1)(3434 - 2533) = 900.8\ \text{kW};$$

The exergy equation simplifies as:

$$\dot{W}_{\text{rev}} = \dot{m}\left(\psi_1 - \psi_3\right) = (1)\left[1385.5 - 180.1\right] = 1178\ \text{kW};$$

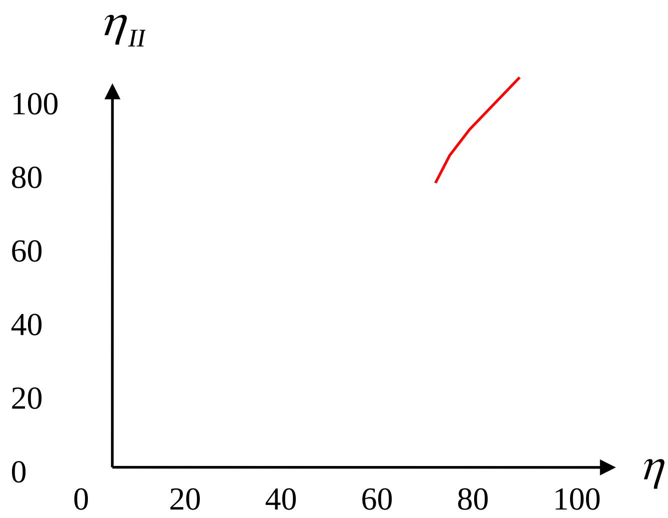
The second law efficiency is

$$\eta_{II} = \frac{\dot{W}_u}{\dot{W}_{\text{rev}}} = \frac{\dot{W}_{\text{ext}}}{\dot{W}_{\text{rev}}} = \frac{900.8}{1178} = 76.5\%$$

TEST Solution:

Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, ideal and actual exit states from the given conditions. In the device panel load the inlet and the actual exit states (for State-3, enter p3 = p2 and h3 = h1-0.75*(h1-h2)), enter Qdot and T_B, and click Calculate to determine Wdot_ext. In the exergy panel find the reversible and useful work. In the I/O panel calculate the second-law efficiency. Now change h3 expression with a different value of turbine efficiency. Click Super-Calculate to update all calculations. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

η	η_{II}
100%	100%
95%	95.36
90%	90.69
85%	85.97
80%	81.22
75%	76.5



η_{II}
100
80
60
40
20
0
0
20
40
60
80
100
η

6-3-15 [OII] Refrigerant-12 is throttled by a valve from the saturated liquid state at 800 kPa to a pressure of 150 kPa at a mass flow rate of 0.5 kg/s. Assuming the surrounding conditions to be 100 kPa and 25°C, determine (a) the rate of exergy destruction (*I*) and (b) the reversible power.

SOLUTION

Use the manual approach or the PC open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 25^\circ\text{C}$):

$$h_0 = 206.9\ \frac{\text{kJ}}{\text{kg}};\qquad s_0 = 0.838\ \frac{\text{kJ}}{\text{kg K}};$$

State-1 $\left(\text{given } p_1 = 800\text{ kPa}, x_1 = 0,\ m_1 = 0.5\ \frac{\text{kg}}{\text{s}}\right)$:

$T_1 = 305.9$ K;

$$h_1 = 67.30\ \frac{\text{kJ}}{\text{kg}};\qquad v_1 = 0.00078\ \frac{\text{m}^3}{\text{kg}};\qquad s_1 = 0.2487\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 243.1\ \frac{\text{kJ}}{\text{kg}};$$

State-2

$\left(\text{given } p_2 = 150\text{ kPa}, h_2 = h_1 \text{ (assume adiabatic and negligible change in ke and pe)}, \dot m_2 = \dot m_1\right)$:

$$v_2 = 0.03423\ \frac{\text{m}^3}{\text{kg}};\qquad s_2 = 0.269\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 237.2\ \frac{\text{kJ}}{\text{kg}};$$

The exergy balance equation for this open-steady system simplifies as:

$$\cancelto{0}{\frac{d\Phi}{dt}} = \dot{m}_1\psi_1 - \dot{m}_2\psi_2 + \sum_k \cancelto{0}{\dot{Q}_k}\left[1-\frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left(\psi_2 - \psi_1\right) = 2.98 \text{ kW};$$

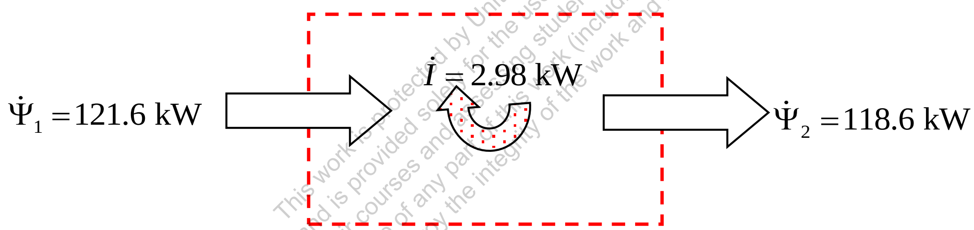
(a) The rate of exergy destruction

$$\dot{I} = W_{\text{rev}} - \cancelto{0}{W_u} = 2.98 \text{ kW}$$

(b) $\dot{W}_{\text{rev}} = -\dot{m}\left(\psi_2 - \psi_1\right) = 2.98 \text{ kW}$

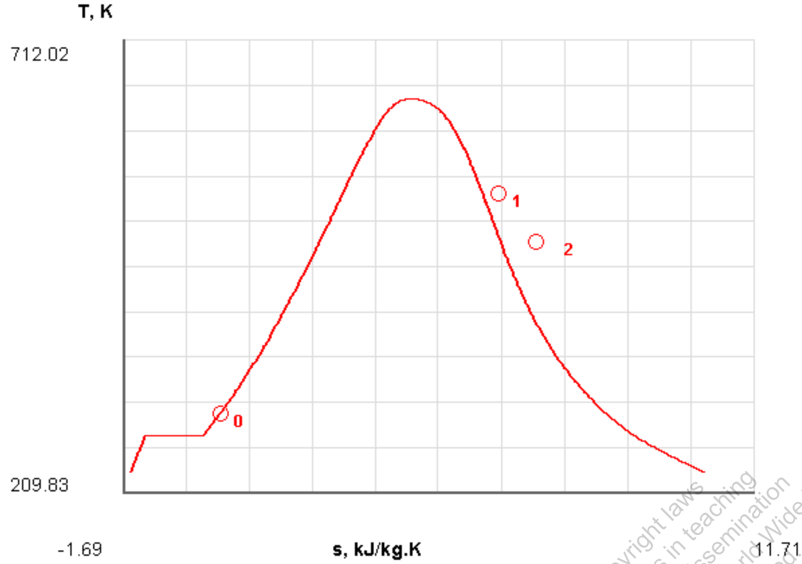
TEST Solution:

Launch the PC open-steady single flow TESTcalc and select R-12. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and the exit states, enter Wdot_ext and T_B, and click Calculate to determine Qdot. Obtain the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.



6-3-16 [OIL] Superheated water vapor enters a valve at 3445 kPa, 260°C and exits at a pressure of 551 kPa. Determine (a) the specific flow exergy (ψ) at the inlet and exit and (b) the rate of exergy destruction in the valve per unit of mass. Let T_0 = 25°, p_0 = 1 atm.

SOLUTION



Use the manual approach or the PC open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100$ kPa and $T_0 = 25^\circ$C):

$$h_0 = 104.98\ \frac{\text{kJ}}{\text{kg}};\quad s_0 = 0.367\ \frac{\text{kJ}}{\text{kg K}};$$

State-1 $\left(\text{given } p_1 = 3445 \text{ kPa, } T_1 = 260^\circ\text{C, and } \dot{m}_1 = 1\ \frac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 2887.98\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 6.289\ \frac{\text{kJ}}{\text{kg K}};$$

State-2 (given $p_2 = 551$ kPa, $\dot{m}_2 = \dot{m}_1$):

$$h_2 = h_1;\quad s_2 = 7.08\ \frac{\text{kJ}}{\text{kg K}};$$

(a) Specific flow energy

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 1017.6\ \frac{\text{kJ}}{\text{kg}}$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 781.4\ \frac{\text{kJ}}{\text{kg}}$$

(b) The exergy balance equation for this open-steady system simplifies as:

$$\cancel{\frac{d\Phi}{dt}}^{0} = \dot{m}_1\psi_1 - \dot{m}_2\psi_2 + \sum_k \cancel{\dot{Q}_k}^{0}\left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

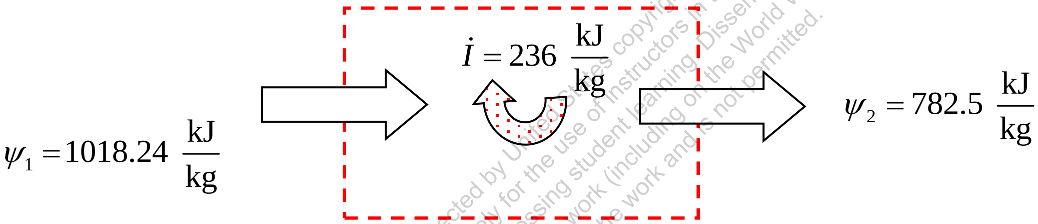
$$\Rightarrow \dot{W}_{\text{rev}} = -\dot{m}\left(\psi_2 - \psi_1\right) = 236.2 \text{ kW};$$

The rate of exergy destruction

$$\dot{I} = W_{\text{rev}} - \cancel{W_u}^{0} = 236.2 \text{ kW}$$

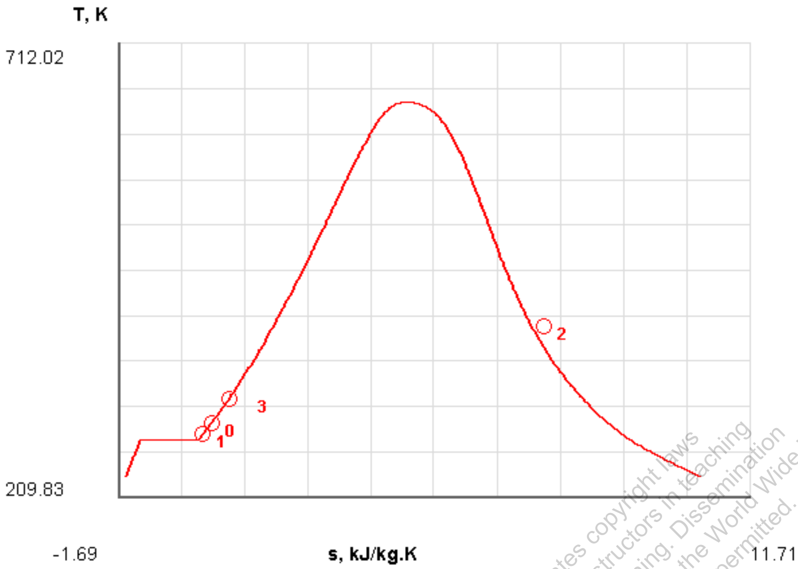
TEST Solution:

Launch the PC open-steady single flow TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the inlet and the two exit states, enter Wdot_ext and T_B, and click Calculate to determine Qdot. Obtain the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.



6-3-17 [OIG] Water at 140 kPa and 280 K enters a mixing chamber at a rate of 2 kg/s, where it is mixed steadily with steam entering at 140 kPa and 400 K. The mixture leaves the chamber at 140 kPa and 320 K, and heat is lost to the surrounding air at 20°C at a rate of 3 kW. Determine (a) the reversible work and (b) the rate of exergy destruction (I).

SOLUTION



Use the manual approach or the PC multi-flow mixing open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 20^\circ\text{C}$):

$$h_0 = 84.1\ \frac{\text{kJ}}{\text{kg}};\quad s_0 = 0.297\ \frac{\text{kJ}}{\text{kg K}};$$

State-1 $\left(\text{given } p_1 = 140 \text{ kPa}, T_1 = 280 \text{ K}, m_1 = 2\ \frac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 28.90\ \frac{\text{kJ}}{\text{kg}};\quad v_1 = 0.0010\ \frac{\text{m}^3}{\text{kg}};\quad s_1 = 0.1039\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 1.338\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = p_1$, $T_2 = 400$ K):

$$h_2 = 2726.17\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 7.334\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 578.8\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_1,\ T_3 = 320\text{ K}$):

$$h_3 = 196.30\ \frac{\text{kJ}}{\text{kg}};\qquad s_3 = 0.663\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \cancel{ke_3}^{0} + \cancel{pe_3}^{0} = 4.887\ \frac{\text{kJ}}{\text{kg}};$$

The energy balance equation for this open-steady system simplifies as:

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

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

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

$$\Rightarrow 0 = 2(28.90 - 196.30) + \dot{m}_2 (2726.17 - 196.30) + (-3);$$

$$\Rightarrow \dot{m}_2 = 0.1335\ \frac{\text{kg}}{\text{s}};$$

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 2 + 0.1335 = 2.1335\ \frac{\text{kg}}{\text{s}};$$

(a) The exergy balance equation for this open-steady system simplifies as:

$$\frac{\cancel{d\Phi}^{0}}{\cancel{dt}} = \dot{m}_1 \psi_1 + \dot{m}_2 \psi_2 - \dot{m}_3 \psi_3 + \sum_k \cancel{\dot{Q}_k}^{0} \left[1 - \frac{T_0}{T_k}\right] - \dot{W}_{\text{rev}};$$

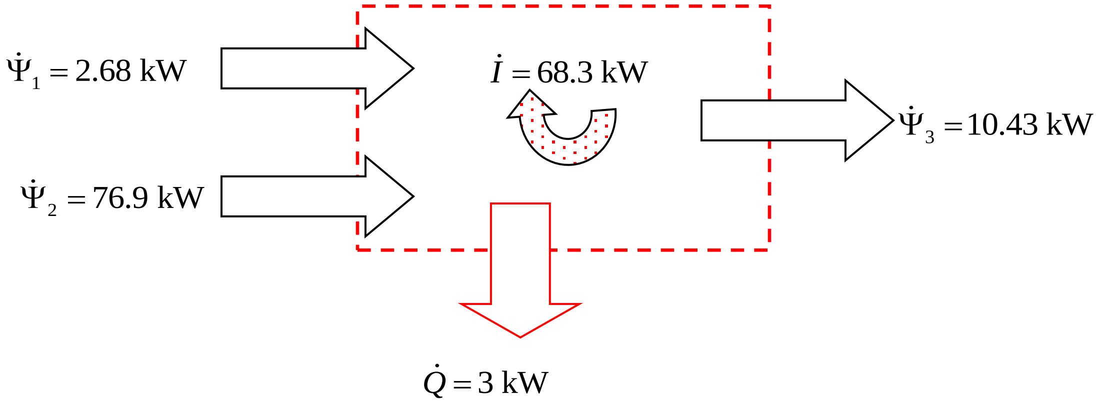
$$\Rightarrow \dot{W}_{\text{rev}} = \dot{m}_1 \psi_1 + \dot{m}_2 \psi_2 - \dot{m}_3 \psi_3 = 69.5\text{ kW}$$

(b) The exergy destroyed is given as

$$\dot{I} = \dot{W}_{\text{rev}} - \cancel{\dot{W}_u}^{0} = 69.5\text{ kW}$$

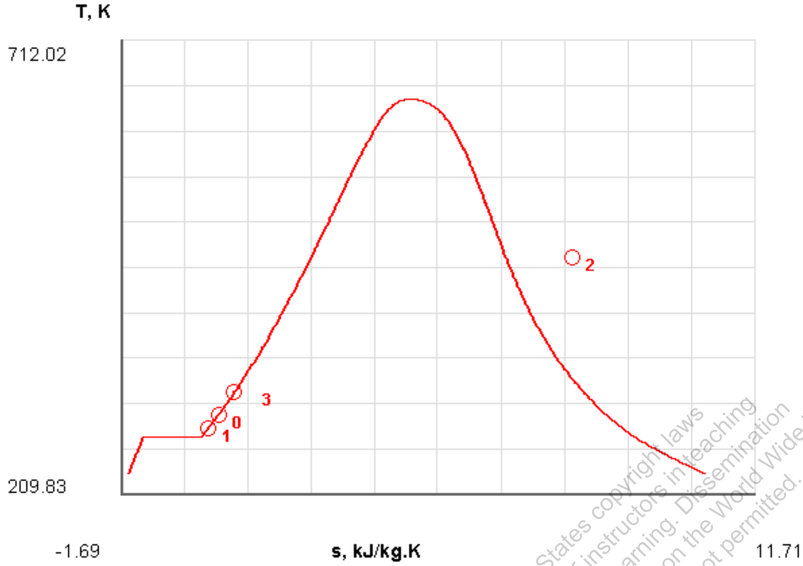
TEST Solution:

Launch the PC open-steady multi-flow mixing TESTcalc and select H2O. Evaluate the dead, inlets, and exit states from the given conditions. In the device panel load the two inlet and the exit states, enter Qdot, Wdot_ext and T_B, and click Calculate to determine mdot2. Obtain the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.


$\dot{\Psi}_1 = 2.68$ kW
$\dot{\Psi}_2 = 76.9$ kW
$\dot{I} = 68.3$ kW
$\dot{\Psi}_3 = 10.43$ kW
$\dot{Q} = 3$ kW

6-3-18 [OIZ] Liquid water at 100 kPa, 10°C, 1 kg/s is heated by mixing it with an unknown amount of steam at 100 kPa and 200°C in an adiabatic mixing chamber. The surrounding atmosphere is at 100 kPa and 25°C. If the mixture leaves at 100 kPa and 50°C, determine (a) the mass flow rate (m) of steam. Also determine the rate of transport exergy (Ψ) (b) into and (c) out of the chamber.

SOLTUION



Use the manual approach or the PC multi-flow mixing open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100\,\text{kPa}$, $T_0 = 25^\circ\text{C}$):

$$h_0 = 104.98\ \frac{\text{kJ}}{\text{kg}};\quad v_0 = 0.0010\ \frac{\text{m}^3}{\text{kg}};\quad s_0 = 0.36732\ \frac{\text{kJ}}{\text{kg.K}};$$

State-1 $\left(\text{given } p_1 = 100\text{ kPa},\ T_1 = 10^\circ\text{C},\ m_1 = 1\ \frac{\text{kg}}{\text{s}}\right)$:

$$h_1 = 42.10\ \frac{\text{kJ}}{\text{kg}};\quad v_1 = 0.0010\ \frac{\text{m}^3}{\text{kg}};\quad s_1 = 0.1509\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^0 + \cancel{pe_1}^0 = 1.65\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (Given $p_2 = p_1$, $T_2 = 200^\circ\text{C}$):

$$h_2 = 2875.25\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 7.834\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^0 + \cancel{pe_2}^0 = 544.0\ \frac{\text{kJ}}{\text{kg}};$$

State-3 (Given $p_3 = p_1,\ T_3 = 50^{o}\text{C}$):

$$h_3 = 209.42\ \frac{\text{kJ}}{\text{kg}};\qquad s_3 = 0.7038\ \frac{\text{kJ}}{\text{kg.K}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \cancel{\text{ke}_3}^{0} + \cancel{\text{pe}_3}^{0} = 4.12\ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy balance equation for this open-steady system simplifies as:

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

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

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

$$\Rightarrow 0 = 1(42.1 - 209.42) + \dot{m}_2 (2875.25 - 209.42);$$

$$\Rightarrow \dot{m}_2 = 0.0628\ \frac{\text{kg}}{\text{s}}$$

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 1 + 0.0628 = 1.0628\ \frac{\text{kg}}{\text{s}};$$

(b) The exergy transport into the chamber:

$$\dot{m}_1\psi_1 + \dot{m}_2\psi_2 = 1.613 + (0.0628\text{x}545.19) = 35.85\ \text{kW}$$

(c) The exergy transport out of the chamber:

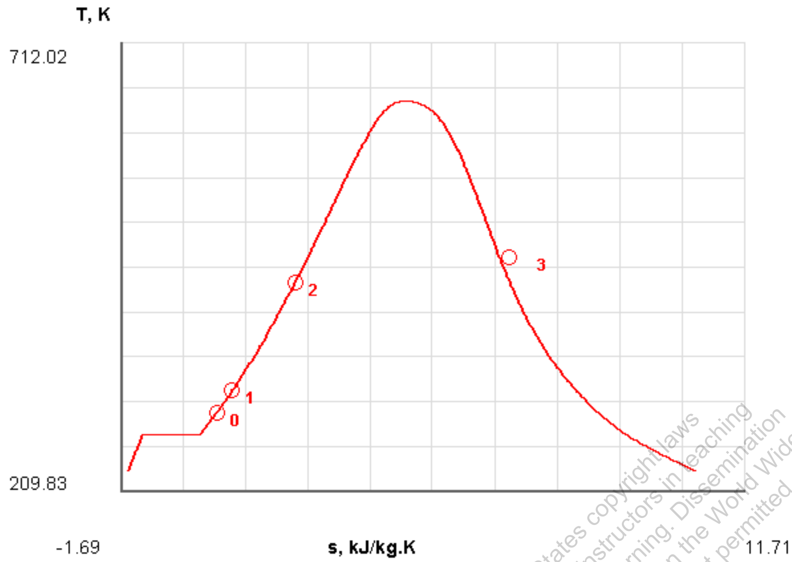
$$\dot{m}_3\psi_3 = 1.0628\text{x}4.169 = 4.43\ \text{kW}$$

TEST Solution:

Launch the PC open-steady multi-flow mixing TESTcalc and select H2O. Evaluate the dead, inlets, and exit states from the given conditions. In the device panel load the two inlet and the exit states, enter Qdot, Wdot_ext and T_B, and click Calculate to determine mdot2. Obtain the answers in the exergy panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-19 [OIU] Steam enters a closed feedwater heater at 1.1 MPa, 200°C and leaves as saturated liquid at the same pressure. Feedwater enters the heater at 2.5 MPa, 50°C and in an isobaric manner leaves 12°C below the exit temperature of the steam. Neglecting any heat losses, determine (a) the mass flow rate (*m*) ratio and (b) the exergetic efficiency of the heat exchanger. Assume surroundings to be at 100 kPa and 25°C.

SOLUTION



Use the manual approach or the PC multi-flow non-mixing open-steady TESTcalc to determine the states.

State-0 (given $p_0 = 100$ kPa and $T_0 = 25$°C):

$$h_0 = 104.98 \ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 0.367 \ \frac{\text{kJ}}{\text{kg.K}};$$

State-1 $\left(\text{given } p_1 = 2.5 \text{ MPa}, \ T_1 = 50^\circ\text{C and } \dot{m}_1 = 1 \ \frac{\text{kg}}{\text{s}} \right)$:

$$v_1 = 0.00101 \ \frac{\text{m}^3}{\text{kg}}; \quad h_1 = 211.85 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.704 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_1 = (h_1 - h_0) - T_0(s_1 - s_0) + \cancel{ke_1}^{\,0} + \cancel{pe_1}^{\,0} = 6.55 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $T_2 = 172.09^\circ\text{C}$, $p_2 = p_1$ and $\dot{m}_2 = \dot{m}_1$):

$$v_2 = 0.00112 \ \frac{\text{m}^3}{\text{kg}}; \quad h_2 = 730.24 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 2.062 \ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_2 = (h_2 - h_0) - T_0(s_2 - s_0) + \cancel{ke_2}^{\,0} + \cancel{pe_2}^{\,0} = 119.89 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = 1.1$ MPa and $T_3 = 200^{\circ}\text{C}$):

$$v_3 = 0.18596\ \frac{\text{m}^3}{\text{kg}};\quad h_3 = 2821.85\ \frac{\text{kJ}}{\text{kg}};\quad s_3 = 6.639\ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \cancel{ke_3}^0 + \cancel{pe_3}^0 = 846.9\ \frac{\text{kJ}}{\text{kg}};$$

State-4 (given $p_4 = 1.1$ MPa, $x_4 = 0$ and $\dot{m}_4 = \dot{m}_3$):

$T_4 = 184.09^{\circ}\text{C}$;

$$v_4 = 0.00113\ \frac{\text{m}^3}{\text{kg}};\quad h_4 = 781.37\ \frac{\text{kJ}}{\text{kg}};\quad s_4 = 2.179\ \frac{\text{kJ}}{\text{kg K}};$$

$$\psi_4 = (h_4 - h_0) - T_0(s_4 - s_0) + \cancel{ke_4}^0 + \cancel{pe_4}^0 = 136.2\ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy equation simplifies as:

$$0 = (\dot{m}_1 j_1 + \dot{m}_3 j_3) - (\dot{m}_2 j_2 + \dot{m}_4 j_4) + \dot{Q} - \dot{W}_{\text{ext}};$$

$$\Rightarrow 0 = (\dot{m}_1 h_1 + \dot{m}_3 h_3) - (\dot{m}_2 h_2 + \dot{m}_4 h_4) + \cancel{\dot{Q}}^0 - \cancel{\dot{W}_{ext}}^0;$$

$$\Rightarrow \dot{m}_3 (h_4 - h_3) = \dot{m}_1 (h_1 - h_2);$$

$$\Rightarrow \frac{\dot{m}_3}{\dot{m}_1} = \frac{(h_1 - h_2)}{(h_4 - h_3)} = \frac{(211.85 - 730.24)}{(781.37 - 2821.85)} = 0.254$$

(b) Exergetic efficiency is given by:

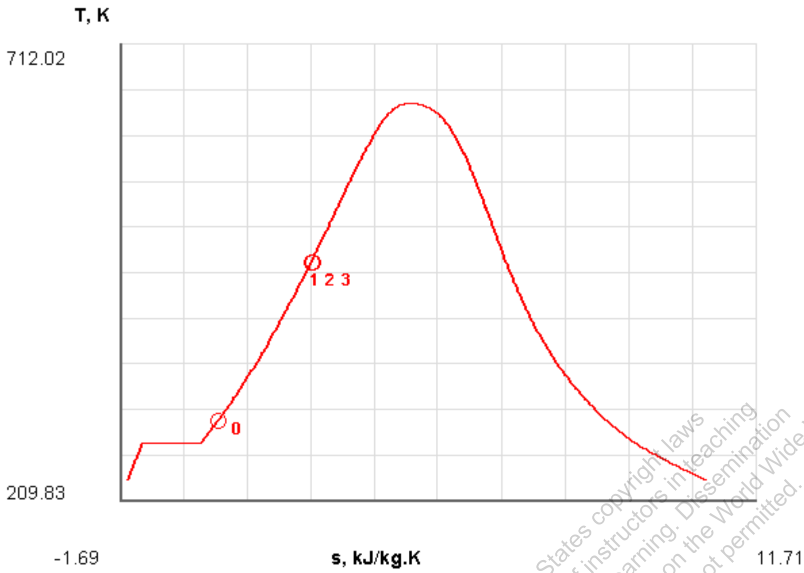
$$\eta_{II} = \frac{\text{Exergy recovered}}{\text{Exergy supplied}} \Rightarrow \frac{\dot{m}_1(\psi_2 - \psi_1)}{\dot{m}_3(\psi_3 - \psi_4)} = 62.8\%$$

TEST Solution:

Launch the PC open-steady non-mixing TESTcalc and select H2O. Evaluate the dead, inlet, and exit states from the given conditions. In the device panel load the two inlet and two exit states, enter Qdot, Wdot_ext and T_B, select non-mixing button, and click Calculate to determine mdot2. Calculate the efficiency in the I/O panel. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-20 [OIK] A 0.5 m^3 tank initially contains saturated liquid water at 200^{o}C. A valve on the bottom of the tank is opened and half the liquid is drained. Heat is transferred from a source at 300^{o}C to maintain constant temperature inside the tank. Determine (a) the heat transfer (Q) and (b) the reversible work. Assume the surroundings to be at 25^{o}C and 100 kPa.

SOLUTION



Use the manual approach or the PC open-process TESTcalc to determine the states.

State-0 (given $p_0 = 100$ kPa and $T_0 = 25^{o}$C)

State-1 [beginning] (given $x_1 = 0, T_1 = 200^{o}\text{C and } \cancel{V}_1 = 0.5\ \text{m}^3$):

$$h_0 = 104.98\ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 0.367\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$p_1 = 1.554\ \text{MPa}; \quad e_1 = 850.65\ \frac{\text{kJ}}{\text{kg}};$$

$$h_1 = 852.45\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 2.3309\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad m_1 = 432.15\ \text{kg};$$

$$\phi_1 = (u_1 - u_0) - T_0(s_1 - s_0) + p_0(v_1 - v_0) + \cancel{ke_1}^{0} + \cancel{pe_1}^{0} = 160.3\ \frac{\text{kJ}}{\text{kg}};$$

State-2 [final] $\left(\text{given } T_2 = T_1,\ \cancel{V}_2 = \cancel{V}_1, \text{ and } m_2 = \frac{m_1}{2}\right)$:

$$p_2 = 1.554 \text{ MPa}; \quad e_2 = 866.64 \ \frac{\text{kJ}}{\text{kg}};$$

$$h_2 = 870.24 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 2.36849 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\phi_2 = (u_2 - u_0) - T_0(s_2 - s_0) + p_0(v_2 - v_0) + \cancel{ke_2}^{\,0} + \cancel{pe_2}^{\,0} = 165.2 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 [exit] $\left(\text{given } x = 0, T_3 = T_1, \text{and } m_3 = m_1 - m_2 = \dfrac{m_1}{2}\right)$:

$$p_3 = 1.554 \text{ MPa}; \quad e_3 = 850.65 \ \frac{\text{kJ}}{\text{kg}};$$

$$h_3 = 852.45 \ \frac{\text{kJ}}{\text{kg}}; \quad s_3 = 2.3309 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \cancel{ke_3}^{\,0} + \cancel{pe_3}^{\,0} = 162.0 \ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy equation for this open process simplifies as:

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

$$\Rightarrow \ m_f e_f - m_b e_b = -m_e h_e + Q;$$

$$\Rightarrow Q = (216.075)(866.64) - (432.15)(850.65) + (216.075)(852.45) = 3843 \text{ kJ}$$

(b) The exergy equation for this open process simplifies as:

$$\Delta\Phi = \cancel{m_i \psi_i}^{\,0} - m_e \psi_e + Q_k\left[1 - \frac{T_0}{T_k}\right] - W_{\text{rev}} \ ;$$

$$\Rightarrow W_{\text{rev}} = -\left(m_f \phi_f - m_b \phi_b\right) - m_e \psi_e + Q_k\left|1 - \frac{T_0}{T_k}\right|;$$

$$\Rightarrow W_{\text{rev}} = -\left(m_2 \phi_2 - m_1 \phi_1\right) - m_3 \psi_3 + Q\left[1 - \frac{298}{573}\right] = 33588.82 - 35010.5 + 1843.5 = 421.7 \text{ kJ}$$

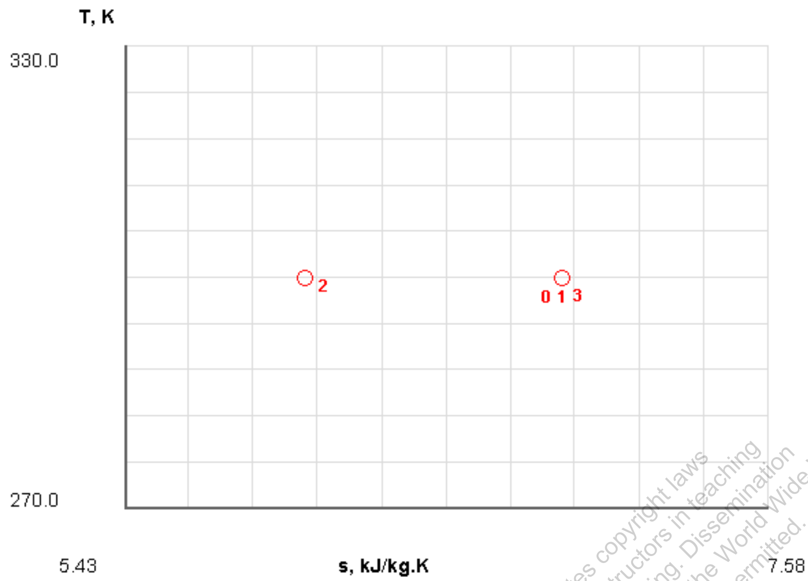
Note that by doing an entropy analysis it is possible to find the entropy generated in the universe and, hence, the irreversibilities. Because no useful work is produced on consumed, the reversible work is equal to the irreversibilities.

TEST Solution:

Launch the PC open-process TESTcalc and select H2O. Evaluate the dead, initial, final, and exit states from the given conditions. In the process panel load the initial, final, and exit states, and enter Wdot_ext and T_B. Calculate to obtain Q. In the I/O panel evaluate the desired answers. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.

6-3-21 [OIP] A 100 m^3 rigid tank initially contains atmospheric air at 100 kPa and 300 K is to be used as a storage vessel for compressed air at 2 MPa and 300 K. Compressed air is to be supplied by a compressor that takes in atmospheric air at 100 kPa and 300 K. Determine the reversible work (W_{rev}). Use the PG model for air.

SOLUTION



From Table C-1 or the PG open-process TESTcalc, obtain $R = 0.2870\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ and $c_p = 1.005\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ for air.

State-0 [dead] (given $p_1 = 100$ kPa, $T_1 = 300$ K and $\mathcal{V}_1 = 100\ \text{m}^3$)

State-1 [beginning] (given $p_1 = 100$ kPa, $T_1 = 300$ K and $\mathcal{V}_1 = 100\ \text{m}^3$):

$$m_1 = \frac{p_1 \mathcal{V}_1}{RT_1} = 116.1\ \text{kg};$$

$$\phi_1 = (u_1 - u_0) - T_0(s_1 - s_0) + p_0(v_1 - v_0) + \cancel{ke_1}^{\,0} + \cancel{pe_1}^{\,0} = 0\ \frac{\text{kJ}}{\text{kg}};$$

State-2 [final] (given $p_2 = 2$ kPa, $T_2 = T_1$, and $\mathcal{V}_2 = \mathcal{V}_1$):

$$\phi_2 = (u_2 - u_0) - T_0(s_2 - s_0) + p_0(v_2 - v_0) + \cancel{ke_2}^{\,0} + \cancel{pe_2}^{\,0};$$

$$\Rightarrow \phi_2 = c_v(T_2 - T_0) - T_0\left(c_p \ln\frac{T_2}{T_0} - R\ln\frac{p_2}{p_1}\right) + p_0 RT_0\left(\frac{1}{p_2} - \frac{1}{p_1}\right);$$

$$\Rightarrow \phi_2 = RT_0\left[\ln\frac{p_2}{p_1} + \frac{p_0}{p_2} - \frac{p_0}{p_1}\right] = 176\ \frac{\text{kJ}}{\text{kg}};$$

The change in stored exergy is the reversible work because the flow exergy entering the compressor is zero.

$$\Delta\Phi = m_i\psi_i + \sum_k Q_k\left[1-\frac{T_0}{T_k}\right] - W_{\text{rev}} = \left(-Q_{loss}\right)\left[1-\frac{T_0}{T_0}\right] - W_{\text{rev}};$$

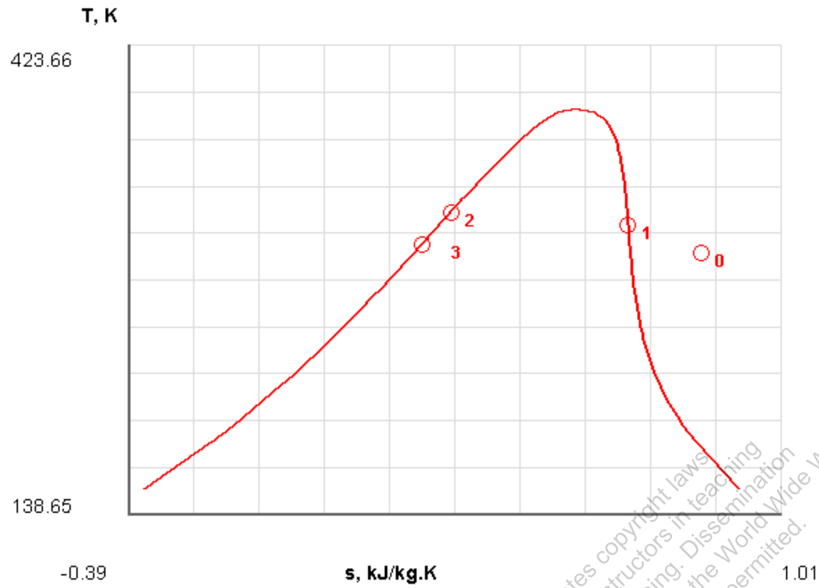
$$\Rightarrow W_{\text{rev}} = -m_2\phi_2 = -(116.1)(176) = 409.1 \text{ MJ}$$

TESTSolution:

Launch the PG open-process TESTcalc and select Air. Evaluate the dead, initial, and final states from the given conditions. In the I/O panel evaluate m2*phi2.

xxx6-3-22 [OIX] A 0.2 m^3 tank initially contains R-12 at 1 MPa and x = 1. The tank is charged to 1.2 MPa, x = 0 from a supply line that carries R-12 at 1.5 MPa and 30°C. Determine (a) the heat transfer (Q) and (b) the wasted work potential associated with the process. Assume the surrounding temperature to be 50°C.

SOLUTION



Use the manual approach or the PC open-process TESTcalc to determine the states.

State-0 (given $p_0 = 100$ kPa and $T_0 = 25$°C):

$$h_0 = 222.57 \ \frac{\text{kJ}}{\text{kg}}; \quad s_0 = 0.88888 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 [beginning] (given $x_1 = 1$, $p_1 = 1$ MPa and $\mathcal{V}_1 = 0.2$ m^3):

$$T_1 = 41.626°\text{C}; \quad e_1 = 186.31 \ \frac{\text{kJ}}{\text{kg}}; \quad m_1 = 11.4628 \text{ kg};$$

$$h_1 = 203.74 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.68204 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\phi_1 = (u_1 - u_0) - T_0(s_1 - s_0) + p_0(v_1 - v_0) + \cancel{ke_1}^0 + \cancel{pe_1}^0 = 27.75 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 [final] (given $x_2 = 0$, $p_2 = 1.2$ MPa, and $\mathcal{V}_2 = \mathcal{V}_1$):

$$T_2 = 49.3°\text{C};\quad e_2 = 82.45\ \frac{\text{kJ}}{\text{kg}};\quad m_2 = 242.7477\ \text{kg};$$

$$h_2 = 83.43\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 0.30146\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\phi_2 = (u_2 - u_0) - T_0(s_2 - s_0) + p_0(v_2 - v_0) + \cancel{ke_2}^{0} + \cancel{pe_2}^{0} = 35.70\ \frac{\text{kJ}}{\text{kg}};$$

State-3 [inlet] (given $x = 0, p_3 = 1.5$ MPa, $T_3 = 30°\text{C}$, and $m_3 = m_2 - m_1$):

$$e_3 = 64.01\ \frac{\text{kJ}}{\text{kg}};\quad m_3 = 231.2845\ \text{kg};$$

$$h_3 = 65.17\ \frac{\text{kJ}}{\text{kg}};\quad s_3 = 0.2399\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \cancel{ke_3}^{0} + \cancel{pe_3}^{0} = 36.69\ \frac{\text{kJ}}{\text{kg}};$$

(a) Using the energy equation for the open process

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

$$\Rightarrow Q = m_f e_f - m_b e_b - m_i h_i;$$

$$\Rightarrow Q = Q = (242.7477)(83.43) - (11.4628)(186.31) - (231.2845)(65.17);$$

$$\Rightarrow Q = 2806\ \text{kJ}$$

(b) The wasted work potential is the reversible work, which is entirely destroyed in this process.

The exergy equation for this open process simplifies as:

$$\Delta\Phi = \cancel{m_i\psi_i}^{0} - m_e\psi_e + Q_k\left[1 - \frac{T_0}{T_k}\right] - W_{\text{rev}};$$

$$\Rightarrow W_{\text{rev}} = -(m_f\phi_f - m_b\phi_b) - m_e\psi_e + Q_k\left[1 - \frac{T_0}{T_k}\right];$$

$$\Rightarrow W_{\text{rev}} = -(m_2\phi_2 - m_1\phi_1) - m_3\psi_3 + Q\left[1 - \frac{298}{323}\right] = -8347.0 - 8487.5 + 215. = 356.2\ \text{kJ}$$

Note that by doing an entropy analysis it is possible to find the entropy generated in the universe and, hence, the irreversibilities. Because no useful work is produced on consumed, the reversible work is equal to the irreversibilities.

TEST Solution:

Launch the PC open-process TESTcalc and select H2O. Evaluate the dead, initial, final, and exit states from the given conditions. In the process panel load the initial, final, and exit states, and enter Wdot_ext and T_B. Calculate to obtain Q. In the I/O panel evaluate the desired answers. The TEST-code for this problem can be found in the problems module of the TEST-pro site at www.thermofluids.net.