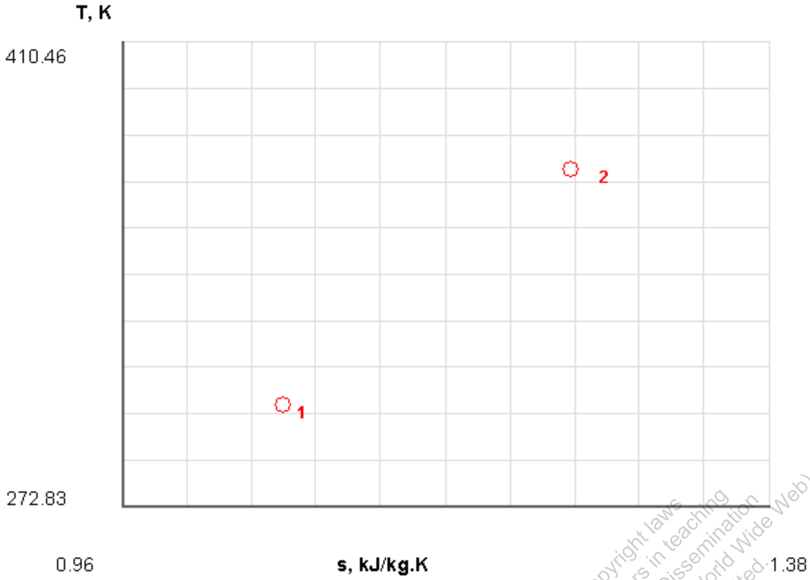
5-1-1 [OBU] Determine (a) the amount of heat necessary to raise the temperature of 1 kg of aluminum from 30°C to 100°C. (b) ***What-if scenario:*** How would the answer in part (a) change if the working substance was wood instead of aluminum?

SOLUTION



Given:

$$c = 0.9 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 (given T_1, m_1)

State-2 (given $T_2,\ m_2 = m_1$)

(a) The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = mc(T_2 - T_1);$$

$$\Rightarrow Q = (1)(0.9)(100 - 30);$$

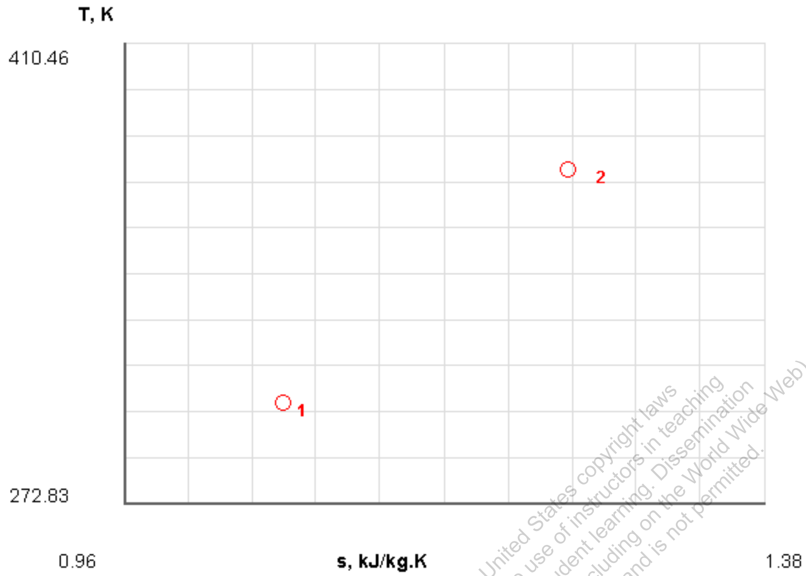
$$\Rightarrow Q = 63 \text{ kJ}$$

TEST Solution and What-if Scenario:

Launch the SL uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-2 [OBX] Suppose the aluminum block in the above problem was heated by a reservoir (TER) at 200°C. Determine (a) the change in entropy of the block, and (b) the entropy that is transferred from the reservoir. (c) How do you account for the discrepancy between the two results? (d) ***What-if scenario:*** How would the answers in parts (a) and (b) be if the reservoir was at 500°C?

SOLUTION



Given:

$c = 0.9 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$T_B = 200°\text{C};$

State-1 (given T_1, m_1)

State-2 (given $T_2,\ m_2 = m_1$)

The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$
$$\Rightarrow Q = \Delta U;$$
$$\Rightarrow Q = m(u_2 - u_1);$$
$$\Rightarrow Q = mc(T_2 - T_1);$$
$$\Rightarrow Q = (1)(0.9)(373 - 303);$$
$$\Rightarrow Q = 63 \text{ kJ};$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = mc\ln\left(\frac{T_2}{T_1}\right);$$

$$\Rightarrow \Delta S = (1)(0.9)\ln\left(\frac{373}{303}\right);$$

$$\Rightarrow \Delta S = 0.187\ \frac{\text{kJ}}{\text{K}}$$

(b) The amount of entropy transfer by heat

$$\frac{Q}{T_B} = \frac{63}{473} = 0.133\ \frac{\text{kJ}}{\text{K}}$$

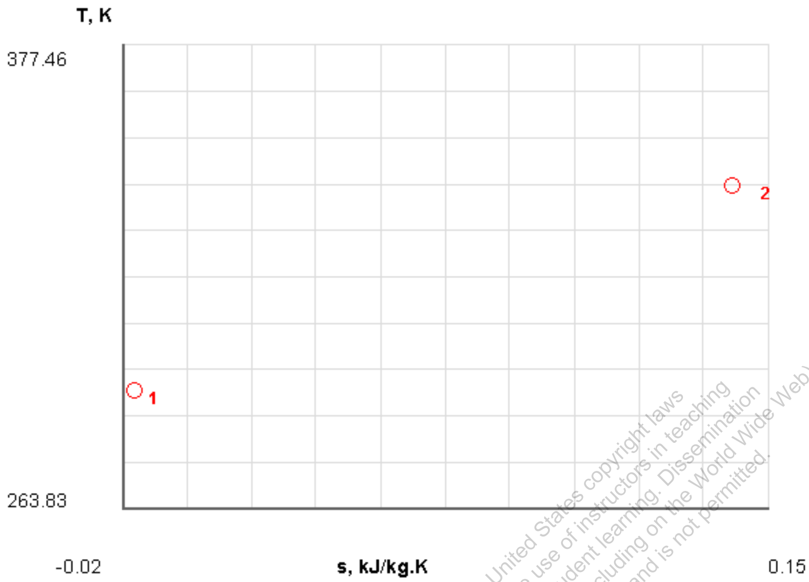
(c) The reason for discrepancy between two results is due to spontaneous entropy generation.

TEST Solution and What-if Scenario:

Launch the SL uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-3 [OBC] A mug contains 0.5 kg of coffee (properties: density = 1000 kg/m^3, c_v = 1 kJ/kg.K) at 20^{o}C. (a) Determine the amount of heat (in kJ) necessary (there is no work transfer) to raise the temperature to 70^{o}C. (b) Amount of work (kJ) necessary to move it up by a height of 10 m. (c) Amount of work (kJ) necessary to accelerate the mug from 0 to 30 m/s. Assume the mug to have no mass. Also, for the last two parts assume the mug to be adiabatic.

SOLUTION



Given:

$$\rho = 1000 \ \frac{\text{kg}}{\text{m}^3};$$

$$c_v = c = 1 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

State-1 (given T_1, V_1, m_1)

State-2 (given $T_2,\ m_2 = m_1$)

State-3 (given $\Delta z,\ m_3 = m_1$)

State-4 (given $V_4,\ m_4 = m_1$)

(a) For the heating process

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = mc(T_2 - T_1);$$

$$\Rightarrow Q = (0.5)(1)(343 - 293);$$

$$\Rightarrow Q = 25 \text{ kJ}$$

(b) For the elevation change

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

$$\Rightarrow W_{\text{ext}} = -\Delta \text{PE};$$

$$\Rightarrow W_{\text{ext}} = -mg\Delta z;$$

$$\Rightarrow W_{\text{ext}} = -(0.5)(9.81)(10);$$

$$\Rightarrow W_{\text{ext}} = -49.05 \text{ J};$$

$$\Rightarrow \therefore W_{\text{req}} = |W_{\text{ext}}| = 0.049 \text{ kJ}$$

(c) For the velocity change

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

$$\Rightarrow W_{\text{ext}} = -\Delta \text{KE};$$

$$\Rightarrow W_{\text{ext}} = -m\frac{V_4^2 - V_1^2}{2000};$$

$$\Rightarrow W_{\text{ext}} = -0.5\frac{30^2 - 0^2}{2000};$$

$$\Rightarrow W_{\text{ext}} = -0.225 \text{ kJ};$$

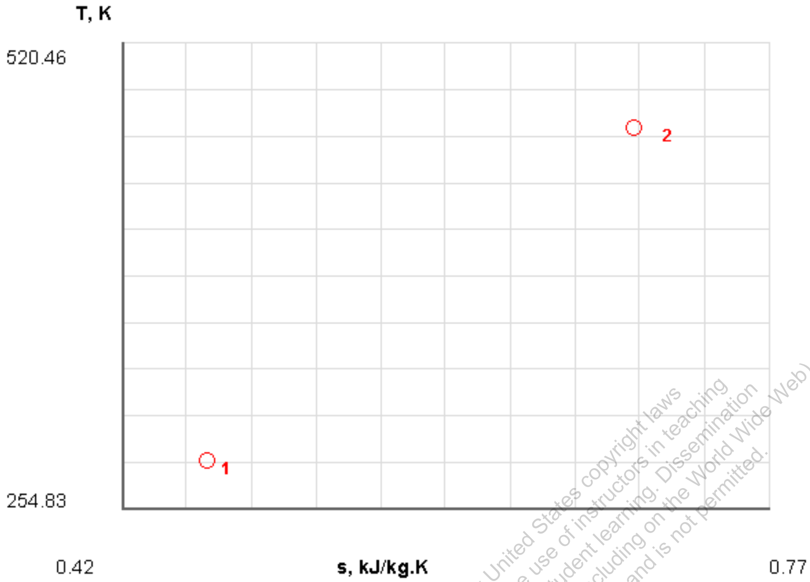
$$\Rightarrow \therefore W_{\text{req}} = |W_{\text{ext}}| = 0.225 \text{ kJ}$$

TEST Solution:

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

5-1-4 [OBV] A block of iron (specific heat: 0.45 kJ/kg.K) with a mass of 20 kg is heated from its initial temperature of 10^{o}C to a final temperaure of 200^{o}C by keeping it in thermal contact with a thermal energy reservoir (TER) at 300^{o}C. All other faces of the block are completely insulated. Determine the amount of (a) heat and (b) entropy transfer from the reservoir. (c) Also calculate the entropy generated in the system's universe due to this heat transfer.

SOLUTION



Given:

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

$T_B = 300°\text{C}$;

State-1 (given T_1, m_1)

State-2 (given $T_2, m_2 = m_1$)

(a) The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = mc(T_2 - T_1);$$

$$\Rightarrow Q = (20)(0.45)(473 - 283);$$

$$\Rightarrow Q = 1710 \text{ kJ}$$

The change in entropy

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

$$\Rightarrow \Delta S = mc\ln\left(\frac{T_2}{T_1}\right);$$

$$\Rightarrow \Delta S = (20)(0.45)\ln\left(\frac{473}{283}\right);$$

$$\Rightarrow \Delta S = 4.622\ \frac{\text{kJ}}{\text{K}};$$

(b) The amount of entropy transfer by heat

$$\frac{Q}{T_B} = \frac{1710}{573} = 2.984\ \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = 4.622 - 2.984;$$

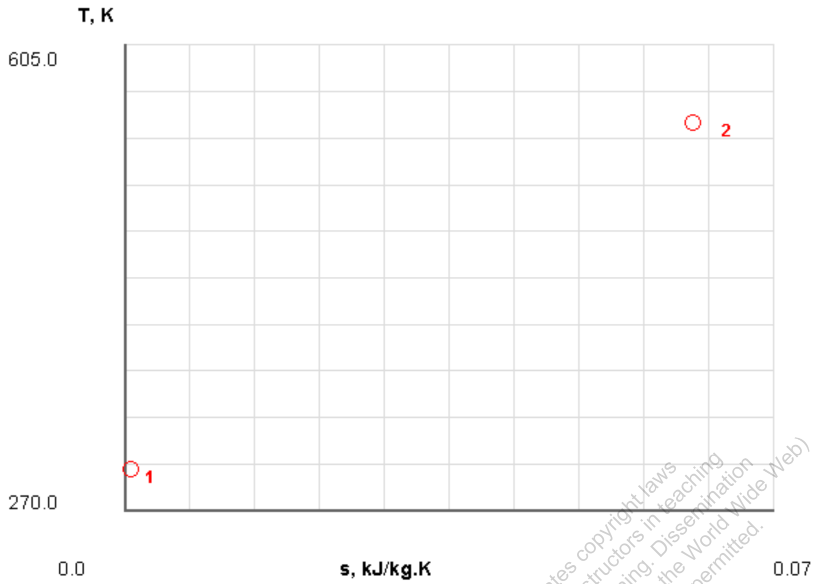
$$\Rightarrow S_{\text{gen,univ}} = 1.637\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-5 [OBT] A block of solid of mass 2 kg is heated from 300 K to a final temperature of 550 K by transferring 50 kJ of heat from a reservoir at 1000 K. Determine (a) the specific heat (c) of the solid and (b) the entropy generation in the universe due to this heating process.

SOLUTION



Given:

$T_B = 1000$ K;

State-1 (given T_1, m_1)

State-2 (given $T_2, m_2 = m_1$)

(a) The energy equation yields

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

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

$$\Rightarrow m(u_2 - u_1) = Q;$$

$$\Rightarrow mc(T_2 - T_1) = Q;$$

$$\Rightarrow c = \frac{Q}{m(T_2 - T_1)};$$

$$\Rightarrow c = \frac{50}{(2)(550 - 300)};$$

$$\Rightarrow c = 0.1 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

The change in entropy

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

$$\Rightarrow \Delta S = mc\ln\left(\frac{T_2}{T_1}\right);$$

$$\Rightarrow \Delta S = (2)(0.1)\ln\left(\frac{550}{300}\right);$$

$$\Rightarrow \Delta S = 0.121\frac{\text{kJ}}{\text{K}};$$

The amount of entropy transfer by heat

$$\frac{Q}{T_B} = \frac{50}{1000} = 0.05\ \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = 0.121 - 0.05;$$

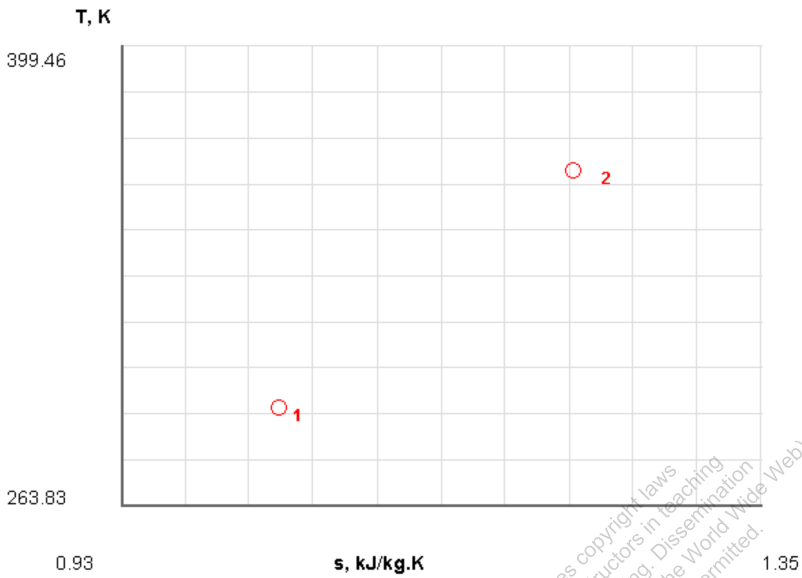
$$\Rightarrow S_{\text{gen,univ}} = 0.071\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-6 [OBQ] A block of aluminum with m = 0.5 kg, T = 20°C is dropped into a reservoir at a temperature 90°C. Calculate (a) the change in stored energy, (b) the amount of heat transfer, (c) the change in entropy, (d) the amount of entropy transfer by heat, and (e) the entropy generation in the system's universe during the heat transfer process.

SOLUTION



Given:

$c = 0.9 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$T_B = 90°\text{C};$

State-1 (given T_1, m_1)

State-2 (given $T_2 = T_B, m_2 = m_1$)

(a) The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = mc(T_2 - T_1);$$

` $$\Rightarrow Q = (0.5)(0.9)(363 - 293);$$

$$\Rightarrow Q = \Delta E = 31.5 \text{ kJ}$$

(b) $Q = 31.5 \text{ kJ}$

(c) The change in entropy

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

$$\Rightarrow \Delta S = mc\ln\left(\frac{T_2}{T_1}\right);$$

$$\Rightarrow \Delta S = (0.5)(0.9)\ln\left(\frac{363}{293}\right);$$

$$\Rightarrow \Delta S = 0.0964\ \frac{\text{kJ}}{\text{K}}$$

(d) The amount of entropy transfer by heat

$$\frac{Q}{T_B} = \frac{31.5}{363} = 0.0868\ \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = 0.0964 - 0.0868;$$

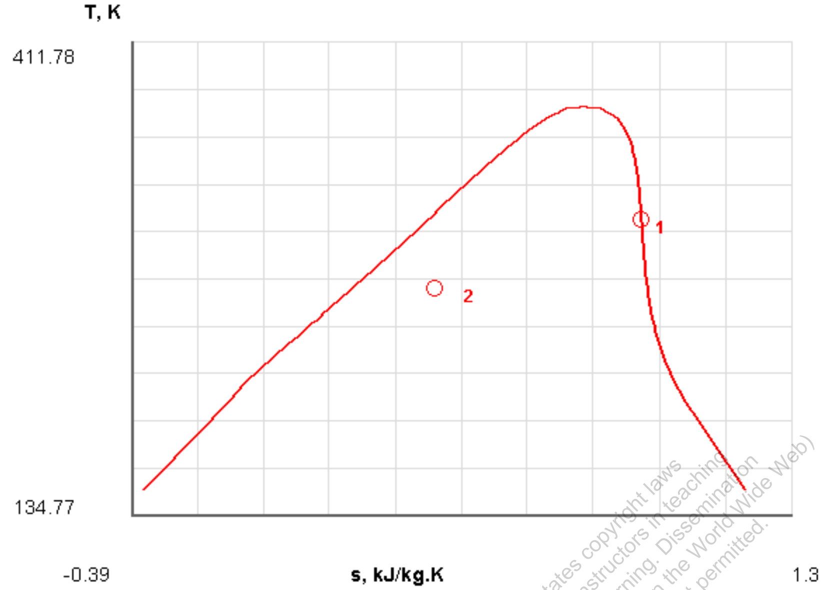
$$\Rightarrow S_{\text{gen,univ}} = 0.0096\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-7 [OBF] A 0.8 m^3 rigid tank initially contains refrigerant-134a in the saturated vapor form at 0.9 MPa. As a result of heat transfer from refrigerant, the pressure drops to 250 kPa. Determine (a) the final temperature, (b) the amount of refrigerant that condenses, and (c) the heat transfer.

SOLUTION



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

$$v_1 = 0.0226\ \frac{\text{m}^3}{\text{kg}}; \qquad u_1 = 245.88\ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2, \cancel{V}_2 = \cancel{V}_1, v_2 = v_1$):

$$v_f = 0.000764\ \frac{\text{m}^3}{\text{kg}}; \qquad v_g = 0.081\ \frac{\text{m}^3}{\text{kg}};$$

$$u_f = 44.12\ \frac{\text{kJ}}{\text{kg}}; \qquad u_{fg} = 180.53\ \frac{\text{kJ}}{\text{kg}};$$

(a) The final temperature

$$T_2 = T_{\text{sat@250kPa}} = -4.42^\circ\text{C}$$

(b) The amount of refrigerant that condenses

$$x = \frac{v_2 - v_f}{v_{fg}};$$

$$\Rightarrow x = \frac{0.0226 - 0.000764}{0.081 - 0.000764};$$

$$\Rightarrow x = 0.272;$$

$$m = \frac{\cancel{V}}{v_1};$$
$$\Rightarrow m = 35.40\,\text{kg};$$

$$x = \frac{m_g}{m};$$
$$\Rightarrow 0.272 = \frac{m_g}{35.40};$$
$$\Rightarrow m_g = 9.628\,\text{kg};$$

$$m_f = m - m_g;$$
$$\Rightarrow m_f = 35.40 - 9.628;$$
$$\Rightarrow m_f = 25.77\text{ kg}$$

$$T_1 = T_{\text{sat@0.9MPa}} = 35.49\,^{\text{o}}\text{C}$$
$$u_2 = u_f + x_2 u_{fg} = 93.22\ \frac{\text{kJ}}{\text{kg}}$$

(c) The energy equation yields

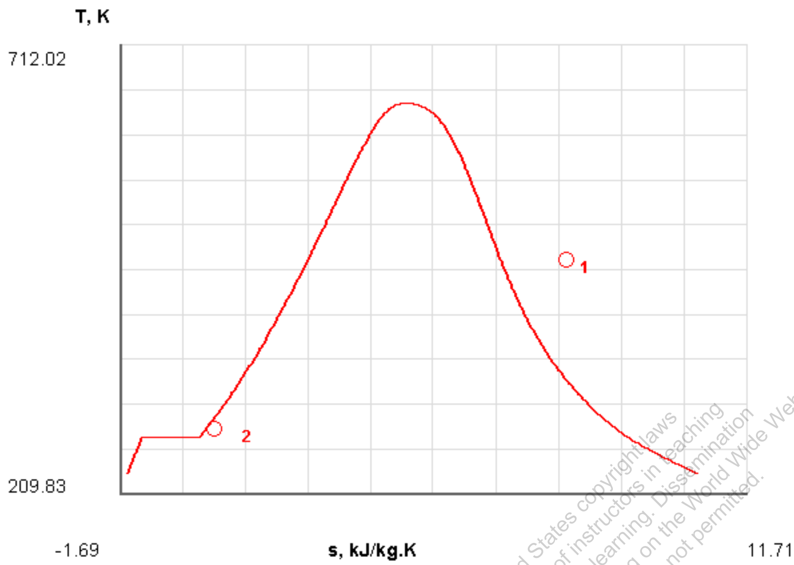
$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \cancel{W_{\text{ext}}}^{0};$$
$$\Rightarrow Q = \Delta U;$$
$$\Rightarrow Q = m(u_2 - u_1);$$
$$\Rightarrow Q = (35.40)(93.22 - 245.88);$$
$$\Rightarrow Q = -5404\text{ kJ}$$

TEST Solution:

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

5-1-8 [OBD] A rigid tank of volume 50 m^3 contains superheated steam at 100 kPa, 200°C. The tank is allowed to cool down to the atmospheric temperature of 10°C. Determine (a) the final pressure, (b) the heat transfer, (c) the change in entropy of steam, and (d) the entropy generation in the tank's universe. (e) ***What-if scenario:*** How would the answer in part (a) change if the steam was initially at 500 kPa?

SOLUTION



Given:

$T_B = 10°\text{C};$

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

$$u_1 = 2658.2\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 7.8356\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{p_1\cancel{V}_1}{RT_1} = \frac{(100)(50)}{(0.4615)(473)} = 22.9\ \text{kg};$$

$$v_1 = 2.183\ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $T_2,\ v_1 = v_2$):

$$u_f = 42.02\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 2346.6\ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 0.1511\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_{fg} = 8.7488\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_f = 0.001\ \frac{\text{m}^3}{\text{kg}}; \quad v_g = 106.32\ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = 0.0205;$$

$$u_2 = u_f + x_2 u_{fg} = 90.13\ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_f + x_2 s_{fg} = 0.3304\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_2 = 1.2281\ \text{kPa}$

(b) The energy equation yields

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

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

$$\Rightarrow Q = m\left(u_2 - u_1\right);$$

$$\Rightarrow Q = (22.9)(90.13 - 2658.2);$$

$$\Rightarrow Q = -58.808\ \text{MJ}$$

(c) The change in entropy

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

$$\Rightarrow \Delta S = 22.9(0.3304 - 7.8356);$$

$$\Rightarrow \Delta S = -171.86\ \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = -171.86 + \frac{58808}{283};$$

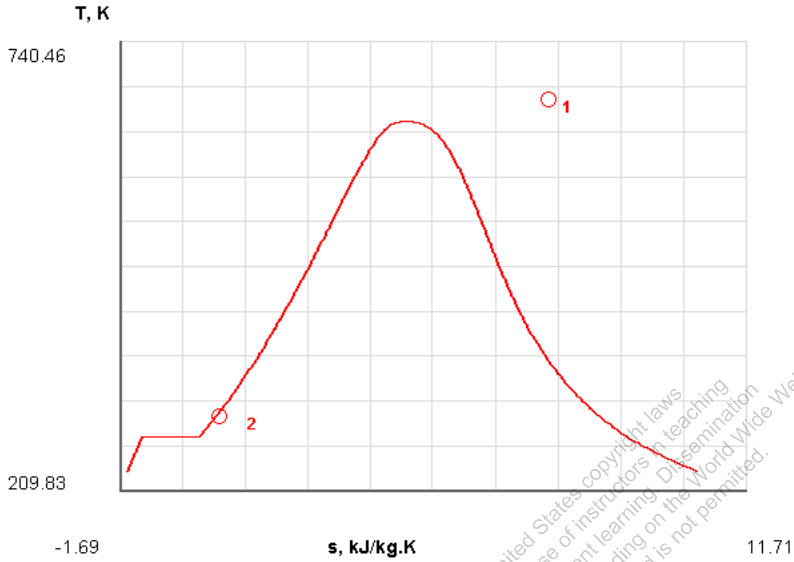
$$\Rightarrow S_{\text{gen,univ}} = 35.9\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution and What-if Scenario:

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

5-1-9 [OBY] A rigid tank of volume 10 m^3 contains superheated steam at 1 MPa and 400°C. Due to heat loss to the outside atmosphere, the tank gradually cools down to the atmospheric temperature of 25°C. Determine (a) the heat transfer, and (b) the entropy generated in the system's universe during this cooling process. (c) Plot how the pressure changes as temperature decreases during the process (pressure vs. temperature plot). (d) Can you explain the discontinuity in the plot?

SOLUTION



Use the PC model to find state properties. Since tank is rigid and closed,

$m_1 = m_2;\ V_1 = V_2;\ \therefore v_1 = v_2;$

State-1	**State-2**
$p_1 = 1$ MPa	$p_2 = 3.16$ kPa
$T_1 = 400^\circ$C	$T_2 = 25^\circ$C
$v_1 = 0.30659$ m^3/kg	$v_2 = 0.30659$ m^3/kg
$u_1 = 2957.27$ kJ/kg	$u_2 = 121.066$ kJ/kg
$h_1 = 3263.86$ kJ/kg	$h_2 = 122.03$ kJ/kg
$s_1 = 7.465$ kJ/kg·K	$s_2 = 0.425$ kJ/kg·K

$$m = \frac{V}{v} = \frac{10\ \text{m}^3}{0.30659\ \frac{\text{m}^3}{\text{kg}}} = 32.626\ \text{kg};$$

(a) The energy equation yields

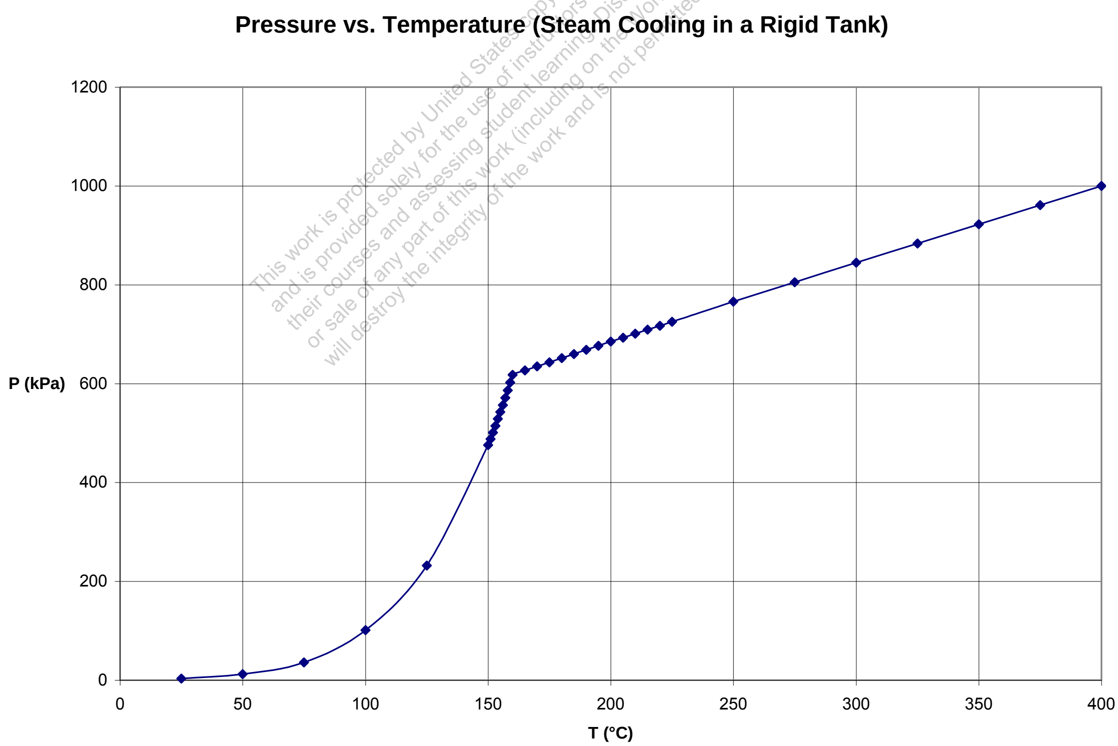
$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \cancel{W_{ext}}^0;$$

$$\Rightarrow Q = \Delta U;$$
$$\Rightarrow Q = m\left(u_2 - u_1\right);$$
$$\Rightarrow Q = (32.626)(121.066 - 2957.27);$$
$$\Rightarrow Q = -92.54 \text{ MJ}$$

(b) The entropy equation yields

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = m\left(s_2 - s_1\right) - \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = (32.626)(0.4248 - 7.465) - \frac{-92535.1}{298};$$
$$\Rightarrow S_{\text{gen,univ}} = 80.825 \ \frac{\text{kJ}}{\text{K}}$$

(c)



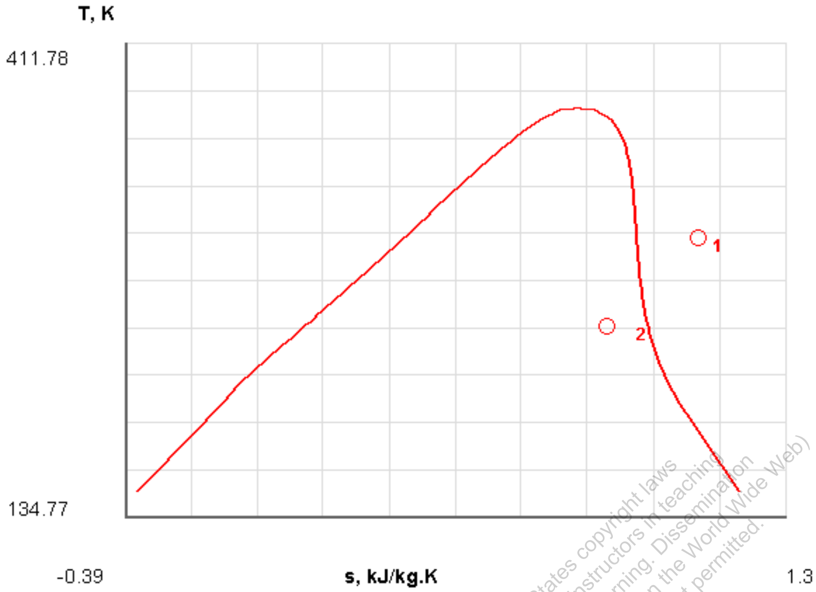
(d) The discontinuity appears when the fluid transitions from a pure vapor to a two-phase mixture.

TEST Solution:

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

5-1-10 [OSR] A rigid tank contains 3.2 kg of refrigerant-134a initially at 26°C and 140 kPa. The refrigerant is now cooled until its pressure drops to 100 kPa. Determine (a) the entropy change of the refrigerant, (b) the entropy transfer to a reservoir at -50°C, and (c) the entropy generation in the universe due to the process.

SOLUTION



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

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.08149)(299)}{140} = 0.174 \frac{\text{m}^3}{\text{kg}};$$

$$u_1 = 251.75 \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 1.075 \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

State-2 (given $p_2, v_1 = v_2, m_2 = m_1$):

$T_2 = -26.43^{\circ}\mathrm{C};$

$u_f = 16.22\ \dfrac{\mathrm{kJ}}{\mathrm{kg}};\quad u_{fg} = 195.96\ \dfrac{\mathrm{kJ}}{\mathrm{kg}};$

$s_f = 0.0678\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}};\quad s_{fg} = 0.8717\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}};$

$v_f = 0.000726\ \dfrac{\mathrm{m}^3}{\mathrm{kg}};\quad v_{fg} = 0.1917\ \dfrac{\mathrm{m}^3}{\mathrm{kg}};$

$x_2 = \dfrac{v_2 - v_f}{v_{fg}} = 0.904;$

$u_2 = u_f + x_2 u_{fg} = 193.36\ \dfrac{\mathrm{kJ}}{\mathrm{kg}};$

$s_2 = s_f + x_2 s_{fg} = 0.855\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}};$

(a) The entropy change of the refrigerant

$$\Delta S = m(s_2 - s_1);$$
$$\Rightarrow \Delta S = 3.2(0.855 - 1.075);$$
$$\Rightarrow \Delta S = -0.704\ \frac{\mathrm{kJ}}{\mathrm{K}}$$

The heat transfer at the reservoir

$$\Delta U + \cancel{\Delta \mathrm{KE}}^{0} + \cancel{\Delta \mathrm{PE}}^{0} = Q - \cancel{W_{\mathrm{ext}}}^{0};$$
$$Q = \Delta U;$$
$$\Rightarrow Q = m(u_2 - u_1);$$
$$\Rightarrow Q = (3.2)(193.36 - 251.75);$$
$$\Rightarrow Q = -186.84\ \mathrm{kJ};$$

(b) The amount of entropy transfer by heat

$$\frac{Q}{T_B} = \frac{186.84}{223} = 0.837\ \frac{\mathrm{kJ}}{\mathrm{K}}$$

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

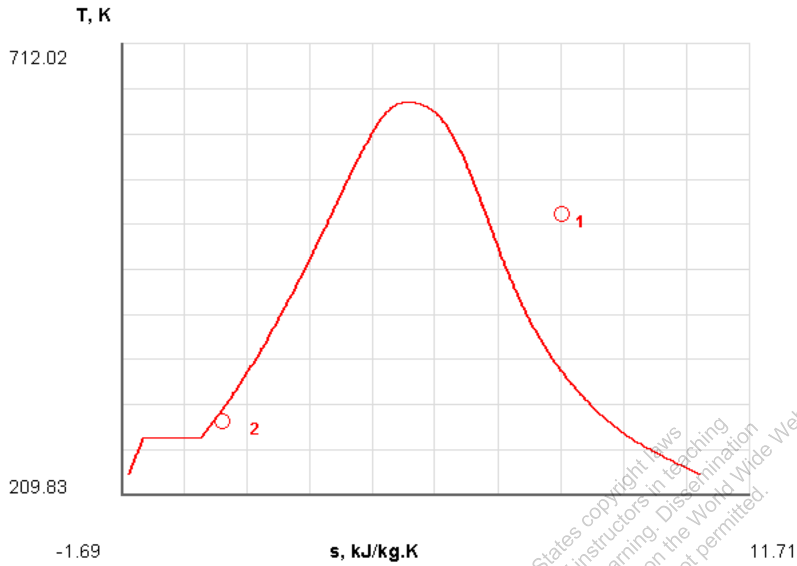
$$S_{\mathrm{gen,univ}} = \Delta S - \frac{Q}{T_B};$$
$$\Rightarrow S_{\mathrm{gen,univ}} = -0.704 + 0.837;$$
$$\Rightarrow S_{\mathrm{gen,univ}} = 0.133\ \frac{\mathrm{kJ}}{\mathrm{K}}$$

TEST Solution:

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

5-1-11 [OBM] A steam radiator (used for space heating) has a volume of 20 L and is filled up with steam at 200 kPa and 250°C. Now the inlet and exit ports are closed. As the radiator cools down to a room temperature of 20°C, determine (a) the heat transfer and show the process on a p-v diagram. (b) ***What-if scenario:*** How would the answer in part (a) change if the steam pressure in the radiator was 400 kPa instead?

SOLUTION



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

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.4615)(523)}{200} = 1.206\ \frac{\text{m}^3}{\text{kg}};$$

$$u_1 = 2731.2\ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.02}{1.206} = 0.0165\ \text{kg};$$

State-2 (given $T_2, \cancel{V}_2 = \cancel{V}_1, m_2 = m_1$):

$$p_2 = p_{\text{sat@20°C}} = 2.339\ \text{kPa};$$

$$u_f = 83.95\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 2318.95\ \frac{\text{kJ}}{\text{kg}};$$

$$v_f = 0.001002\ \frac{\text{m}^3}{\text{kg}}; \quad v_{fg} = 57.79\ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = 0.0208;$$

$$u_2 = u_f + x_2 u_{fg} = 132.18\ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy equation yields

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

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

$$\Rightarrow Q = m\left(u_2 - u_1\right);$$

$$\Rightarrow Q = \left(0.0165\right)\left(132.18 - 2731.2\right);$$

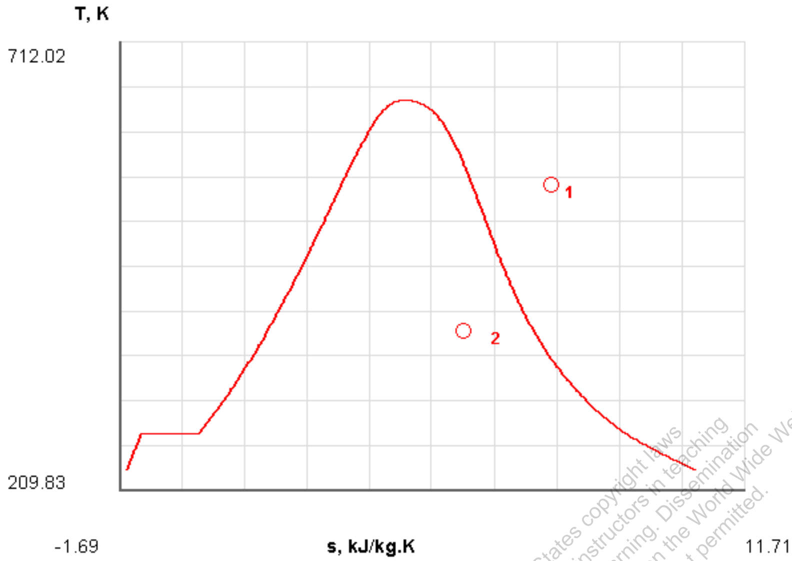
$$\Rightarrow Q = -42.88 \text{ kJ}$$

TEST Solution and What-if Scenario:

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

5-1-12 [OBJ] A steam radiator has a volume of 25 L and is filled up with steam at 350 kPa and 280°C. Now the inlet and exit ports are closed. As the radiator pressure drops down to 180 kPa, determine (a) the heat transfer and show the process on a p-v diagram. (b) ***What-if scenario:*** How would the answer in part (a) change if the steam pressure in the radiator was 500 kPa instead?

SOLUTION



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

$$v_1 = \frac{RT_1}{p_1} = \frac{(0.4615)(553)}{350} = 0.729\ \frac{\text{m}^3}{\text{kg}};$$

$$u_1 = 2774.39\ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.025}{0.729} = 0.03428\ \text{kg};$$

State-2 (given $p_2, \cancel{V}_2 = \cancel{V}_1, m_2 = m_1$):

$$T_2 = T_{\text{sat@180 kPa}} = 116.93^\circ\text{C};$$

$$u_f = 490.8\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 2035.8\ \frac{\text{kJ}}{\text{kg}};$$

$$v_f = 0.001058\ \frac{\text{m}^3}{\text{kg}}; \quad v_{fg} = 0.998\ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = 0.73;$$

$$u_2 = u_f + x_2 u_{fg} = 1976.93\ \frac{\text{kJ}}{\text{kg}};$$

(a) The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = (0.03428)(1976.93 - 2774.39);$$

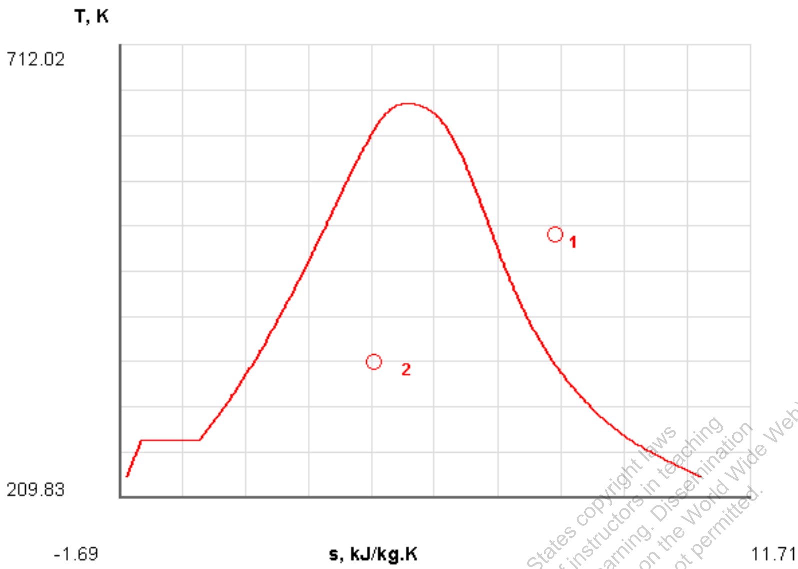
$$\Rightarrow Q = -27.33\ \mathrm{kJ}$$

TEST Solution and What-if Scenario:

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

5-1-13 [OSO] The radiator of a steam heating system has a volume of 15 L and is filled with superheated water vapor at 225 kPa and 230°C. Now the inlet and exit ports are closed. After a while the temperature of the steam drops to 88°C as a result of heat transfer to the room air. Determine (a) the heat transfer, (b) and the entropy change of the steam during this process.

SOLUTION



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

$$u_1 = 2699.718\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 7.571\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad v_1 = 1.022\ \frac{\text{m}^3}{\text{kg}};$$

$$m_1 = m_2 = 0.01467\ \text{kg};$$

State-2 (given $T_2,\ v_1 = v_2$):

$$p_2 = 64.92 \text{ kPa};$$

$$u_f = 368.55 \ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 2122.9 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 1.16958 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_{fg} = 6.3347 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_f = 0.001031 \ \frac{\text{m}^3}{\text{kg}}; \quad v_g = 2.54602 \ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_g} = 0.4;$$

$$u_2 = u_f + x_2 u_{fg} = 1217.7 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_f + x_2 s_{fg} = 3.7035 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The energy equation yields

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

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

$$\Rightarrow Q = m\left(u_2 - u_1\right);$$

$$\Rightarrow Q = \left(0.01467\right)\left(1217.7 - 2699.72\right);$$

$$\Rightarrow Q = -21.74 \text{ kJ}$$

(b) The change in entropy

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

$$\Rightarrow \Delta S = \left(0.01467\right)(3.7035 - 7.571);$$

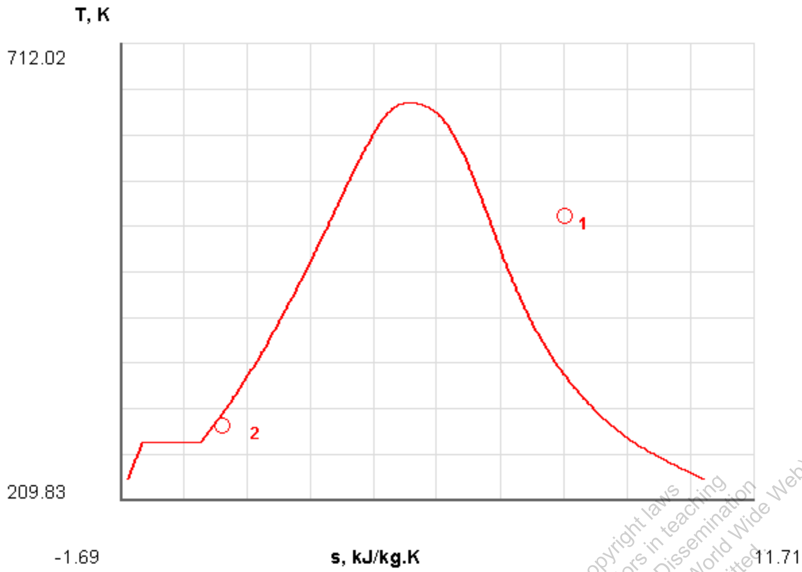
$$\Rightarrow \Delta S = -0.0567 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-14 [OSS] A steam radiator has a volume of 20 L and is filled up with steam at 200 kPa and 250°C. Now the inlet and exit ports are closed. As the radiator cools down to a room temperature of 20°C, determine (a) the final pressure, and (b) the entropy generated in the universe.

SOLUTION



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

$$u_1 = 2731.4\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 7.71\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad v_1 = 1.1989\ \frac{\text{m}^3}{\text{kg}};$$

$$m_1 = m_2 = 0.01668\ \text{kg};$$

State-2 (given $T_2,\ v_1 = v_2$):

$$u_f = 83.913\ \frac{\text{kJ}}{\text{kg}};\quad u_{fg} = 2318.4\ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 0.2965\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad s_{fg} = 8.6661\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_f = 0.001002\ \frac{\text{m}^3}{\text{kg}};\quad v_g = 57.762\ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_g} = 0.0207;$$

$$u_2 = u_f + x_2 u_{fg} = 131.9\ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_f + x_2 s_{fg} = 0.4759\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $p_2 = 2.34 \text{ kPa}$

The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = (0.01668)(131.9 - 2713.4);$$

$$\Rightarrow Q = -43.06 \text{ kJ};$$

The change in entropy

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

$$\Rightarrow \Delta S = (0.01668)(0.4759 - 7.71);$$

$$\Rightarrow \Delta S = -0.1206 \ \frac{\text{kJ}}{\text{K}};$$

(b) The entropy generated in the tank and its immediate surroundings

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

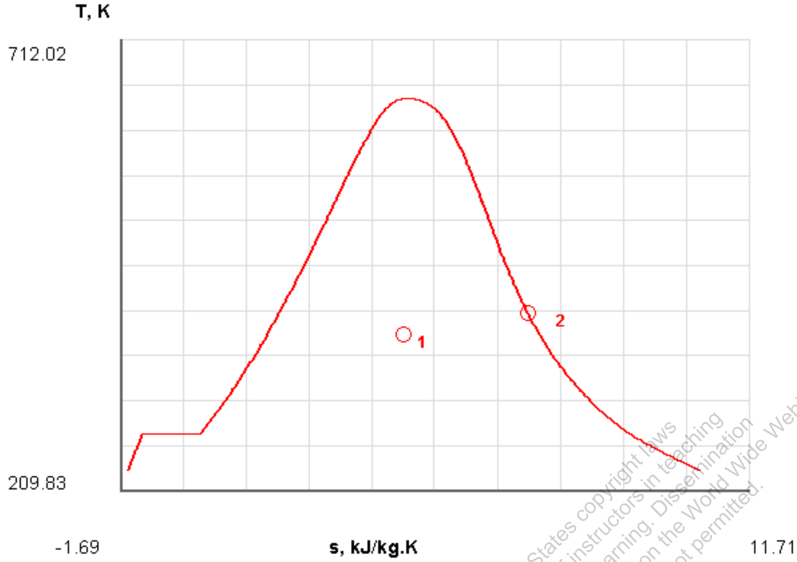
$$\Rightarrow S_{\text{gen,univ}} = 0.0264 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-15 [OBW] A well-insulated rigid tank contains 6 kg of saturated liquid vapor mixture of water at 150 kpa. Initially, half of the mass is in liquid phase. An electric resistance heater placed in the tank is now turned on and kept on until all the liquid is vaporized. Determine (a) the electrical work, (b) the entropy change of the steam during this process, and (c) the entropy generated in the system's universe.

SOLUTION



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

$T_1 = 111.35°\text{C};$

$u_f = 466.94\ \frac{\text{kJ}}{\text{kg}};\qquad u_{fg} = 2052.3\ \frac{\text{kJ}}{\text{kg}};$

$v_f = 0.001053\ \frac{\text{m}^3}{\text{kg}};\qquad v_g = 1.1594\ \frac{\text{m}^3}{\text{kg}};$

$s_f = 1.4337\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad s_{fg} = 5.7894\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$m_1 = 6\ \text{kg};$

$u_1 = u_f + xu_{fg} = 1493.23\ \frac{\text{kJ}}{\text{kg}};$

$s_1 = s_f + xs_{fg} = 4.3285\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$v_1 = v_f + xv_{fg} = 0.581\ \frac{\text{m}^3}{\text{kg}};$

State-2 (given $v_2 = v_1, x_2$):

$$u_2 = 2545.05\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 6.9773\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = \cancel{Q}^{0} - \left(W_{\text{el}} + \cancel{W_O}^{0}\right);$$

$$\Rightarrow W_{\text{el}} = -\Delta U;$$

$$\Rightarrow W_{\text{el}} = -m\left(u_2 - u_1\right);$$

$$\Rightarrow W_{\text{el}} = -(6)(2545.05 - 1493.23);$$

$$\Rightarrow W_{\text{el}} = -6.31\ \text{MJ}$$

(b) The change in entropy

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

$$\Rightarrow \Delta S = (6)(6.9773 - 4.3285);$$

$$\Rightarrow \Delta S = 15.893\ \frac{\text{kJ}}{\text{K}}$$

(c) The entropy generated in the tank and its immediate surroundings

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

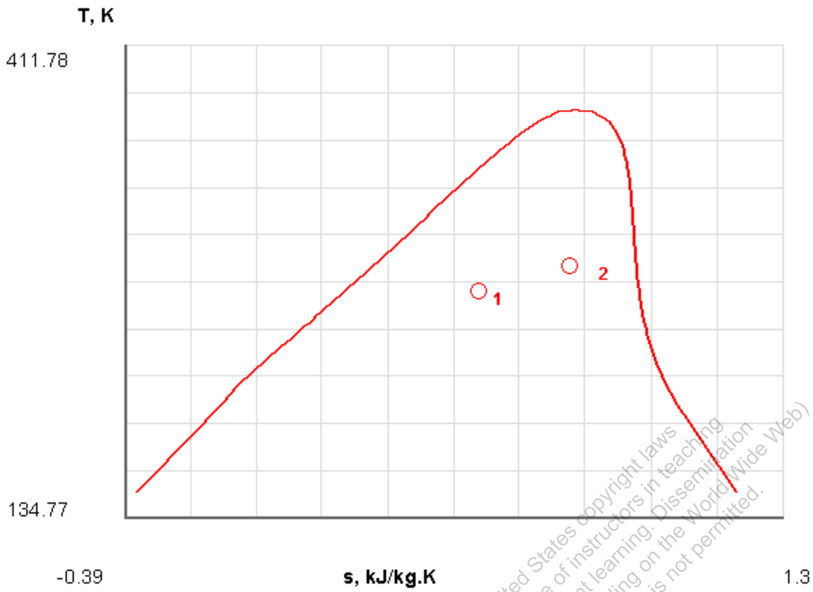
$$\Rightarrow S_{\text{gen,univ}} = 15.893\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-16 [OSB] A 0.4 m^3 rigid tank contains refrigerant-134a initially at 250 kPa and 45 percent quality. Heat is transferred now to the refrigerant from a source at 37°C until pressure rises to 420 kPa. Determine (a) the entropy change of the refrigerant, (b) the entropy change of the heat source, and (c) the total entropy generation in the universe due to the process.

SOLUTION



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

$$T_1 = -4.42^{\circ}\text{C};$$

$$u_f = 45.75\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 181.9\ \frac{\text{kJ}}{\text{kg}};$$

$$v_f = 0.000764\ \frac{\text{m}^3}{\text{kg}}; \quad v_{fg} = 0.0812\ \frac{\text{m}^3}{\text{kg}};$$

$$s_f = 0.1827\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_{fg} = 0.7513\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$u_1 = u_f + xu_{fg} = 126.631\ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_f + xs_{fg} = 0.521\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_1 = v_f + xv_g = 0.037\ \frac{\text{m}^3}{\text{kg}};$$

$$m_1 = \frac{\mathcal{V}_1}{v_1} = \frac{0.4}{0.037} = 10.8\ \text{kg};$$

State-2 (given $v_2 = v_1$, p_2):

$$T_2 = 10.33^{\circ}\mathrm{C};$$

$$v_f = 0.000794 \frac{\mathrm{m}^3}{\mathrm{kg}}; \quad v_{fg} = 0.0489 \frac{\mathrm{m}^3}{\mathrm{kg}};$$

$$u_f = 65.55 \frac{\mathrm{kJ}}{\mathrm{kg}}; \quad u_{fg} = 170.28 \frac{\mathrm{kJ}}{\mathrm{kg}};$$

$$s_f = 0.254 \frac{\mathrm{kJ}}{\mathrm{kg \cdot K}}; \quad s_{fg} = 0.672 \frac{\mathrm{kJ}}{\mathrm{kg \cdot K}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = 0.74;$$

$$u_2 = u_f + x u_{fg} = 191.6 \frac{\mathrm{kJ}}{\mathrm{kg}};$$

$$\mathrm{s}_2 = s_f + x s_{fg} = 0.751 \frac{\mathrm{kJ}}{\mathrm{kg \cdot K}};$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = (10.8)(0.751 - 0.521);$$

$$\Rightarrow \Delta S = 2.484 \frac{\mathrm{kJ}}{\mathrm{K}}$$

(b) The entropy change of the heat source

$$\frac{Q}{T_B} = \frac{m\left(u_2 - u_1\right)}{T_B};$$

$$\Rightarrow \frac{Q}{T_B} = \frac{701.66}{310};$$

$$\Rightarrow \frac{Q}{T_B} = 2.26 \frac{\mathrm{kJ}}{\mathrm{K}}$$

(c) The total entropy generation in the universe

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

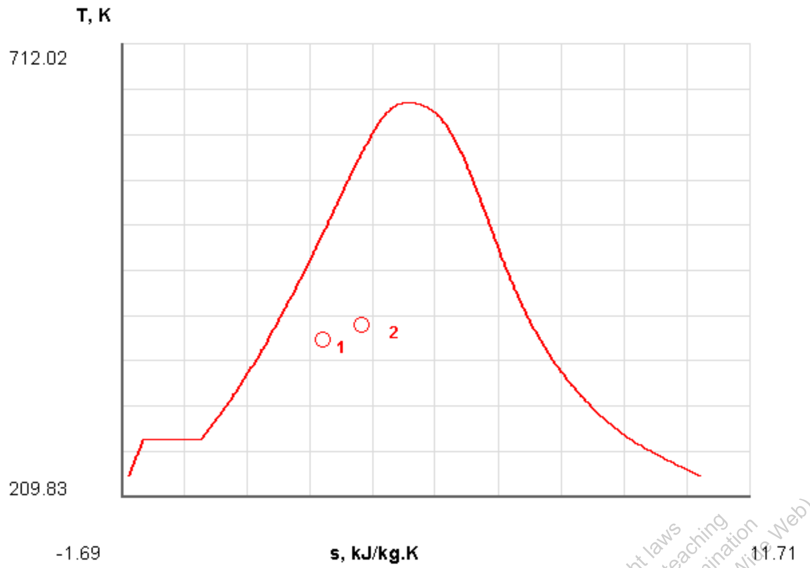
$$\Rightarrow S_{\mathrm{gen,univ}} = 0.224 \frac{\mathrm{kJ}}{\mathrm{K}}$$

TEST Solution:

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

5-1-17 [OSA] A rigid tank with 3 kg of H_2O at 150 kPa, x = 0.2 is heated with 1000 kJ. Determine (a) the final pressure, (b) phase composition of H_2O. (c) ***What-if scenario:*** How would the answer in part (a) change if the tank was heated with 500 kJ?

SOLUTION



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

$T_1 = 111.37^{\circ}\mathrm{C};$

$$u_f = 466.94\ \frac{\mathrm{kJ}}{\mathrm{kg}}; \quad u_{fg} = 2052.76.7\ \frac{\mathrm{kJ}}{\mathrm{kg}};$$

$$v_f = 0.001053\ \frac{\mathrm{m}^3}{\mathrm{kg}}; \quad v_{fg} = 1.1593\ \frac{\mathrm{m}^3}{\mathrm{kg}};$$

$$s_f = 1.4336\ \frac{\mathrm{kJ}}{\mathrm{kg}\cdot\mathrm{K}}; \quad s_{fg} = 5.789\ \frac{\mathrm{kJ}}{\mathrm{kg}\cdot\mathrm{K}};$$

$$u_1 = u_f + x u_{fg} = 877.49\ \frac{\mathrm{kJ}}{\mathrm{kg}};$$

$$s_1 = s_f + x s_{fg} = 2.59\ \frac{\mathrm{kJ}}{\mathrm{kg}\cdot\mathrm{K}};$$

$$v_1 = v_f + x v_{fg} = 0.2329\ \frac{\mathrm{m}^3}{\mathrm{kg}};$$

$$\cancel{V}_1 = m_1 \times v_1 = 0.698\ \mathrm{m}^3;$$

State-2 (given $v_2 = v_1, m_2 = m_1$)

The energy equation yields

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

$$\Rightarrow Q = \Delta U;$$
$$\Rightarrow Q = m(u_2 - u_1);$$
$$\Rightarrow 1000 = (3)(u_2 - 877.49);$$
$$\Rightarrow u_2 = 1210.82\ \frac{\text{kJ}}{\text{kg}};$$

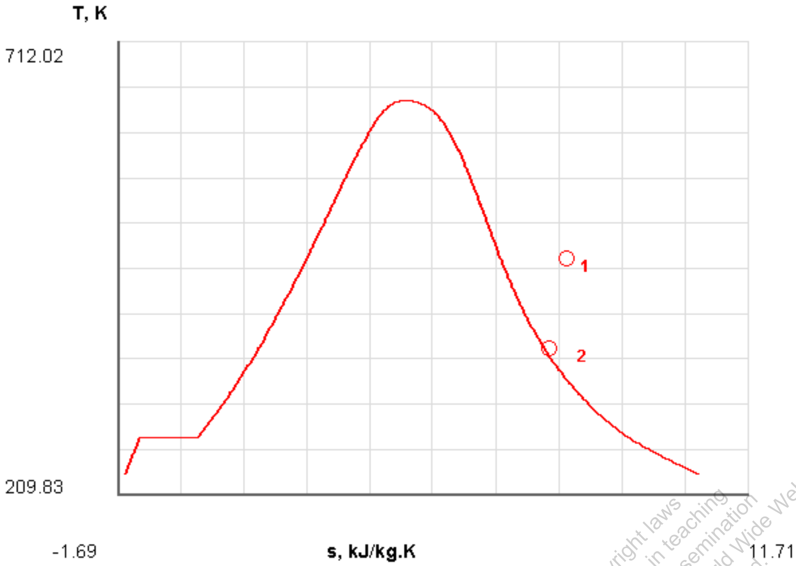
(a) Knowing v_2 and u_2, and looking at a table, it can be determined that the fluid is a saturated mixture at 260 kPa.

(b) The phase composition of the H_2O saturated mixture.

TEST Solution and What-if Scenario:
Launch the PC uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-18 [OSH] A rigid chamber of volume 1 m^3 contains steam at 100 kPa, 200°C. (a) Determine the mass of steam. (b) Determine the amount of heat loss (in kJ) necessary for the steam to cool down at constant pressure to 100°C. Use the PC model for H_2O.

SOLUTION



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

$T_{\text{sat@100kPa}} = 99.63°\text{C} \therefore$ superheated vapor

$$v = 2.172 \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2658.1 \frac{\text{kJ}}{\text{kg}};$$

$$\text{(a)} \quad m = \frac{\mathcal{V}}{v}; \quad \Rightarrow m = \frac{1}{2.172}; \quad \Rightarrow m = 0.46 \text{ kg}$$

State-2 (given $T_2, \mathcal{V}_2 = \mathcal{V}_1, m_2 = m_1$):

Still saturated vapor at 100°C and 100 kPa.

$$u_2 = 2506.7 \frac{\text{kJ}}{\text{kg}};$$

(b) The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = (0.46)(2506.7 - 2658.1);$$

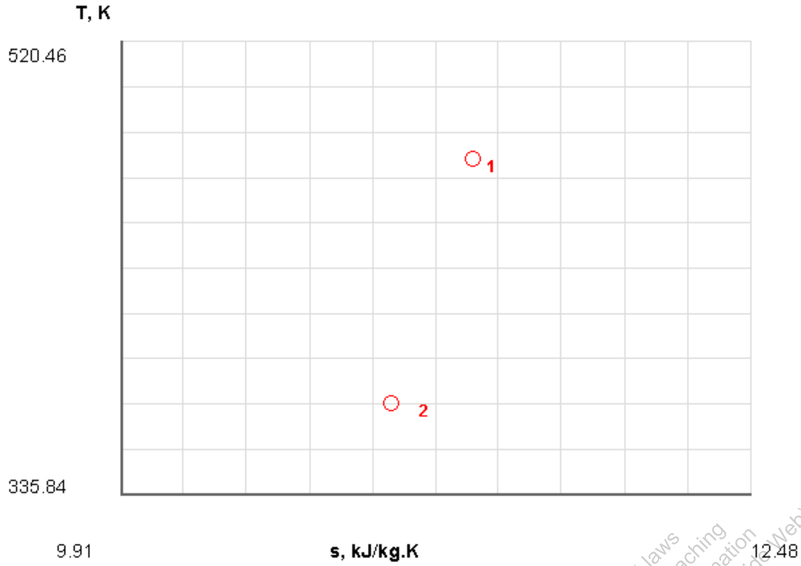
$$\Rightarrow Q = -69.64 \text{ kJ} \;\therefore\; Q_{\text{loss}} = 69.64 \text{ kJ}$$

TEST Solution:

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

5-1-19 [OSN] Repeat problem 5-1-18 [OSH] using the PG model for H_2O. (c) ***What-if Scenario:*** How would the answer in part (b) change if the IG model were used?

SOLUTION



Given:

$$c_v = 1.4063 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.4614 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

(a) $m_1 = \dfrac{p_1\cancel{V}_1}{RT_1} = \dfrac{(100)(1)}{(0.4614)(473)} = 0.458 \text{ kg}$

State-2 (given $T_2, \cancel{V}_2 = \cancel{V}_1, m_2 = m_1$)

(b) The energy equation yields

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

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

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = mc_v(T_2 - T_1);$$

$$\Rightarrow Q = (0.458)(1.4063)(373 - 473);$$

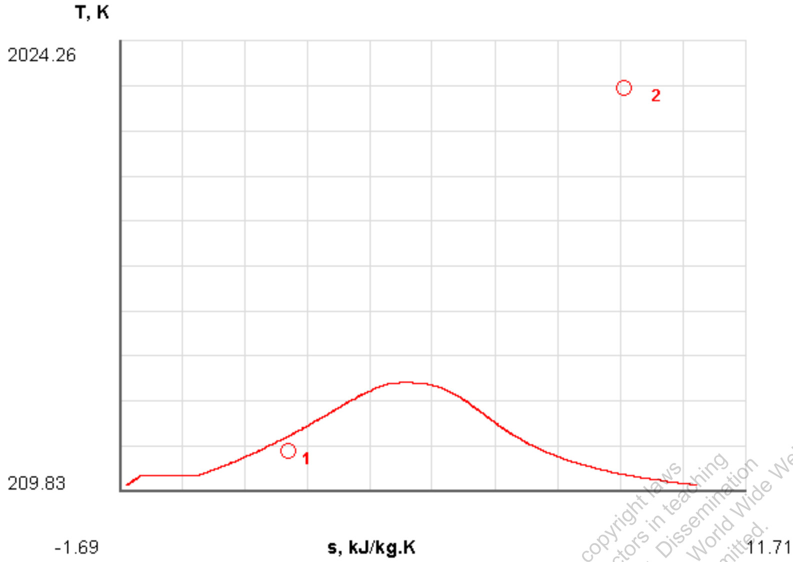
$$\Rightarrow Q = -64.41 \text{ kJ} \;\therefore\; Q_{\text{loss}} = 64.41 \text{ kJ}$$

TEST Solution and What-if Scenario:

Launch the PG/IG uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-20 [OSE] A rigid tank contains 1 kg of H_2O at 100 kPa, x = 0.1. Given that the tank can withstand a maximum internal pressure of 5 MPa, determine (a) the maximum temperature to which the steam in the tank can be heated, and (b) the amount of heat transfer necessary to reach the critical pressure.

SOLUTION



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

$T_1 = 99.61^o\text{C};$

$u_f = 417.4\ \frac{\text{kJ}}{\text{kg}};\quad u_{fg} = 2088.2\ \frac{\text{kJ}}{\text{kg}};$

$v_f = 0.001043\ \frac{\text{m}^3}{\text{kg}};\quad v_{fg} = 1.6931\ \frac{\text{m}^3}{\text{kg}};$

$s_f = 1.3028\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad s_{fg} = 6.0562\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$u_1 = u_f + xu_{fg} = 626.22\ \frac{\text{kJ}}{\text{kg}};$

$s_1 = s_f + xs_{fg} = 1.9084\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$v_1 = v_f + xv_{fg} = 0.1703\ \frac{\text{m}^3}{\text{kg}};$

State-2 (given $p_2,\ v_2 = v_1$):

$u_2 = 5247.81\ \frac{\text{kJ}}{\text{kg}};\quad s_2 = 9.108\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

(a) $T_2 = 1567.08^{\circ}\text{C}$

(b) The energy equation yields

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

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

$$\Rightarrow Q = m\left(u_2 - u_1\right);$$

$$\Rightarrow Q = (1)(5247.81 - 626.22);$$

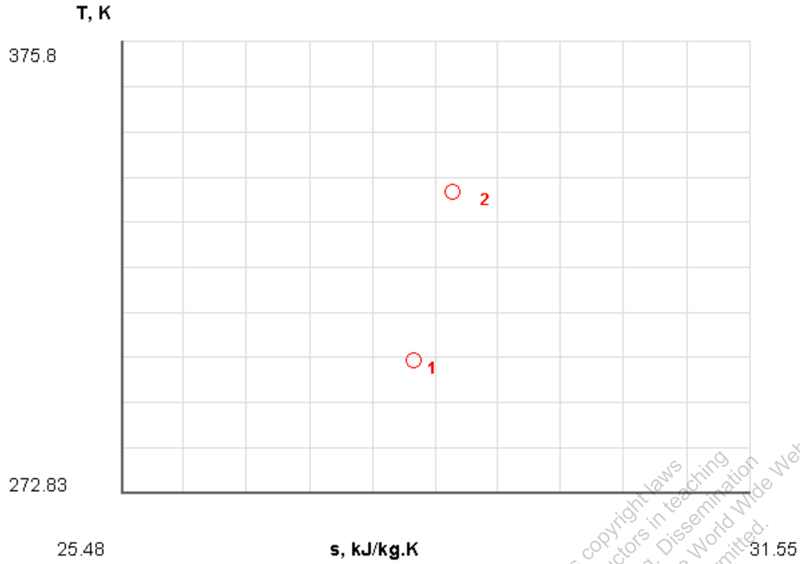
$$\Rightarrow Q = 4621.6 \text{ kJ}$$

TEST Solution:

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

5-1-21 [OSI] An insulated rigid tank contains 1.5 kg of helium at 30°C and 500 kPa. A paddle wheel with a power rating of 0.1 kW is operated within the tank for 30 minutes. Determine (a) the final temperature, (b) pressure, (c) and the entropy generated in the tank.

SOLUTION



Given:

$$c_v = 3.1156 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$R = 2.0769 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

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

$$v_1 = \frac{RT_1}{p_1} = \frac{(2.0769)(303)}{500} = 1.258 \ \frac{\text{m}^3}{\text{kg}};$$

$$\cancel{V}_1 = m_1 \times v_1 = 1.887 \text{ m}^3;$$

State-2 (given $\cancel{V}_1 = \cancel{V}_2,\ m_2 = m_1$)

(a) The energy equation yields

$$W_{\text{sh}} = W_{\text{sh}} \Delta t;$$

$$\Rightarrow W_{\text{sh}} = (0.1)(30)(60);$$

$$\Rightarrow W_{\text{sh}} = 180 \text{ kJ};$$

$$W_{\text{sh}} = m(u_2 - u_1);$$

$$\Rightarrow W_{sh} = mc_v\left(T_2 - T_1\right);$$
$$\Rightarrow W_{sh} = (1.5)(3.1156)\left(T_2 - 303\right);$$
$$\Rightarrow 180 = (1.5)(3.1156)\left(T_2 - 303\right);$$
$$\Rightarrow T_2 = 341.58\text{ K} = 68.58^{\circ}\text{C}$$

(b) $p_2 = \dfrac{RT_2}{v_2};$

$$\Rightarrow p_2 = \frac{(2.0769)(341.58)}{1.258};$$
$$\Rightarrow p_2 = 563.93\text{ kPa}$$

The change in entropy

$$\Delta S = m\left(c_v \ln\frac{T_2}{T_1} + \cancel{R\ln\frac{V_2}{V_1}}^{\,0}\right);$$
$$\Rightarrow \Delta S = (1.5)\left((3.1156)\ln\frac{341.58}{303}\right);$$
$$\Rightarrow \Delta S = 0.56\,\frac{\text{kJ}}{\text{K}};$$

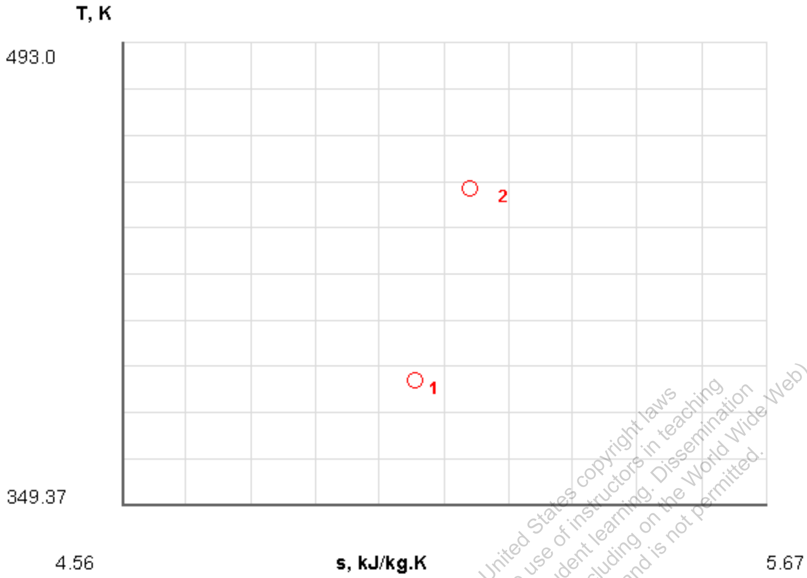
(c) The entropy generated in the tank and its immediate surroundings

$$S_{\text{gen,univ}} = \Delta S - \cancel{\frac{Q}{T_B}}^{\,0};$$
$$\Rightarrow S_{\text{gen,univ}} = 0.56\,\frac{\text{kJ}}{\text{K}}$$

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

5-1-22 [OSL] A 2 m^3 insulated rigid tank contains 3 kg of carbon dioxide at 110 kPa. Now paddle wheel work is done on the system until the pressure in the tank rises to 127 kPa. Determine (a) the entropy change of carbon dioxide, (b) work done by paddle wheel, and (c) the entropy generated in the tank and its immediate surroudings. Use the PG model. (d) ***What-if scenario:*** How would the answer in part (b) change if the IG model was used instead?

SOLUTION



Given:

$$c_v = 0.657 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.1889 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-1 (given p_1, $\cancel{V}_1$, m_1):

$$T_1 = \frac{p_1 \cancel{V}_1}{mR} = \frac{(100)(2)}{(3)(0.1889)} = 388.1 \text{ K};$$

$$s_1 = 5.0648 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given p_2, $\cancel{V}_1 = \cancel{V}_2$, $m_2 = m_1$):

$$T_2 = \frac{p_2 \cancel{V}_2}{mR} = \frac{(127)(2)}{(3)(0.1889)} = 448.2 \text{ K};$$

$$s_2 = 5.158 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in entropy

$$\Delta S = m\left(c_v \ln\frac{T_2}{T_1} + \cancel{R\ln\frac{V_2}{V_1}}^{\,0} \right);$$

$$\Rightarrow \Delta S = (3)\left((0.657)\ln\frac{448.2}{388.1} \right);$$

$$\Rightarrow \Delta S = 0.284\ \frac{\text{kJ}}{\text{K}}$$

(b) The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^{\,0} + \cancel{\Delta \text{PE}}^{\,0} = \cancel{Q}^{\,0} - \left(\cancel{W_B}^{\,0} + W_O \right);$$

$$\Rightarrow W_O = -\Delta U;$$

$$\Rightarrow W_O = -m(u_2 - u_1);$$

$$\Rightarrow W_O = -mc_v(T_2 - T_1);$$

$$\Rightarrow W_O = -(3)(0.657)(448.2 - 388.1);$$

$$\Rightarrow W_O = -117.9\ \text{kJ}$$

(c) The entropy generated in the tank and its immediate surroundings

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

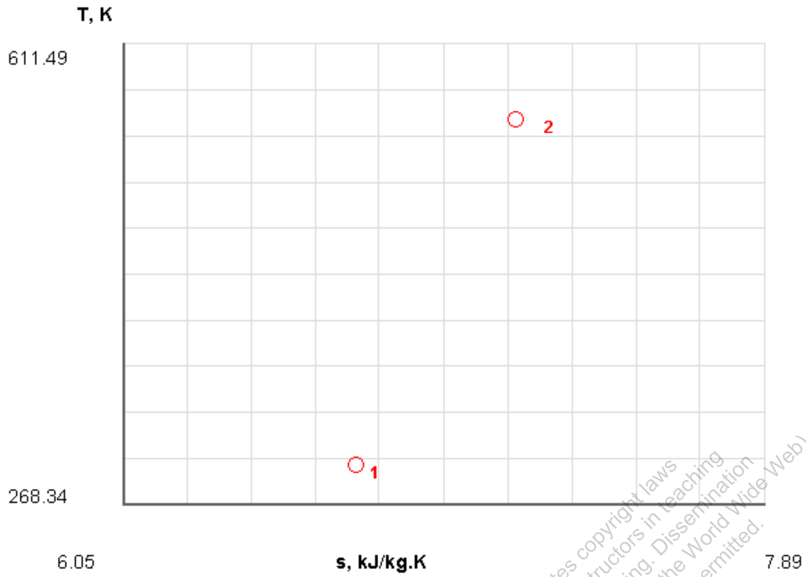
$$\Rightarrow S_{\text{gen,univ}} = 0.284\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution and What-if Scenario:

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

5-1-23 [OSV] Air is contained in an insulated, rigid volume at 25°C and 180 kPa. A paddle wheel, inserted in the volume, does 800 kJ of work on air. If the volume is 2m^3, determine (a) the entropy increase, (b) final pressure, and (c) temperature. Use the IG model for air.

SOLUTION



Given:

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

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

$$m = \frac{p_1 \cancel{V_1}}{RT_1} = \frac{(180)(2)}{(0.287)(298.15)} = 4.207 \text{ kg};$$

$$u_1 = 213.04 \ \frac{\text{kJ}}{\text{kg}}; \qquad s_1 = 6.718 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $v_2 = v_1, m_2 = m_1$)

The energy equation yields

$$\Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} = \cancel{Q}^{0} - \left(\cancel{W_B}^{0} + W_O\right);$$

$$\Rightarrow W_O = -\Delta U;$$

$$\Rightarrow W_O = -m(u_2 - u_1);$$

$$\Rightarrow u_2 = -\frac{W_O}{m} + u_1;$$

$$\Rightarrow u_2 = -\frac{-800}{4.207} + 213.04;$$

$$\Rightarrow u_2 = 403.2\ \frac{\text{kJ}}{\text{kg}};$$

$$\Rightarrow \therefore s_2 = 7.176\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = 4.207(7.176 - 6.718);$$

$$\Rightarrow \Delta S = 1.926\ \frac{\text{kJ}}{\text{K}}$$

(b) $p_2 = \frac{p_1 T_2}{T_1} = \frac{180(557.9)}{298} = 336.9\ \text{kPa}$

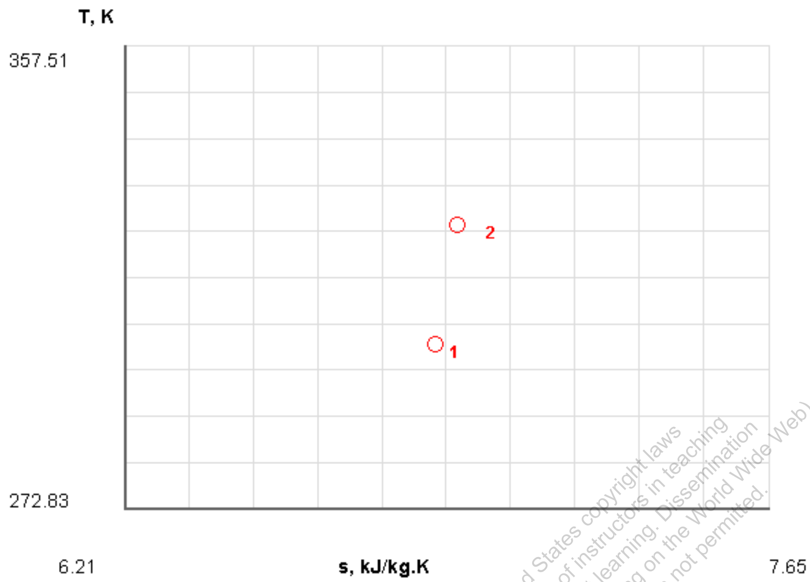
(c) $T_2 = 284^{\circ}\text{C}$

TEST Solution:

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

5-1-24 [OSG] A person living in a 4m x 5m x 5m room turns on a 100-W fan before he leaves the warm room at 100 kPa, 30^{o}C, hoping that the room will be cooler when he comes back after 5 hours. Disregarding any heat transfer and using the PG model for air, determine (a) the temperature he discovers when he comes back. (b) ***What-if scenario:*** How would the answer in part (a) change if the fan power was 50 W instead?

SOLUTION



$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

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

$$\rho_1 = \frac{p_1}{RT_1} = \frac{100}{(0.287)(303)} = 1.15 \ \frac{\text{kg}}{\text{m}^3};$$

$$m_1 = \rho_1 \mathcal{V}_1 = (1.15)(100) = 115 \text{ kg};$$

State-2 (given $m_2 = m_1$)

100W fan runs for 5 hours, hence the W_{el} can be evaluated as

$$W_{\text{el}} = (-100)(5)(3600) = -1800 \text{ kJ};$$

(a) The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = \cancel{Q}^{0} - \left(W_{\text{el}} + \cancel{W_O}^{0}\right);$$

$$\Rightarrow 0 = \Delta U + W_{\text{el}};$$

$$\Rightarrow 0 = mc_v\left(T_2 - T_1\right) + W_{\text{el}};$$

$$\Rightarrow T_2 = -\frac{W_{\text{el}}}{mc_v} + T_1;$$

$$\Rightarrow T_2 = -\frac{-1800}{(115)(0.717)} + 303;$$

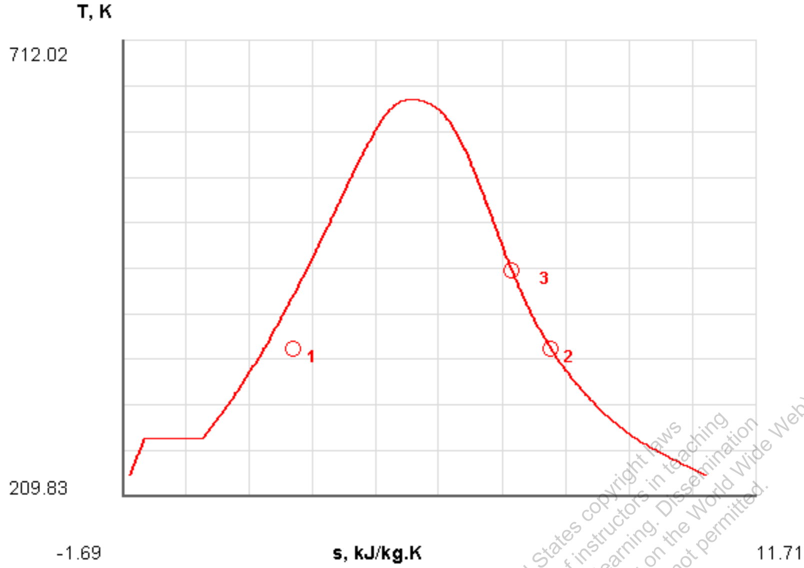
$$\Rightarrow T_2 = 324.83 \text{ K} = 51.83^{\circ}\text{C}$$

TEST Solution and What-if Scenario:

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

5-1-25 [OSZ] A piston-cylinder device contains 0.01 kg of steam at a pressure of 100 kPa and a quality of 10%. Determine the heat transfer necessary to improve the quality to 100% when heating is carried out (a) in a constant pressure manner by allowing the piston to move freely, or (b) in a constant volume manner by locking the piston in its initial position.

SOLUTION



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

$T_1 = 99.63^o\text{C};$

$$u_f = 417.36\ \frac{\text{kJ}}{\text{kg}};\qquad u_{fg} = 2088.2\ \frac{\text{kJ}}{\text{kg}};$$

$$v_f = 0.001043\ \frac{\text{m}^3}{\text{kg}};\qquad v_{fg} = 1.6941\ \frac{\text{m}^3}{\text{kg}};$$

$$s_f = 1.3028\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad s_{fg} = 6.0562\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$u_1 = u_f + xu_{fg} = 626.22\ \frac{\text{kJ}}{\text{kg}};$$

$$\text{s}_1 = s_f + xs_{fg} = 1.9084\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_1 = v_f + xv_g = 0.1704\ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $p_2 = p_1, x_2, m_2 = m_1$):

$$v_2 = 1.694\ \frac{\text{m}^3}{\text{kg}};\qquad u_2 = 2506.1\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 7.3594\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p-\cancel{V}$ diagram.

$$W_B = p_1(\cancel{V}_2 - \cancel{V}_1);$$

$$\Rightarrow W_B = p_1 m(v_2 - v_1);$$

$$\Rightarrow W_B = (100)(0.01)(1.694 - 0.1704);.$$

$$\Rightarrow W_B = 1.52 \text{ kJ};$$

(a) The energy equation yields

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

$$\Rightarrow Q = \Delta U + W_{\text{ext}};$$

$$\Rightarrow Q = m(u_2 - u_1) + W_{ext};$$

$$\Rightarrow Q = (0.01)(2506.1 - 626.22) + 1.52;$$

$$\Rightarrow Q = 20.31 \text{ kJ}$$

For constant volume process

$$v_2 = 0.1703 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_2 = 2587.1 \ \frac{\text{kJ}}{\text{kg}};$$

$$W_{\text{ext}} = 0 \text{ kJ};$$

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

$$\Rightarrow Q = \Delta U + W_{\text{ext}};$$

$$\Rightarrow Q = m(u_2 - u_1) + 0;$$

$$\Rightarrow Q = (0.01)(2587.1 - 626.22) + 0;$$

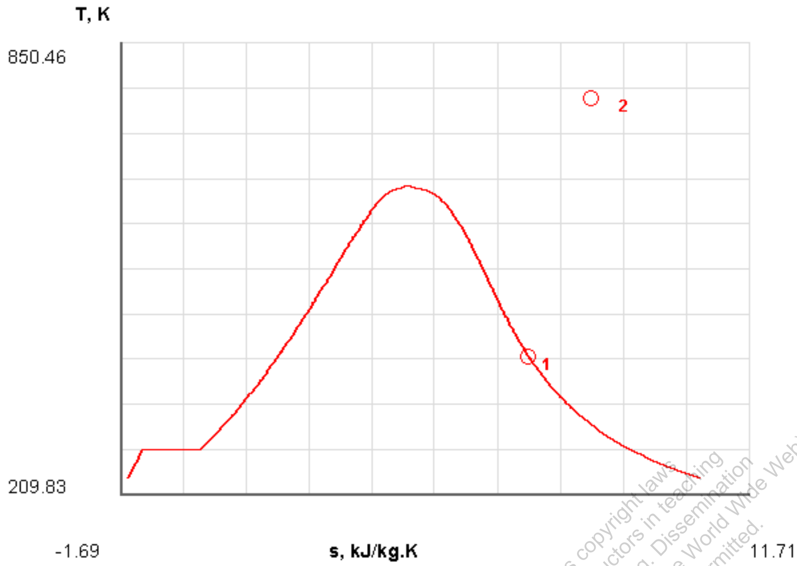
$$\Rightarrow Q = 19.60 \text{ kJ}$$

TEST Solution:

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

5-1-26 [OSU] A mass of 10 kg of saturated water vapor at 300 kPa is heated at constant pressure until the temperature reaches 500°C. Calculate (a) the work done by the steam during the process, and (b) the amount of heat transfer. (c) ***What-if scenario:*** How would the answer in part (b) change if the pressure remained constant at 600 kPa?

SOLUTION



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

$T_1 = 133.52^{o}\text{C};$

$v_1 = 0.6058\ \dfrac{\text{m}^3}{\text{kg}};\quad u_1 = 2543.2\ \dfrac{\text{kJ}}{\text{kg}};\quad s_1 = 6.9917\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$m_1 = 10\ \text{kg};$

State-2 (given $p_2 = p_1,\ m_2 = m_1,\ T_2$):

$v_2 = 1.1867\ \dfrac{\text{m}^3}{\text{kg}};\quad u_2 = 3130.6\ \dfrac{\text{kJ}}{\text{kg}};\quad s_2 = 8.3271\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \mathcal{V}$ diagram.

(a) $W_B = p_1\left(\mathcal{V}_2 - \mathcal{V}_1\right);$

$$\Rightarrow W_B = p_1 m\left(v_2 - v_1\right);$$

$$\Rightarrow W_B = (300)(10)(1.1867 - 0.6058);.$$

$$\Rightarrow W_B = 1742.7\ \text{kJ}$$

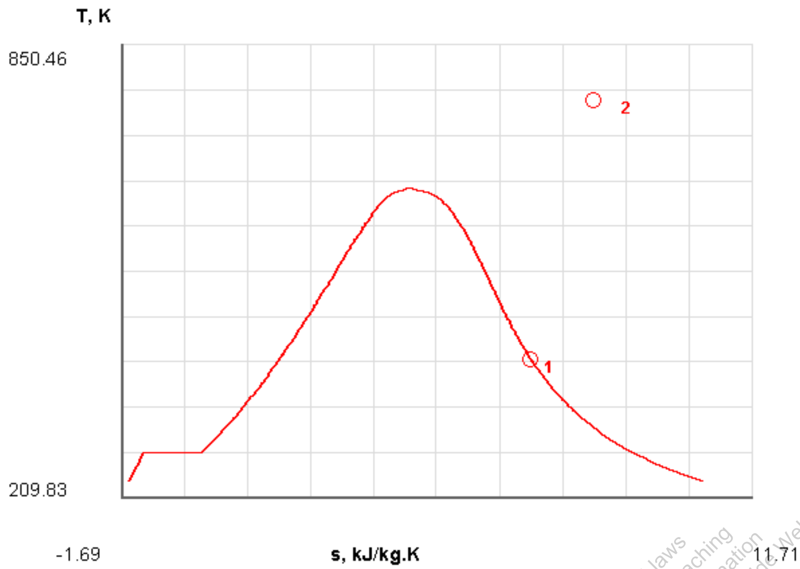
(b) The energy equation yields

$$\Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} = Q - W_{ext};$$
$$\Rightarrow Q = \Delta U + W_{ext};$$
$$\Rightarrow Q = m(u_2 - u_1) + W_{ext};$$
$$\Rightarrow Q = (10)(3130.6 - 2543.2) + 1742.7;$$
$$\Rightarrow Q = 7616.7 \text{ kJ}$$

TEST Solution and What-if Scenario:
Launch the PC uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-27 [OSK] In problem 5-1-26 [OSU], determine the minimum average value of the boundary temperature for which the second law is not violated.

SOLUTION



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

$T_1 = 133.52^o\text{C};$

$$v_1 = 0.6058\ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2543.2\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 6.9917\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$m_1 = 10\ \text{kg};$

State-2 (given $p_2 = p_1$, $m_2 = m_1$, T_2):

$$v_2 = 1.1867\ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = 3130.6\ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 8.3271\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

In order to not violate the second law

$$S_{\text{gen,univ}} \geq 0\ \frac{\text{kJ}}{\text{K}}$$

The change in entropy

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

$$\Rightarrow \Delta S = (10)(8.3271 - 6.9917);$$

$$\Rightarrow \Delta S = 13.354\ \frac{\text{kJ}}{\text{K}};$$

With the previous information, the entropy equation yields

$$\Rightarrow 0 = \Delta S_{\text{system}} - \frac{Q}{T_B};$$

$$\Rightarrow \frac{Q}{T_B} = \Delta S_{\text{system}};$$

$$\Rightarrow T_B = \frac{Q}{\Delta S_{\text{system}}};$$

$$\Rightarrow T_B = \frac{7616.7}{13.354};$$

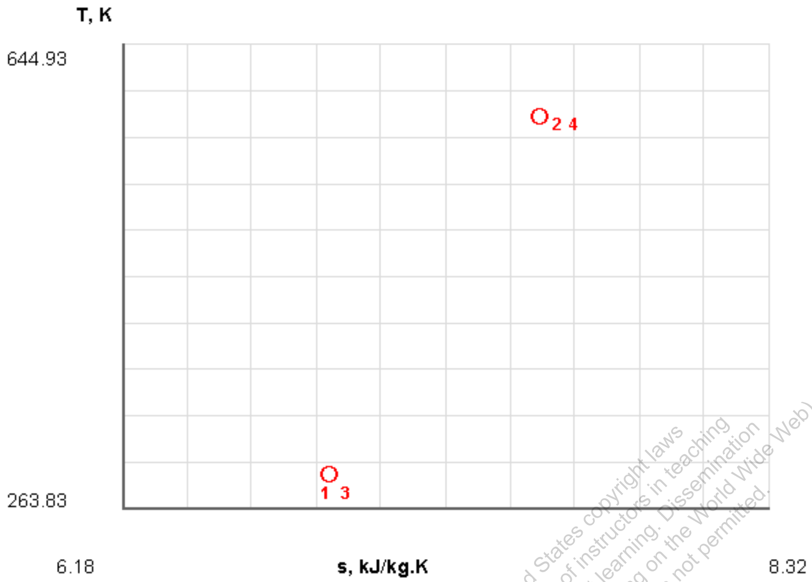
$$\Rightarrow T_B = 570.4\,\text{K} = 297.4°\text{C}$$

TEST Solution:

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

5-1-28 [OSP] A vertical piston-cylinder assembly contains 10 L of air at 20°C. The cylinder has an internal diameter of 20 cm. The piston is 2 cm thick and is made of steel of density 7830 kg/m^3. If the atmospheric pressure outside is 101 kPa and the volume of air doubles, determine the (a) heat and (b) work transfer during the process. (c) What-if scenario: How would the answers change if the piston weight was neglected?

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

State-1 (given $T_1, \forall_1$):

$$m_{\text{piston}} = \forall_{\text{piston}}\rho = \frac{\pi D^2}{4}(t)(\rho) = 4.9 \text{ kg};$$

$$p_{\text{piston}} = \frac{F}{A} = \frac{mg}{A} = \frac{(4.9)(9.8)}{0.0314} = 1.54 \text{ kPa};$$

$$p_1 = p_{\text{atm}} + p_{\text{piston}} = 101 + 1.54 = 102.54 \text{ kPa};$$

$$m = \frac{p_1\forall_1}{RT_1} = \frac{(102.54)(0.01)}{(0.287)(293)} = 0.0122 \text{ kg};$$

$$v_1 = 0.8201 \ \frac{\text{m}^3}{\text{kg}};$$

State-2 (given $p_2 = p_1,\ 2\forall_2 = \forall_1,\ m_2 = m_1$):

$$T_2 = \frac{p_2 \cancel{V}_2}{mR} = \frac{(102.54)(0.02)}{(0.0122)(0.287)} = 585.7 \text{ K};$$

(a) The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(W_B + \cancel{W_O}^0\right);$$

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

$$\Rightarrow Q = m(u_2 - u_1) + W_B;$$

$$\Rightarrow Q = mc_v(T_2 - T_1) + W_B;$$

$$\Rightarrow Q = (0.0122)(0.717)(585.7 - 293) + 1.0254;$$

$$\Rightarrow Q = 3.586 \text{ kJ}$$

(b) Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \cancel{V}$ diagram.

$$W_B = p_1(\cancel{V}_2 - \cancel{V}_1);$$

$$\Rightarrow W_B = (102.54)(0.02 - 0.01);$$

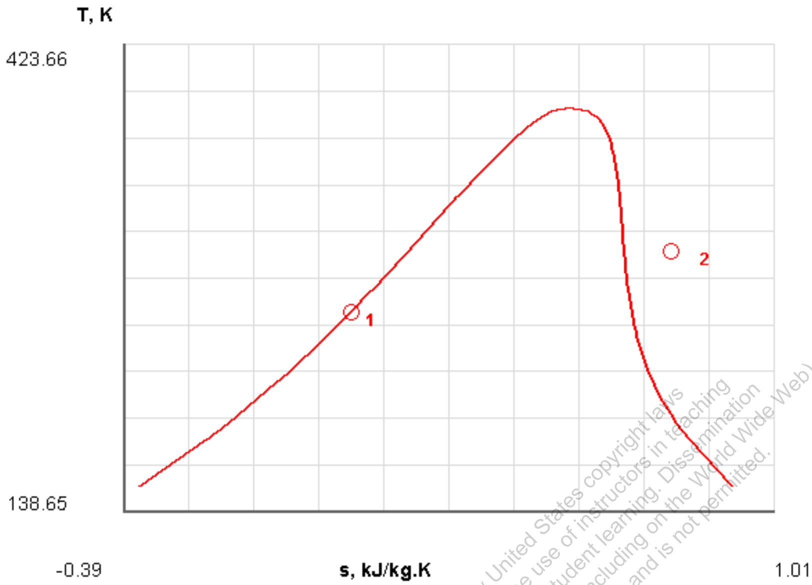
$$\Rightarrow W_B = 1.0254 \text{ kJ}$$

TEST Solution and What-if Scenario:

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

5-1-29 [OSX] A frictionless piston-cylinder device contains 0.1 kg of refrigerant-12 as a saturated liquid. The piston is free to move, and its mass is such that it maintains a pressure of 200 kPa on the refrigerant. Due to heat transfer from the atmosphere, the temperature of the refrigerant gradually rises to the atmospheric temperature of 25°C. Calculate (a) the work transfer, (b) the heat transfer, (c) the change of entropy of the refrigerant, and (d) the entropy generated in the system's universe.

SOLUTION



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

$T_1 = -12.52^\circ\mathrm{C};$

$$v_1 = 0.0007\ \frac{\mathrm{m}^3}{\mathrm{kg}};\quad u_1 = 24.435\ \frac{\mathrm{kJ}}{\mathrm{kg}};\quad s_1 = 0.0992\ \frac{\mathrm{kJ}}{\mathrm{kg}\cdot\mathrm{K}};$$

State-2 (given $p_2 = p_1,\ T_2,\ m_2 = m_1$):

$$v_2 = 0.09832\ \frac{\mathrm{m}^3}{\mathrm{kg}};\quad u_2 = 185.769\ \frac{\mathrm{kJ}}{\mathrm{kg}};\quad s_2 = 0.7871\ \frac{\mathrm{kJ}}{\mathrm{kg}\cdot\mathrm{K}};$$

(a) Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \cancel{V}$ diagram.

$$W_B = p_1\left(\cancel{V}_2 - \cancel{V}_1\right);$$

$$\Rightarrow W_B = p_1 m\left(v_2 - v_1\right);$$

$$\Rightarrow W_B = (200)(0.1)(0.09832 - 0.0007);$$

$$\Rightarrow W_B = 1.95\ \mathrm{kJ}$$

(b) The energy equation yields

$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \left(W_B + \cancel{W_O}^0\right);$$

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

$$\Rightarrow Q = m(u_2 - u_1) + W_B;$$

$$\Rightarrow Q = (0.1)(185.769 - 24.435) + 1.95;$$

$$\Rightarrow Q = 18.08 \text{ kJ}$$

(c) The change in entropy

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

$$\Rightarrow \Delta S = (0.1)(0.7871 - 0.0992);$$

$$\Rightarrow \Delta S = 0.06879 \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = 0.06879 - \left(\frac{18.08}{298}\right);$$

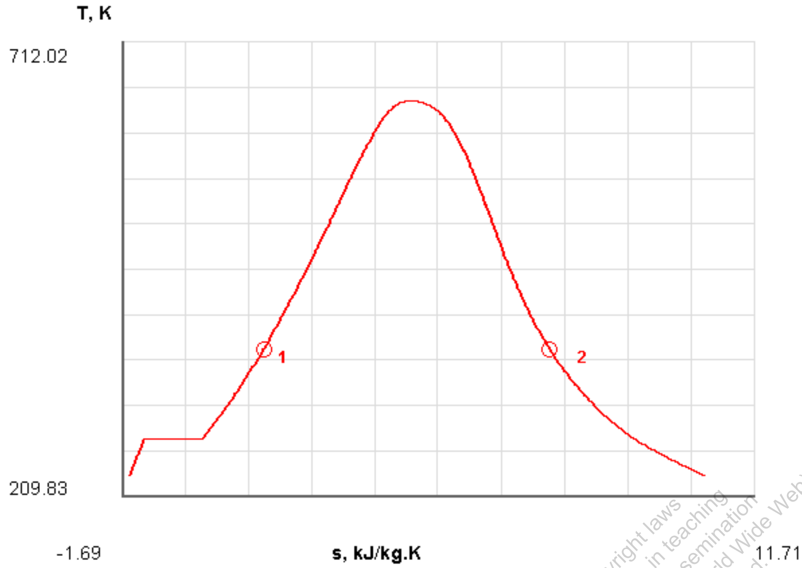
$$\Rightarrow S_{\text{gen,univ}} = 0.00812 \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-30 [OSC] A mass of 2 kg of liquid water is completely vaporized at a constant pressure of 1 atm. Determine (a) the heat added. (b) ***What-if scenario:*** How would the answer change if the pressure was 2 atm?

SOLUTION



State-1 (given p_1, m_1):

$$v_1 = 0.00104 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_1 = 418.84 \ \frac{\text{kJ}}{\text{kg}};$$

$$\mathcal{V}_1 = m_1 \times v_1 = 0.00208 \text{ m}^3;$$

State-2 (given $p_2 = p_1,\ x_2,\ m_2 = m_1$):

$$v_2 = 1.674 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_2 = 2506.1 \ \frac{\text{kJ}}{\text{kg}};$$

$$\mathcal{V}_2 = m_2 \times v_2 = 3.348 \text{ m}^3;$$

Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \mathcal{V}$ diagram

$$W_B = p_1 \left(\mathcal{V}_2 - \mathcal{V}_1 \right);$$

$$\Rightarrow W_B = (101.325)(3.348 - 0.00208);$$

$$\Rightarrow W_B = 339.02 \text{ kJ};$$

(a) The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \left(W_B + \cancel{W_O}^{0} \right);$$

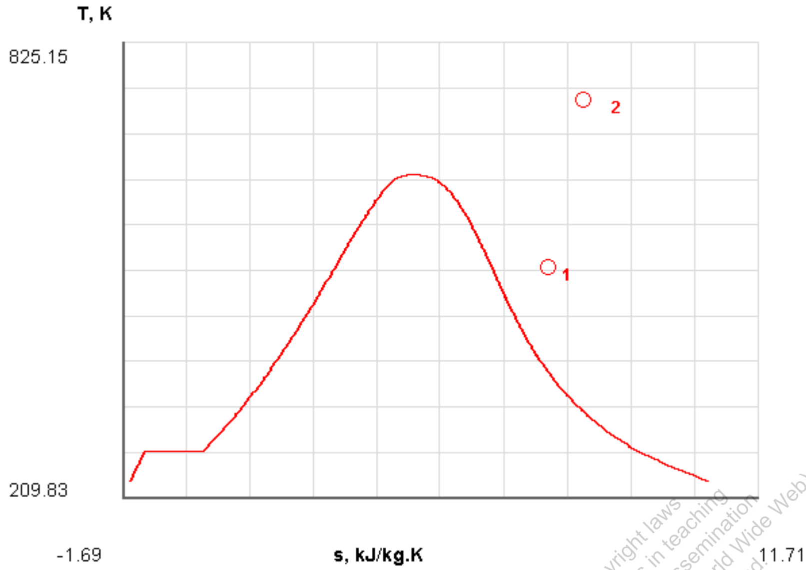
$$\Rightarrow Q = \Delta U + W_B;$$
$$\Rightarrow Q = m(u_2 - u_1) + W_B;$$
$$\Rightarrow Q = (2)(2506.1 - 418.84) + 339.02;$$
$$\Rightarrow Q = 4513.54 \text{ kJ}$$

TEST Solution and What-if Scenario:

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

5-1-31 [OSQ] A frictionless piston is used to provide a constant pressure of 500 kPa in a cylinder containing steam originally at 250°C with a volume of 3 m^3. Determine (a) the final temperature if 3000 kJ of heat is added, (b) the work done by piston.

SOLUTION



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

$$v_1 = 0.4744\ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 2723.5\ \frac{\text{kJ}}{\text{kg}}; \quad h_1 = 2960.6\ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{3}{0.4744} = 6.3237\ \text{kg};$$

State-2 (given $p_2 = p_1,\ m_2 = m_1$):

$$Q = m\left(h_2 - h_1\right);$$

$$\Rightarrow 3000 = (6.3237)(h_2 - 2960.7);$$

$$\Rightarrow h_2 = 3435.1\ \text{kJ};$$

$$v_2 = 0.6894\ \frac{\text{m}^3}{\text{kg}};$$

$$\cancel{V}_2 = m_2 \times v_2 = 4.36\ \text{m}^3;$$

(a) $T_2 = 477°\text{C}$

(b) $W_B = p_1\left(\cancel{V}_2 - \cancel{V}_1\right);$

$$\Rightarrow W_B = (500)(4.36 - 3);$$

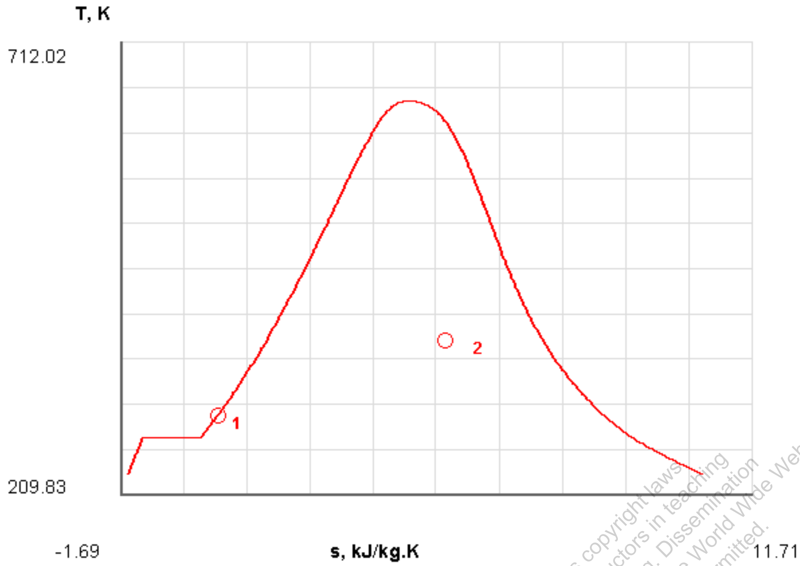
$$\Rightarrow W_B = 679.8\ \text{kJ}$$

TEST Solution:

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

5-1-32 [OST] A piston-cylinder device initially contains 2 kg of liquid water at 140 kPa and 25°C. The water is now heated at a constant pressure by addition of 3600 kJ of heat. Determine (a) the final temperature, (b) the entropy change of the water during this process, and (c) the boundary work.

SOLUTION



State-1 (given $p_1,\ T_1,\ m_1$)

$$v_1 = 0.0010\ \frac{\text{m}^3}{\text{kg}};\quad u_1 = 104.87\ \frac{\text{kJ}}{\text{kg}};\quad h_1 = 105.01\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 0.36732\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_1,\ m_2 = m_1$):

$$Q = m_1\left(h_2 - h_1\right);$$

$$\Rightarrow h_2 = \frac{Q}{m} + h_1 = \frac{3600}{2} + 105.01 = 1905.01\ \frac{\text{kJ}}{\text{kg}};$$

$$v_f = 0.001051\ \frac{\text{m}^3}{\text{kg}}; \quad v_{fg} = 1.2412\ \frac{\text{m}^3}{\text{kg}}; \quad u_f = 457.87\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 2058.9\ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 1.4098\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad s_{fg} = 5.8376\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad h_f = 458.022\ \frac{\text{kJ}}{\text{kg}}; \quad h_{fg} = 2231.8\ \frac{\text{kJ}}{\text{kg}};$$

$$x_2 = \frac{h_2 - h_f}{h_{fg}} = 0.648;$$

$$v_2 = v_f + xv_{fg} = 0.8053\ \frac{\text{m}^3}{\text{kg}};$$

$$u_2 = u_f + xu_{fg} = 1792.04\ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s_f + xs_{fg} = 5.193\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $T_2 = 109.19\ ^{\text{o}}\text{C}$

(b) The change in entropy

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

$$\Rightarrow \Delta S = 2\left(5.193 - 0.36732\right);$$

$$\Rightarrow \Delta S = 9.65\ \frac{\text{kJ}}{\text{K}}$$

(c) Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \cancel{V}$ diagram.

$$W_B = p_1\left(\cancel{V}_2 - \cancel{V}_1\right);$$

$$\Rightarrow W_B = p_1 m\left(v_2 - v_1\right);$$

$$\Rightarrow W_B = \left(140\right)\left(2\right)\left(0.8053 - 0.0010\right);$$

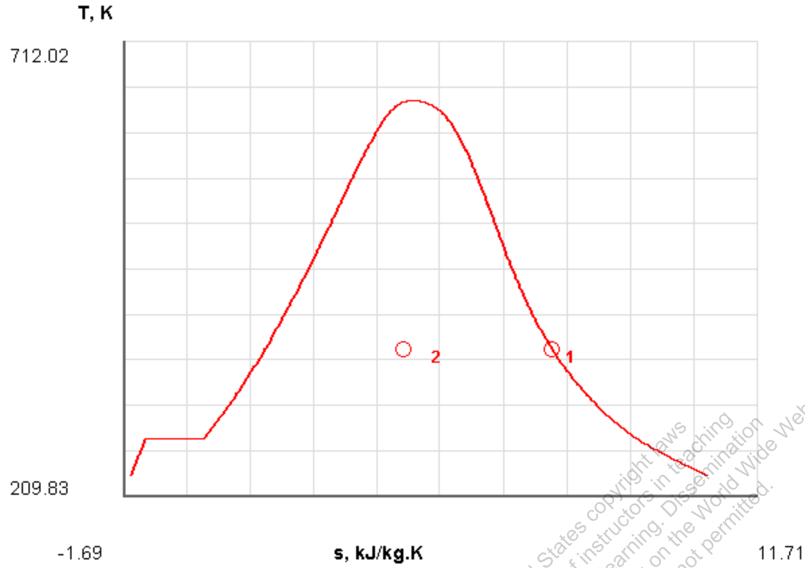
$$\Rightarrow W_B = 225.2\ \text{kJ}$$

TEST Solution:

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

5-1-33 [OSY] A frictionless piston-cylinder device contains 1 m^3 of saturated steam at 100°C. During a constant pressure process, 700 kJ of heat is transferred to the surrounding air at 25°C. As a result, part of the water vapor contained in the cylinder condenses. Determine (a) the entropy change (ΔS) of the water and (b) the total entropy generated (S_{gen}) during this heat transfer process.

SOLUTION



Given:

$T_B = 25°\text{C};$

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

$$v_1 = 1.6729\ \frac{\text{m}^3}{\text{kg}};\quad u_1 = 2506.5\ \frac{\text{kJ}}{\text{kg}};\quad h_1 = 2676.1\ \frac{\text{kJ}}{\text{kg}};\quad s_1 = 7.3549\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{1}{1.6729} = 0.5978\ \text{kg};$$

State-2 (given $p_2 = p_1, m_2 = m_1$):

$$Q = m(h_2 - h_1);$$

$$\Rightarrow -700 = (0.5978)(h_2 - 2676.1);$$

$$\Rightarrow h_2 = 1505.1\ \frac{\text{kJ}}{\text{kg}};$$

$$h_f = 419.04 \ \frac{\text{kJ}}{\text{kg}}; \qquad h_{fg} = 2257.06 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 1.3069 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \qquad s_{fg} = 6.048 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$x_2 = \frac{h_2 - h_f}{h_{fg}} = \frac{1505.1 - 419.04}{2257.06} = 0.481;$$

$$s_2 = s_f + x_2 s_{fg} = 1.3069 + (0.481)(6.048) = 4.216 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = (0.5978)(4.216 - 7.3549);$$

$$\Rightarrow \Delta S = -1.876 \ \frac{\text{kJ}}{\text{K}}$$

(b) The rate of entropy generation

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

$$\Rightarrow S_{\text{gen,univ}} = -1.876 - \frac{-700}{298};$$

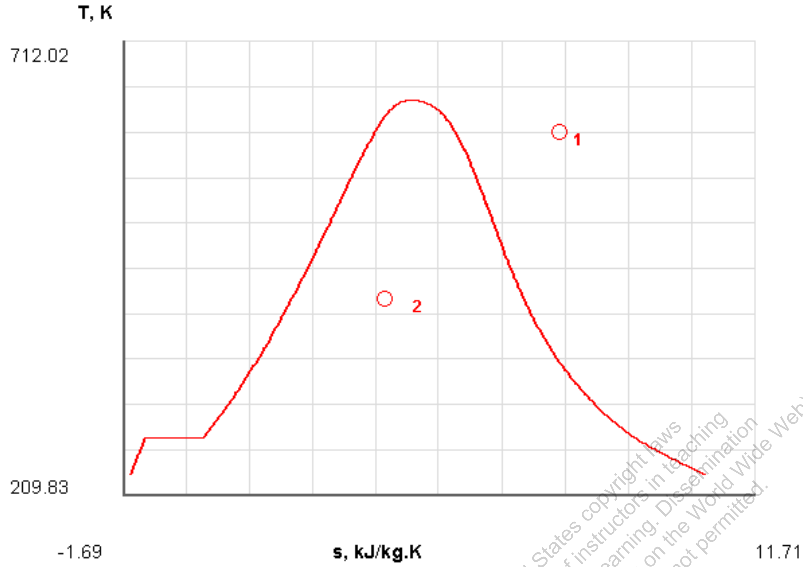
$$\Rightarrow S_{\text{gen,univ}} = 0.473 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-34 [OSF] A frictionless piston-cylinder device contains 10 kg of superheated vapor at 550 kPa and 340°C. Steam is now cooled at constant pressure until 60 percent of it, by mass, condenses. Determine (a) the work done during the process. (b) ***What-if scenario:*** How would the answer in (a) change if steam is cooled at constant pressure until 80 percent of it, by mass, condenses.

SOLUTION



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

$$v_1 = 0.50918 \ \frac{\text{m}^3}{\text{kg}}; \qquad \cancel{V}_1 = 5.0918 \text{ m}^3;$$

State-2 (given $p_2 = p_1$, x_2, $m_2 = m_1$):

$$v_f = 0.001097 \ \frac{\text{m}^3}{\text{kg}}; \qquad v_{fg} = 0.3416 \ \frac{\text{m}^3}{\text{kg}};$$

$$v_2 = v_f + xv_{fg} = 0.001097 + (0.4)(0.3416) = 0.138 \ \frac{\text{m}^3}{\text{kg}};$$

(a) Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \cancel{V}$ diagram

$$W_B = p_1(\cancel{V}_2 - \cancel{V}_1);$$

$$\Rightarrow W_B = p_1 m(v_2 - v_1);$$

$$\Rightarrow W_B = (550)(10)(0.138 - 0.50918);$$

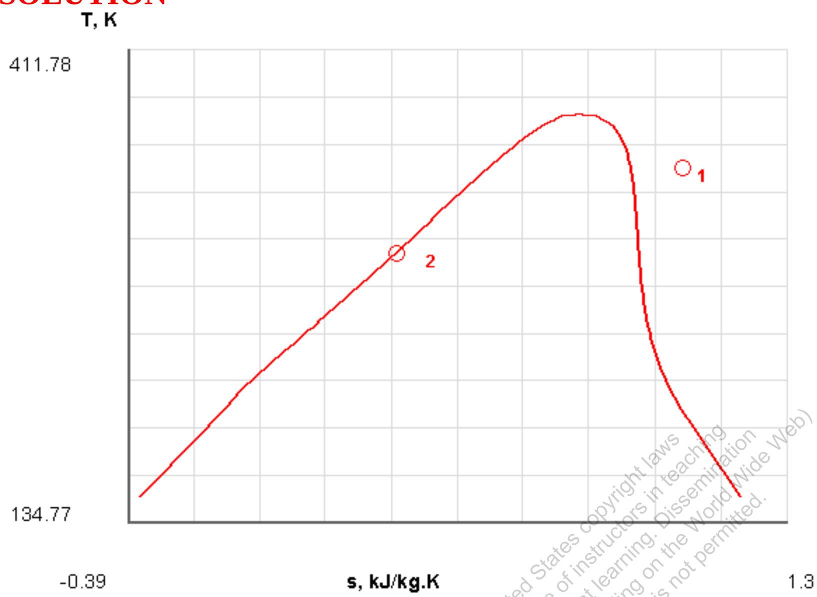
$$\Rightarrow W_B = -2041.5 \text{ kJ}$$

TEST Solution and What-if Scenario:

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

5-1-35 [OSD] A piston-cylinder device contains 8 kg of refrigerant-134a at 850 kPa and 70 °C. The refrigerant is now cooled at constant pressure until it comes to thermal equilibrium with the atmosphere, which is at 20°C. Determine the amount of (a) heat transfer, (b) entropy transfer into the atmosphere, (c) the change of entropy of the refrigerant, and (d) the entropy generated in the system's universe.

SOLUTION



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

$$v_1 = 0.02929\ \frac{\text{m}^3}{\text{kg}};\qquad u_1 = 280.66\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 1.0316\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_1,\ m_2 = m_1,\ T_2$):

$$v_2 = 0.00082\ \frac{\text{m}^3}{\text{kg}};\qquad u_2 = 78.04\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 0.2972\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p-\mathcal{V}$ diagram.

$$W_B = p_1\left(\mathcal{V}_2 - \mathcal{V}_1\right);$$

$$\Rightarrow W_B = p_1 m\left(v_2 - v_1\right);$$

$$\Rightarrow W_B = (850)(8)(0.00082 - 0.02929);$$

$$\Rightarrow W_B = -193.59\ \text{kJ};$$

(a) The energy equation yields

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \left(W_B + \cancel{W_O}^{0}\right);$$

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

$$\Rightarrow Q = m\left(u_2 - u_1\right) + W_B;$$

$$\Rightarrow Q = (8)(78.04 - 280.66) - 193.59;$$

$$\Rightarrow Q = -1814.55 \text{ kJ}$$

(b) The amount of entropy transfer into the atmosphere

$$\frac{Q}{T_B} = \frac{-1814.55}{293} = -6.193 \frac{\text{kJ}}{\text{K}}$$

(c) The change in entropy

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

$$\Rightarrow \Delta S = (8)(0.2972 - 1.0316);$$

$$\Rightarrow \Delta S = -5.875 \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = -5.875 - (-6.193);$$

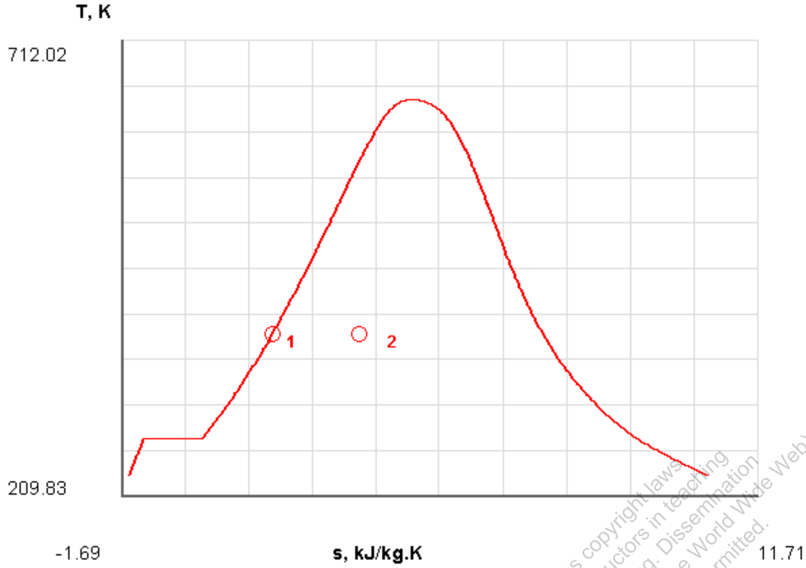
$$\Rightarrow S_{\text{gen,univ}} = 0.3178 \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-36 [OSM] An insulated piston-cylinder device contains 3 L of saturated liquid water at a constant pressure 180 kPa. An electric resistance heater inside the cylinder is now turned on, and 2000 kJ of energy is transferred to the steam. Determine (a) final temperature, (b) the boundary work, and (c) entropy change of water in this process.

SOLUTION



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

$$v_1 = 0.00106 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 490.44 \ \frac{\text{kJ}}{\text{kg}}; \quad h_1 = 490.63 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 1.494 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.003}{0.00106} = 2.83 \text{ kg};$$

State-2 (given $p_2 = p_1, m_2 = m_1$):

$$h_f = 490.63 \ \frac{\text{kJ}}{\text{kg}}; \quad h_{fg} = 2211.18 \ \frac{\text{kJ}}{\text{kg}};$$

$$Q = \Delta U = m(h_2 - h_1);$$

$$\Rightarrow 2000 = (2.83)(h_2 - 490.63);$$

$$\Rightarrow h_2 = 1197.34 \ \frac{\text{kJ}}{\text{kg}};$$

$$x_2 = \frac{h_2 - h_f}{h_{fg}} = \frac{1197.34 - 490.63}{2211.18} = 0.319$$

$$s_f = 1.494\ \frac{\text{kJ}}{\text{kg.K}};\quad s_{fg} = 5.6477\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$s_2 = s_f + x_2 s_{fg} = 3.30\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_f = 0.00106\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad v_{fg} = 0.9439\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$v_2 = v_f + x_2 v_{fg} = 0.302\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\cancel{V}_2 = m_2 \times v_2 = 0.854\ \text{m}^3;$$

(a) $T_2 = 116.92^{\text{o}}\text{C}$

(b) Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \cancel{V}$ diagram.

$$W_B = p_1\left(\cancel{V}_2 - \cancel{V}_1\right);$$

$$\Rightarrow W_B = (180)(0.851);$$

$$\Rightarrow W_B = 153.2\ \text{kJ}$$

(c) The change in entropy

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

$$\Rightarrow \Delta S = (2.83)(3.30 - 1.494);$$

$$\Rightarrow \Delta S = 5.11\frac{\text{kJ}}{\text{K}};$$

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

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

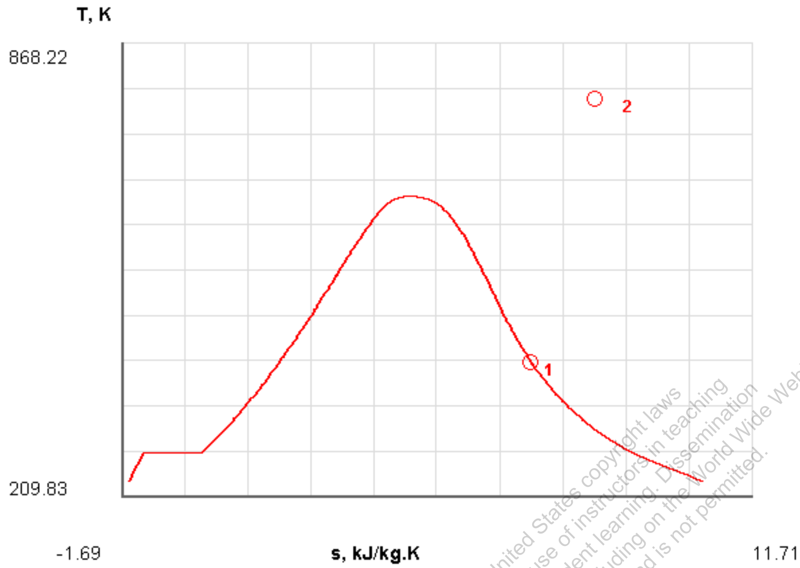
$$\Rightarrow S_{\text{gen,univ}} = 5.11\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-37 [OSJ] A piston-cylinder device initially contains 20 g of saturated water vapor at 300 kPa. A resistance heater is operated within the cylinder with a current of 0.4 A from a 240 V source until the volume doubles. At the same time a heat loss of 4 kJ occurs. Determine (a) the final temperature, (b) duration of the process. (c) ***What-if scenario:*** How would the answer in part (a) change if the piston-cylinder device initially contained saturated water?

SOLUTION



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

$$v_1 = 0.60582\ \frac{\text{m}^3}{\text{kg}};\qquad u_1 = 2543.55\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 6.9918\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2 (given $p_2 = p_1,\ m_2 = m_1,\ v_2 = 2v_1$):

$$v_2 = 1.2116\ \frac{\text{m}^3}{\text{kg}};\qquad u_2 = 3157.511\ \frac{\text{kJ}}{\text{kg}};\qquad s_2 = 8.367\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $T_2 = 516.14\ ^{\circ}\text{C}$

Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p-\mathcal{V}$ diagram.

$$W_B = p_1\left(\mathcal{V}_2 - \mathcal{V}_1\right);$$
$$\Rightarrow W_B = p_1 m\left(v_2 - v_1\right);$$
$$\Rightarrow W_B = (300)(0.02)(0.60682);$$
$$\Rightarrow W_B = 3.635\ \text{kJ};$$

The energy equation yields

$$\Delta U + \cancel{\Delta \mathrm{KE}}^{0} + \cancel{\Delta \mathrm{PE}}^{0} = Q - \left(W_B + W_{\mathrm{el}}\right);$$

$$\Rightarrow W_{\mathrm{el}} = Q - \Delta U - W_B;$$

$$\Rightarrow W_{\mathrm{el}} = Q - m\left(u_2 - u_1\right) - W_B;$$

$$\Rightarrow W_{\mathrm{el}} = -4 - \left[(0.02)(3157.5 - 2543.55)\right] - 3.635;$$

$$\Rightarrow W_{\mathrm{el}} = -19.914 \text{ kJ};$$

(b) Duration of the process

$$P = (0.4)(240) = 96 \text{ W};$$

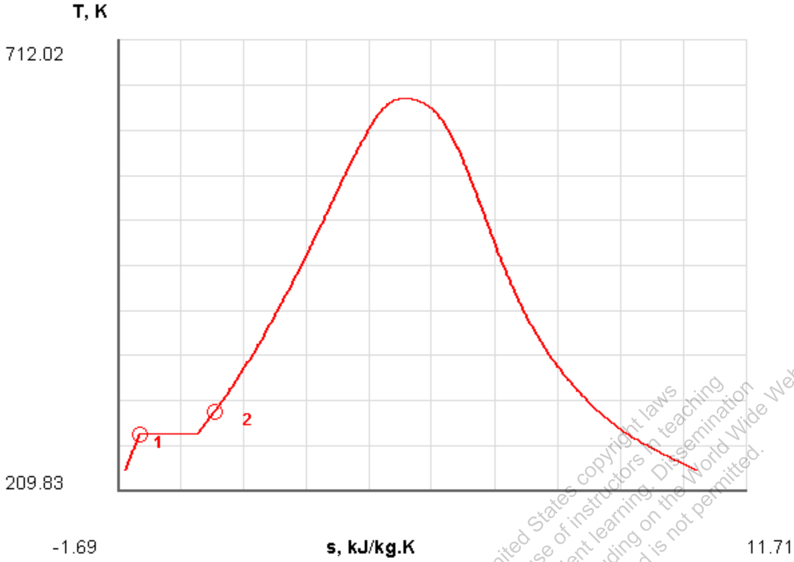
$$t = \frac{W_{\mathrm{el}}}{P} = \frac{19.914}{0.096} = 207.4 \text{ sec}$$

TEST Solution and What-if Scenario:

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

5-1-38 [OAO] An insulated container contains a block of ice of mass 1 ton (US) at 0°C. The insulation is removed, and the ice gradually melts to water and comes to thermal equilibrium with the surroundings at 25°C. Assuming the pressure to remain constant at 100 kPa, determine (a) the boundary work, and (b) the heat transfer during the process. (c) ***What-if scenario:*** By what percentage will the heat transfer increase if the initial temperature of the ice block was -25°C?

SOLUTION



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

$$v_1 = 0.00109 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = -333.45 \ \frac{\text{kJ}}{\text{kg}};$$

$$\mathcal{V}_1 = m_1 \times v_1 = 0.988 \ \text{m}^3;$$

State-2 (given $p_2 = p_1, T_2, \ m_2 = m_1$):

$$u_2 = 104.87 \ \frac{\text{kJ}}{\text{kg}}; \quad v_2 = 0.001 \ \frac{\text{m}^3}{\text{kg}};$$

$$\mathcal{V}_2 = m_2 \times v_2 = 0.91 \ \text{m}^3;$$

(a) Since the pressure remains constant during the process, the boundary work can be evaluated from the area under the $p - \mathcal{V}$ diagram.

$$W_B = p_1 \left(\mathcal{V}_2 - \mathcal{V}_1 \right);$$

$$\Rightarrow W_B = (100)(0.91 - 0.988);$$

$$\Rightarrow W_B = -7.8 \ \text{kJ}$$

(b) The energy equation yields

$$Q = \Delta U;$$

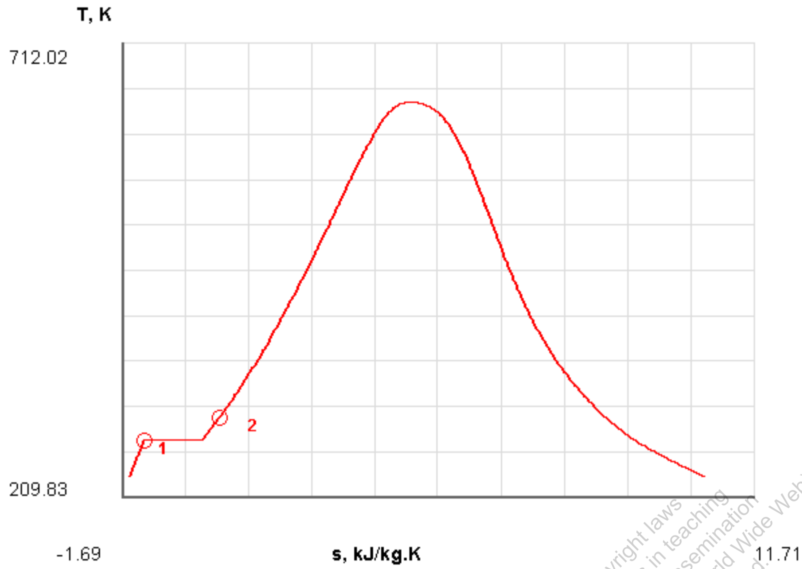
$$\Rightarrow Q = m\left(u_2 - u_1\right);$$
$$\Rightarrow Q = \left(907.2\right)\left(104.87 + 333.45\right);$$
$$\Rightarrow Q = 397.644 \text{ MJ}$$

TEST Solution and What-if Scenario:

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

5-1-39 [OSW] In the problem described above, determine (a) the change of entropy of the system, (b) the entropy transfer from the surroundings, and (c) the entropy generation in the system's universe during the process.

SOLUTION



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

$$v_1 = 0.00109 \ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = -333.45 \ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = -1.221 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$V_1 = m_1 \times v_1 = 0.988 \ \text{m}^3;$$

State-2 (given $p_2 = p_1, T_2, m_2 = m_1$):

$$v_2 = 0.001 \ \frac{\text{m}^3}{\text{kg}}; \quad u_2 = 104.87 \ \frac{\text{kJ}}{\text{kg}}; \quad s_2 = 0.3673 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$V_2 = m_2 \times v_2 = 0.91 \ \text{m}^3;$$

The energy equation yields

$$Q = \Delta U;$$

$$\Rightarrow Q = m(u_2 - u_1);$$

$$\Rightarrow Q = (907.2)(104.87 + 333.45);$$

$$\Rightarrow Q = 397.644 \ \text{MJ};$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = (907.2)(0.3673 + 1.221);$$

$$\Rightarrow \Delta S = 1441\,\frac{\text{kJ}}{\text{K}}$$

(b) The amount of entropy transfer into the atmosphere

$$\frac{Q}{T_B} = \frac{397644}{298} = 1334\,\frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = 1441 - 1334;$$

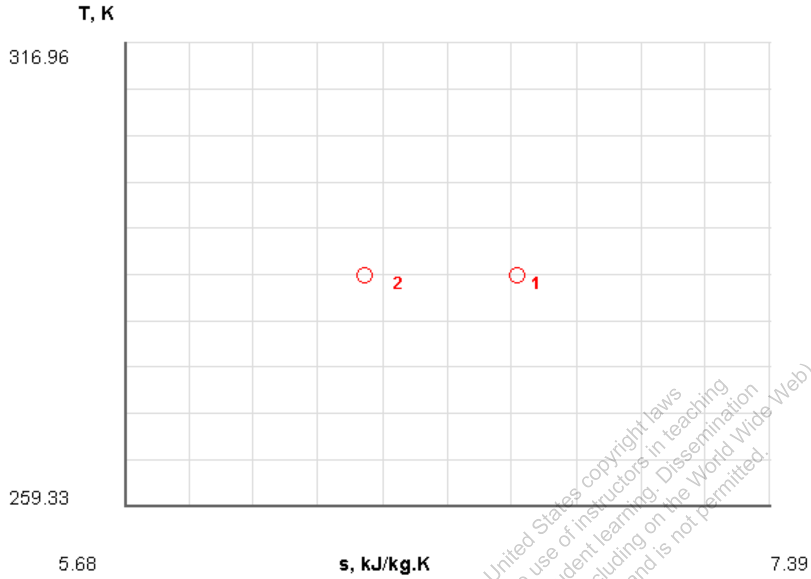
$$\Rightarrow S_{\text{gen,univ}} = 107\,\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-40 [OAR] A mass of 1.5 kg of air at 160 kPa and 15°C is contained in a gas-tight, frictionless piston-cylinder device. The air is now compressed to a final pressure of 650 kPa. During the process heat is transferred from the air such that the temperature inside the cylinder remains constant. (a) Calculate the work done during this process. Use the PG model for air. (b) ***What-if scenario:*** How would the answer change if the IG model was used?

SOLUTION



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

$$\mathcal{V}_1 = \frac{mRT_1}{p_1} = \frac{(1.5)(0.287)(288)}{(160)} = 0.7749 \text{ m}^3;$$

State-2 (given $p_2,\ T_2 = T_1,\ m_2 = m_1$):

$$\mathcal{V}_2 = \frac{mRT_2}{p_2} = \frac{(1.5)(0.287)(288)}{(650)} = 0.1907 \text{ m}^3;$$

(a) The boundary work is as follows

$$W_B = \int_1^2 p\,d\mathcal{V} = \int_1^2 \frac{C}{\mathcal{V}}d\mathcal{V} = C\int_1^2 \frac{d\mathcal{V}}{\mathcal{V}} = C\ln\frac{\mathcal{V}_2}{\mathcal{V}_1} = p_1\mathcal{V}_1\ln\frac{\mathcal{V}_2}{\mathcal{V}_1};$$

$$\Rightarrow W_B = p_1\mathcal{V}_1\ln\frac{\mathcal{V}_2}{\mathcal{V}_1};$$

$$\Rightarrow W_B = (160)(0.7749)\ln\frac{(0.1907)}{(0.7749)};$$

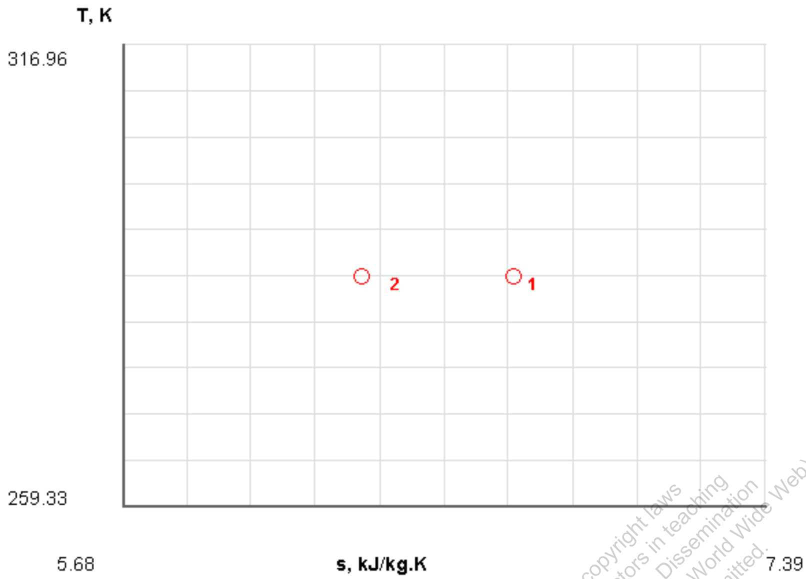
$$\Rightarrow W_B = -173.83 \text{ kJ}$$

TEST Solution and What-if Scenario:

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

5-1-41 [OAA] In the above problem determine (a) the change of entropy of the air, (b) the entropy transferred into the atmosphere at 10 °C, and (c) the entropy generation in the system's universe during the compression process.

SOLUTION



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

$$\mathcal{V}_1 = \frac{mRT_1}{p_1} = \frac{(1.5)(0.287)(288)}{(160)} = 0.7749 \text{ m}^3;$$

State-2 (given p_2, $m_2 = m_1, T_2 = T_1$):

$$\mathcal{V}_2 = \frac{mRT_2}{p_2} = \frac{(1.5)(0.287)(288)}{(650)} = 0.1907 \text{ m}^3;$$

$$W_B = \int_1^2 p\,d\mathcal{V} = \int_1^2 \frac{C}{\mathcal{V}} d\mathcal{V} = C\int_1^2 \frac{d\mathcal{V}}{\mathcal{V}} = C \ln\frac{\mathcal{V}_2}{\mathcal{V}_1} = p_1\mathcal{V}_1 \ln\frac{\mathcal{V}_2}{\mathcal{V}_1};$$

$$\Rightarrow W_B = p_1\mathcal{V}_1 \ln\frac{\mathcal{V}_2}{\mathcal{V}_1};$$

$$\Rightarrow W_B = (160)(0.7749)\ln\frac{(0.1907)}{(0.7749)};$$

$$\Rightarrow W_B = -173.83 \text{ kJ} \therefore Q_{\text{out}} = 173.83 \text{ kJ}$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = m\left(c_v \ln \frac{T_2}{T_1} + R \ln \frac{\cancel{V_2}}{\cancel{V_1}} \right);$$

$$\Rightarrow \Delta S = -0.603 \frac{\text{kJ}}{\text{K}}$$

(b) The amount of entropy transfer into the atmosphere

$$\frac{Q_{\text{out}}}{T_B} = \frac{173.83}{283} = 0.614 \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = -0.603 + 0.614;$$

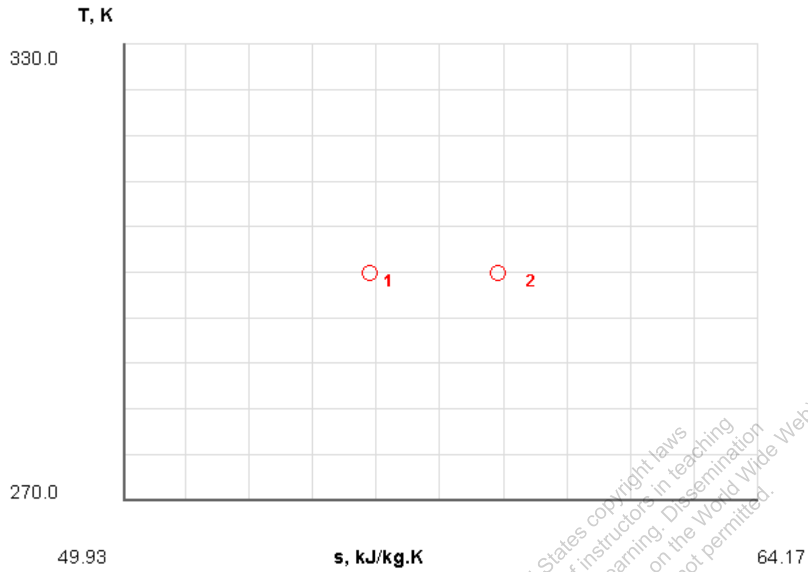
$$\Rightarrow S_{\text{gen,univ}} = 0.0112 \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-42 [BEM] A piston-cylinder device contains 0.1 kg of a gas (PG model: c_v = 10.18, k = 1.4, R= 4.12 kJ/kg-K) at 1000 kPa and 300 K. The gas undergoes an isothermal (constant temperature) expansion process to a final pressure of 500 kPa. (a) Determine the boundary work and (b) the heat transfer. (c) If heat is transferred from the surroundings at 300 K, determine the entropy generation during the expansion process.

SOLUTION



Given:

$$c_p = 14.31 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_v = 10.18 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 4.12 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.4;$$

State-1 (given p_1, T_1):

$$p_1 v_1 = RT_1; \quad \Rightarrow v_1 = \frac{RT_1}{p_1} = \frac{(4.12)(300)}{(1000)} = 1.236 \ \frac{\text{m}^3}{\text{kg}};$$

$$\cancel{V}_1 = (0.1)(1.236) = 0.1236 \ \text{m}^3;$$

State-2 (given $p_2, T_2 = T_1$):

$$p_2 v_2 = RT_2; \quad \Rightarrow v_2 = \frac{RT_2}{p_2} = \frac{(4.12)(300)}{(500)} = 2.472 \ \frac{\text{m}^3}{\text{kg}};$$

$$\cancel{V}_2 = (0.1)(2.472) = 0.2472 \ \text{m}^3;$$

(a) The boundary work follows as

$$W_B = \int_1^2 p d\cancel{V} = \int_1^2 \frac{C}{\cancel{V}} d\cancel{V} = C\int_1^2 \frac{d\cancel{V}}{\cancel{V}} = C \ln \frac{\cancel{V}_2}{\cancel{V}_1} = p_1 \cancel{V}_1 \ln \frac{\cancel{V}_2}{\cancel{V}_1};$$

$$\Rightarrow W_B = (1000)(0.1236)(\ln 2);$$

$$\Rightarrow W_B = 85.67 \text{ kJ}$$

(b) The energy equation provides

$$\cancel{\Delta E}^{0} = Q - W_{\text{ext}};$$

$$\Rightarrow 0 = Q - 85.67;$$

$$\Rightarrow Q = 85.67 \text{ kJ}$$

(c) The entropy equation provides

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

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

$$\Rightarrow S_{\text{gen,univ}} = m\left(c_p \cancel{\ln \frac{T_2}{T_1}}^{0} - R \ln \frac{p_2}{p_1}\right) - \frac{Q}{T_B};$$

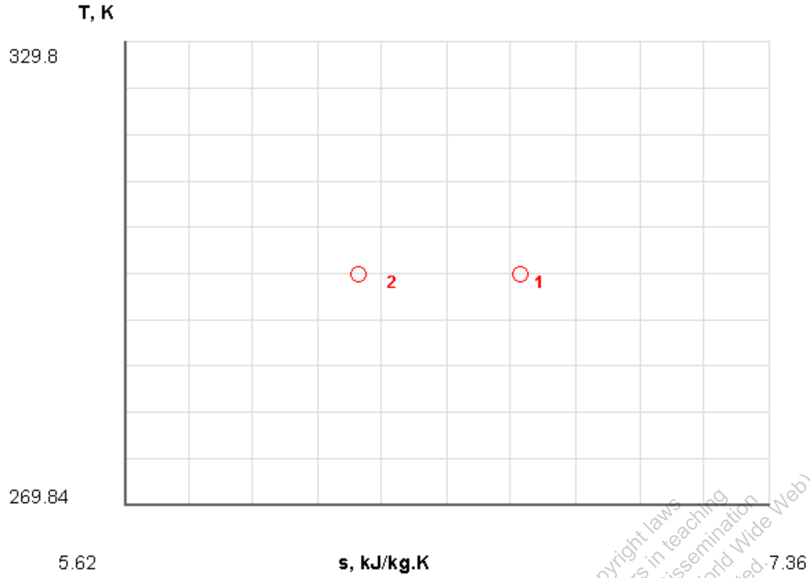
$$\Rightarrow S_{\text{gen,univ}} = (0.1)\left(0 - 4.12 \ln \frac{500}{1000}\right) - \frac{85.67}{300};$$

$$\Rightarrow S_{\text{gen,univ}} \cong 0 \ \frac{\text{kJ}}{\text{K}}$$

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

5-1-43 [OAB] Nitrogen at an initial state of 80°F, 25 psia and 6 ft^3 is pressed slowly in an isothermal process to a final pressure of 110 psia. Determine (a) the work done during the process. (b) ***What-if scenario:*** How would the answer change if pressure was 100 psia?

SOLUTION



Given:

$$R = 0.386 \ \frac{\text{psia}\cdot\text{ft}^3}{\text{lbm}\cdot\text{R}};$$

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

$$m_1 = \frac{p_1\mathcal{V}_1}{RT_1} = \frac{(25)(6)}{(0.386)(539.67)} = 0.72 \text{ lbm};$$

State-2 (given $p_2, T_2 = T_1, m_2 = m_1$):

$$\mathcal{V}_2 = \frac{mRT_2}{p_2} = \frac{(0.72)(0.386)(539.67)}{(110)} = 1.36 \text{ ft}^3;$$

(a) The boundary work is as follows

$$W_B = \int_1^2 p\,d\mathcal{V} = \int_1^2 \frac{C}{\mathcal{V}}d\mathcal{V} = C\int_1^2 \frac{d\mathcal{V}}{\mathcal{V}} = C\ln\frac{\mathcal{V}_2}{\mathcal{V}_1} = p_1\mathcal{V}_1\ln\frac{\mathcal{V}_2}{\mathcal{V}_1};$$

$$\Rightarrow W_B = p_1\mathcal{V}_1\ln\frac{\mathcal{V}_2}{\mathcal{V}_1};$$

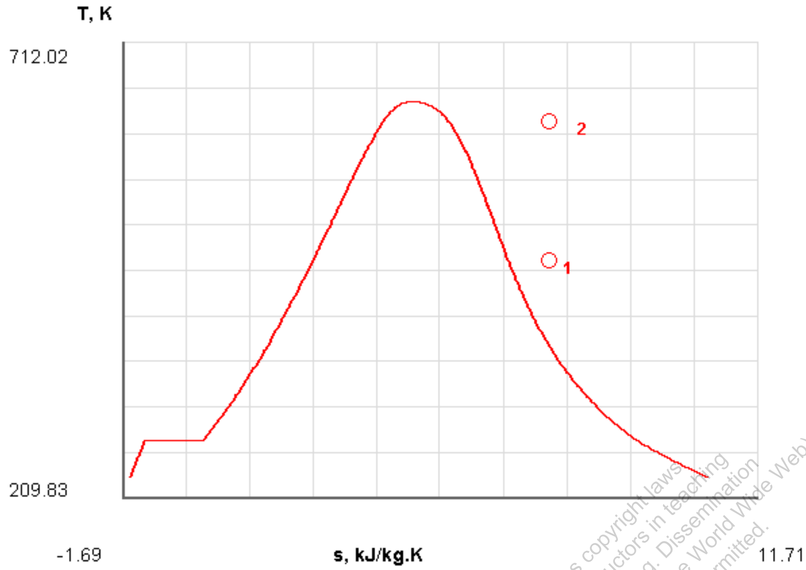
$$\Rightarrow W_B = (25)(6)\ln\frac{(1.36)}{(6)};$$

$$\Rightarrow W_B = -41.22 \text{ Btu}$$

TEST Solution and What-if Scenario:
Launch the IG uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-44 [OAS] An insulated piston-cylinder device contains 0.04 m^3 of steam at 300 kPa and 200^{o}C. Steam is now compressed in a reversible manner to a pressure of 1 MPa. Calculate (a) the work done. (c) ***What-if scenario:*** How would the answer change if the initial temperature was 800^{o}C?

SOLUTION



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

$$v_1 = 0.7163\ \frac{\text{m}^3}{\text{kg}}; \quad s_1 = 7.311\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{\cancel{V}_1}{v_1} = \frac{0.04}{0.7163} = 0.05584\ \text{kg};$$

State-2 (given p_2, $s_2 = s_1$, $m_2 = m_1$):

$$T_2 = 353.19^\text{o}\text{C};$$

$$\cancel{V}_2 = \frac{m_2 R T_2}{p_2} = 0.0158\ \text{m}^3;$$

(a) The boundary work is as follows

$$W_B = \int_1^2 p\,d\cancel{V} = \int_1^2 \frac{C}{\cancel{V}} d\cancel{V} = C\int_1^2 \frac{d\cancel{V}}{\cancel{V}} = C \ln\frac{\cancel{V}_2}{\cancel{V}_1} = p_1 \cancel{V}_1 \ln\frac{\cancel{V}_2}{\cancel{V}_1};$$

$$\Rightarrow W_B = p_1 \cancel{V}_1 \ln\frac{\cancel{V}_2}{\cancel{V}_1};$$

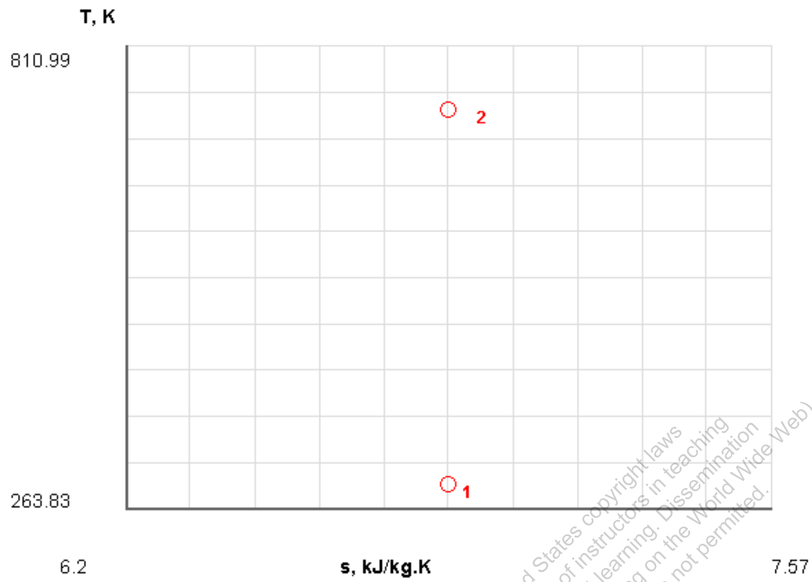
$$\Rightarrow W_B = (300)(0.04)\ln\frac{(0.0158)}{(0.04)};$$

$$\Rightarrow W_B = -11.3\ \text{kJ}$$

TEST Solution and What-if Scenario:
Launch the PC uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-45 [OAH] Air at 20°C, 95 kPa is compressed in a piston-cylinder device of volume 1 L in a frictionless and adiabatic manner. If the volumetric compression ratio is 10, determine (a) the final temperature, (b) the boundary work transfer. Use the PG model for air. (c) ***What-if scenario:*** How would the answer in part (b) change if the initial temperature was 45°?

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$k = 1.4;$$

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

$$s_1 = 6.884 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m_1 = \frac{p_1 \mathcal{V}_1}{RT_1} = \frac{(0.001)(95)}{(0.287)(293)} = 0.00113 \text{ m}^3;$$

State-2 (given $s_2 = \text{s}_1, \mathcal{V}_2 = \mathcal{V}_1/10,\ m_2 = m_1$)

(a) For an isentropic process

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{1-k};$$

$$\Rightarrow T_2 = T_1\left(\frac{v_1}{v_2}\right)^{1-k};$$

$$\Rightarrow T_2 = 293(10)^{0.4};$$

$$\Rightarrow T_2 = 735.98\text{ K} = 462.98°\text{C}$$

From the perfect gas relation

$$m_2RT_2 = \cancel{V_2}p_2;$$

$$\Rightarrow (0.00113)(0.287)(T_2) = (0.0001)p_2;$$

$$\Rightarrow p_2 = 3.2431T_2;$$

$$\Rightarrow p_2 = (3.2431)(735.98);$$

$$\Rightarrow p_2 = 2386.86\text{ kPa};$$

(b) $\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = \cancel{Q}^0 - \left(W_B - \cancel{W_O}^0\right);$

$$\Rightarrow W_B = -\Delta U;$$

$$\Rightarrow W_B = mc_v(T_1 - T_2);$$

$$\Rightarrow W_B = (0.00113)(0.717)(293 - 735.98);$$

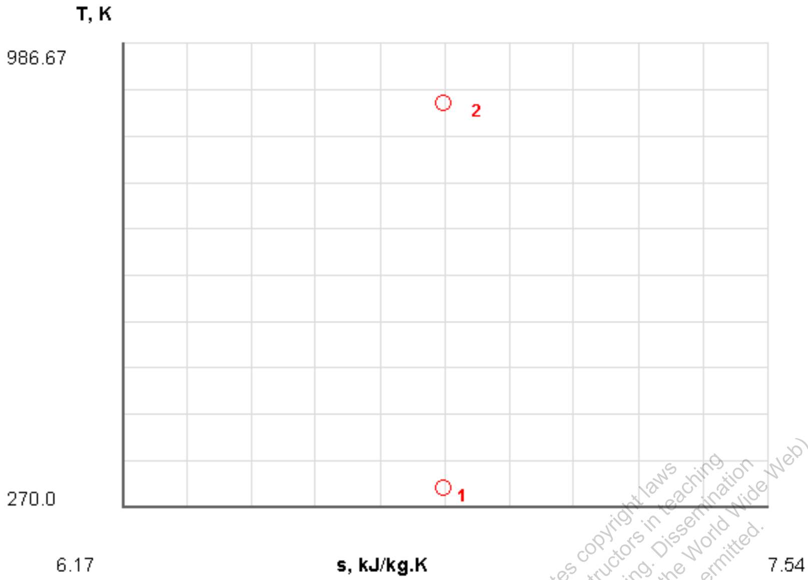
$$\Rightarrow W_B = -0.359\text{ kJ}$$

TEST Solution and What-if Scenario:

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

5-1-46 [BVM] Nitrogen at 300 K, 100 kPa is compressed in a piston-cylinder device of volume 1 m^3 in a frictionless and adiabatic manner. If the volumetric compression ratio is 15, determine (a) the final pressure and (b) the boundary work transfer. Use the PG model.

SOLUTION



Given:
$k = 1.404;$

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

State-2 (given $s_2 = s_1, \cancel{V}_2 = \cancel{V}_1 / 15$)

(a) Using the isentropic relation

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

$$\Rightarrow p_2 = 100(15)^{1.404};$$

$$\Rightarrow p_2 = 4479.5 \text{ kPa}$$

(b) $W_B = \dfrac{p_2 \cancel{V}_2 - p_1 \cancel{V}_1}{1-k};$

$$\Rightarrow W_B = \frac{(4479.5)(0.0667)-(100)(1)}{(1-1.404)};$$

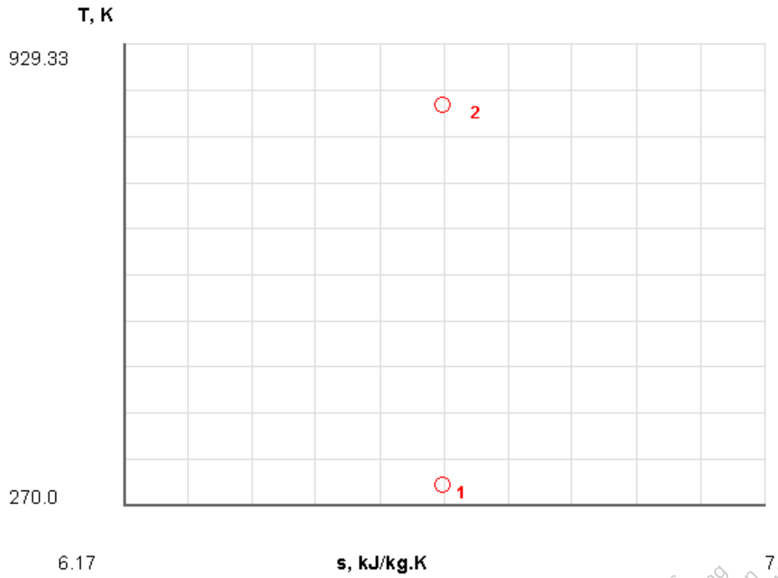
$$\Rightarrow W_B = -492 \text{ kJ}$$

TEST Solution:

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

5-1-47 [BVJ] Solve the previous problem,5-1-46[BVM], using the IG model.

SOLUTION



Given:

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

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

$$u_1 = u(p_1, T_1) = -87.5557 \ \frac{\text{kJ}}{\text{kg}};$$

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)(1)}{(0.297)(300)} = 1.122 \text{ kg};$$

State-2 (given $s_2 = s_1, \cancel{V}_2 = \cancel{V}_1 / 15, m_2 = m_1$):

$$v_2 = \frac{\cancel{V}_2}{m_2} = 0.059 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_2 = u(v_2, s_2) = 340.4997 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $p_2 = p(v_2, s_2) = 4224.2 \text{ kPa}$

(b) From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^{0} + \cancel{\Delta \text{PE}}^{0} = Q - \left(W_B + \cancel{W_O}^{0}\right);$$

$$\Rightarrow W_B = -\Delta U;$$

$$\Rightarrow W_B = m(u_1 - u_2);$$

$$\Rightarrow W_B = (1.122)(-87.5557 - 340.4997);$$

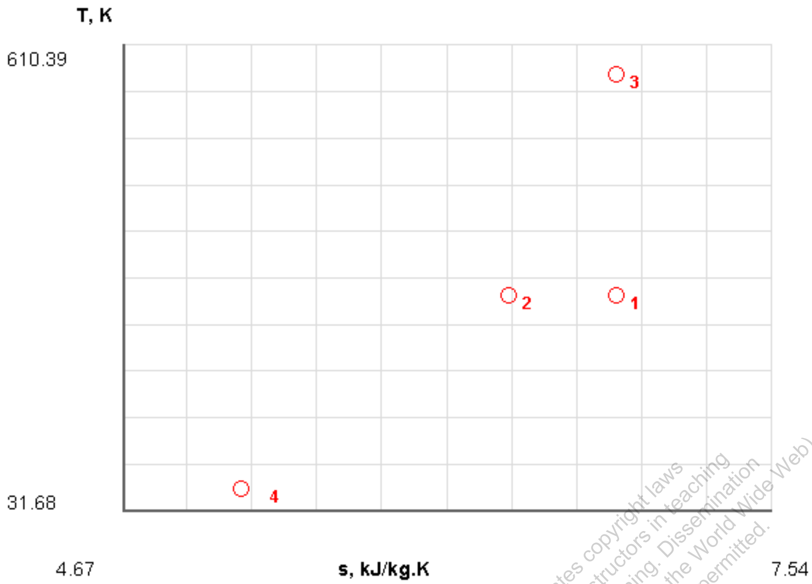
$$\Rightarrow W_B = -480 \text{ kJ}$$

TEST Solution:

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

5-1-48 [OAN] A piston-cylinder device initially contains 0.1 m^3 of N_2 at 100 kPa and 300 K. Determine the work transfer involved in compressing the gas to one-fifth of its original volume in an (a) isothermal, (b) isentropic, and (c) isobaric manner. Show the process on a p-v diagram.

SOLUTION



Given:

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

$$k = 1.404;$$

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

$$m_1 = \frac{p_1 V_1}{RT_1} = \frac{(100)(0.1)}{(0.297)(300)} = 0.1122\ \text{kg};$$

State-2 (given $T_2 = T_1, V_2 = V_1/5, m_2 = m_1$)

State-3 (given $s_3 = s_1, V_3 = V_1/5, m_3 = m_1$)

State-4 (given $p_4 = p_1, V_4 = V_1/5, m_4 = m_1$)

The isothermal path is shown on the diagram from state-1 to state-2. The work from 1-2 is the area under the curve. For the isothermal case

(a) $W_B = mRT\ln\left(\frac{v_2}{v_1}\right);$

$$\Rightarrow W_B = (0.1122)(0.297)(300)\ln(5);$$

$$\Rightarrow W_B = -16.09 \text{ kJ}$$

The isentropic path is shown on the diagram from state-1 to state-3. From the isentropic relation

$$p_3 = p_1\left(\frac{v_1}{v_3}\right)^k;$$

$$\Rightarrow p_3 = 100(5)^{1.404};$$

$$\Rightarrow p_3 = 951.8 \text{ kPa};$$

(b) $$W_B = \frac{p_3 V_3 - p_1 V_1}{1-k};$$

$$\Rightarrow W_B = \frac{(951.8)(0.02)-(100)(0.1)}{(1-1.404)};$$

$$\Rightarrow W_B = -22.37 \text{ kJ}$$

(c) The isobaric path is shown on the diagram from state-1 to state-4. The boundary work is easily computed by calculating the area under the curve on the *p-v* diagram:

$$W_B = p(V_4 - V_1);$$

$$\Rightarrow W_B = 100(0.02-0.1);$$

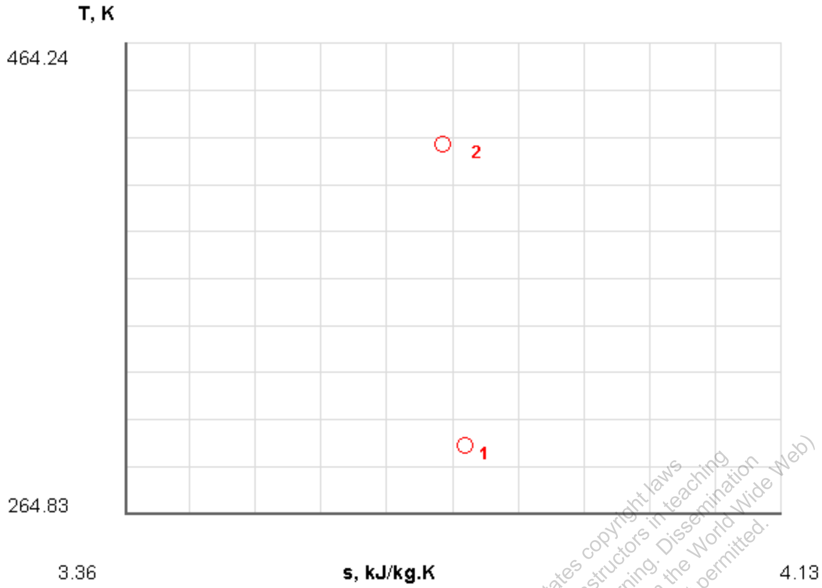
$$\Rightarrow W_B = -8 \text{ kJ}$$

TEST Solution and What-if Scenario:

Launch the PG/IG uniform system closed process TESTcalc to verify the solution and conduct the what-if study. The TEST-code for this problem can be found in the TEST-Pro site at www.thermofluids.net.

5-1-49 [OAI] A piston-cylinder device initially contains 10 ft^3 of argon gas at 25 psia and 70^oF. Argon is now compressed in a polytropic process (pV^n = constant) to 70 psia and 300^oF. Determine (a) if the process is 1: reversible, 2: impossible or 3: irreversible. (b) Also determine the change of entropy for argon.

SOLUTION



Given:

$$R = 0.268 \ \frac{\text{psia}\cdot\text{ft}^3}{\text{lbm}\cdot\text{R}};$$

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

$$s_1 = s\left(p_1, T_1\right) = 0.89769 \ \frac{\text{Btu}}{\text{lbm}\cdot\text{R}};$$

$$m_1 = \frac{p_1\mathcal{V}_1}{RT_1} = \frac{(25)(10)}{(0.268)(529.67)} = 1.757 \text{ lbm};$$

State-2 (given p_2, T_2):

$$s_2 = s\left(p_2, T_2\right) = 0.89133 \ \frac{\text{Btu}}{\text{lbm}\cdot\text{R}};$$

$$\mathcal{V}_2 = \frac{m_2RT_2}{p_2} = 5.122 \text{ ft}^3;$$

For a polytropic process:

$$p_1\mathcal{V}_1^n = p_2\mathcal{V}_2^n; \quad \Rightarrow n = 1.54$$

The boundary work is given as:

$$W_B = \int_1^2 p d\cancel{V} = \frac{p_2 \cancel{V}_2 - p_1 \cancel{V}_1}{1-n} = -29007 \text{ ft} \cdot \text{lbf}$$

The energy equation for this closed process yields:

$$\Delta U = Q - W_{\text{ext}};$$

$$\Rightarrow Q = mc_v \left(T_2 - T_1\right) + W_B = -7.14 \text{ Btu}$$

The process, therefore, is not adiabatic.

(b) The change in entropy

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

$$\Rightarrow \Delta S = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right) = -0.01 \frac{\text{Btu}}{\text{R}};$$

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

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B} = \Delta S - \frac{Q}{T_0};$$

$$\Rightarrow S_{\text{gen,univ}} = 0.0021 \frac{\text{Btu}}{\text{R}};$$

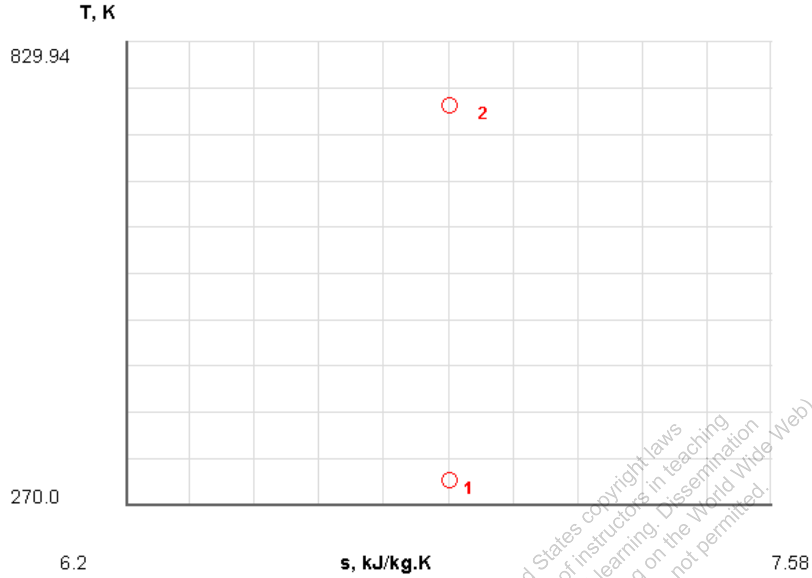
As entropy is generated, the process is irreversible.

TEST Solution:

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

5-1-50 [OAG] Air is compressed in a frictionless manner in an adiabatic piston-cylinder device from an initial volume of 1000 cc to the final volume of 100 cc. If the initial conditions are 100 kPa, 300 K, (a) what is the temperature (in K) right after the compression? (b) Determine the change in internal energy of the gas, and (c) the work transfer during the process.

SOLUTION



Given:

$$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$k = 1.4;$$

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

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)(0.001)}{(0.287)(300)} = 0.00116 \text{ kg};$$

State-2 (given $s_2 = s_1, \cancel{V}_2, m_2 = m_1$)

(a) From the isentropic relationship

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1};$$

$$\Rightarrow T_2 = 300(10)^{0.4};$$

$$\Rightarrow T_2 = 753.56 \text{ K}$$

(b) The change in internal energy of a perfect gas is as follows

$$\Delta U = m\Delta u;$$

$$\Rightarrow m\Delta u = mc_v\left(T_2 - T_1\right);$$

$$\Rightarrow \Delta U = \left(0.00116\right)\left(0.717\right)\left(753.56 - 300\right);$$

$$\Rightarrow T_2 = 0.377\ \text{kJ}$$

(c) From the energy balance equation

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

$$\Rightarrow W_{\text{ext}} = -\Delta U;$$

$$\Rightarrow W_{\text{ext}} = -0.377\ \text{kJ}$$

TEST Solution:

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

5-1-51 [OAE] 0.5 kg of air is compressed to 1/10th its original volume in a piston-cylinder device in an isentropic manner. If the original volume of the piston is 0.5 m^3, molar mass of air is 29 kg/kmol, and k=1.4, determine the final density. Use the PG model for air.

SOLUTION

State-1 (given $p_1, T_1, \cancel{V}_1, m_1$)

State-2 (given $s_2 = s_1, \cancel{V}_2 = \cancel{V}_1/10, m_2 = m_1$):

$$v_2 = \frac{\cancel{V}_2}{m_2} = \frac{0.05}{0.5} = 0.1 \ \frac{\text{m}^3}{\text{kg}};$$

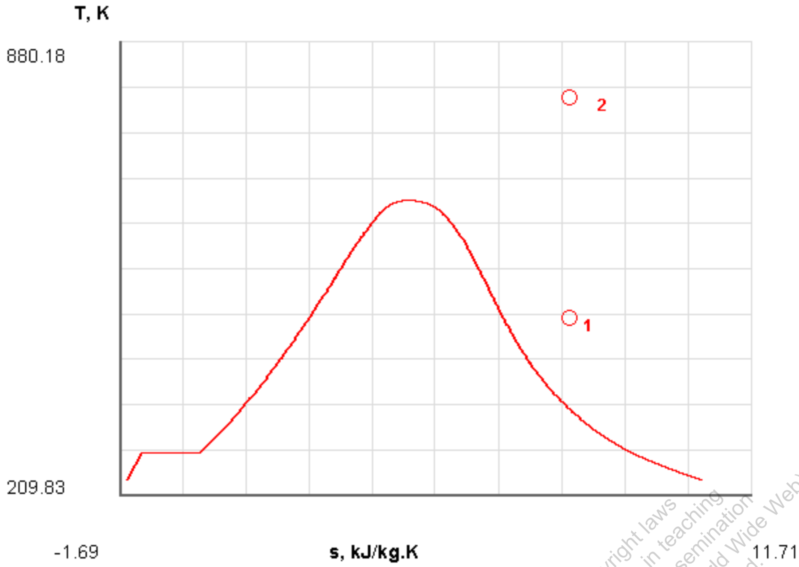
$$\rho_2 = v_2^{-1} = 10 \ \frac{\text{kg}}{\text{m}^3}$$

TEST Solution:

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

5-1-52 [OAL] Steam at 100 kPa 200°C is compressed to a pressure of 1 MPa in an isentropic manner. Determine the final temperature in Celsius using (a) the PC model, (b) the PG model with k = 1.327.

SOLUTION



Given:

$k = 1.327;$

State-1 (given p_1, T_1)

State-2 (given $p_2, s_2 = s_1, m_2 = m_1$)

$$s_1 = s(p_1, T_1) = 7.83416 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) Using the PC model

$$T_2 = T(p_2, s_2) = 527°\text{C}$$

(b) Using the PG model's isentropic relation

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

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

$$\Rightarrow T_2 = 473 \left(\frac{1000}{100} \right)^{\frac{0.327}{1.327}};$$

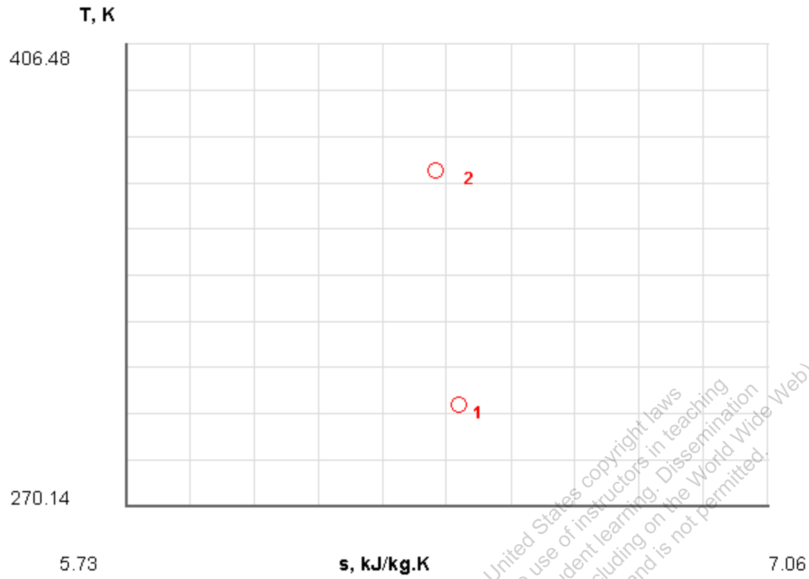
$$\Rightarrow T_2 = 834.22 \text{ K} = 561.22°\text{C}$$

TEST Solution:

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

5-1-53 [OAZ] A piston-cylinder device initially contains 0.8 kg of O_2 at 100 kPa and 27°C. It is now compressed in a polytropic process ($pV^{1.3}$ = constant) to half the original volume. Determine (a) the change of entropy for the system, (b) entropy transfer to the surroundings (at 27°C), and (c) the entropy generated in the system's universe due to this process. (d) ***What-if scenario:*** How would the answer in part (c) change if the surrounding temperature was 0°C?

SOLUTION



Given:

$$c_v = 0.643 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.2598 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$s_1 = 6.417 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\cancel{V}_1 = \frac{m_1 R T_1}{p_1} = \frac{(0.8)(0.2598)(300)}{(100)} = 0.623 \text{ m}^3;$$

State-2 (given $m_2 = m_1, \cancel{V}_2 = \cancel{V}_1 / 2$):

$$s_2 = 6.371 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$p_1 \cancel{V}_1^n = p_2 \cancel{V}_2^n;$$

$$\Rightarrow (100)(0.623)^{1.3} = (p_2)(0.311)^{1.3};$$

$$\Rightarrow p_2 = 245.96 \text{ kPa};$$

$$T_2 = \frac{\cancel{V}_2 p_2}{m_2 R} = \frac{(0.311)(245.96)}{(0.2598)(0.8)} = 368.04 \text{ K};$$

(a) The change in entropy

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

$$\Rightarrow \Delta S = m\left(c_v \ln\frac{T_2}{T_1} + R\ln\frac{\cancel{V}_2}{\cancel{V}_1}\right);$$

$$\Rightarrow \Delta S = -0.0368 \frac{\text{kJ}}{\text{K}}$$

To find the boundary work

$$W_B = \int_1^2 p d\cancel{V};$$

$$\Rightarrow W_B = \frac{p_2 \cancel{V}_2 - p_1 \cancel{V}_1}{1-n};$$

$$\Rightarrow W_B = \frac{mR(T_2 - T_1)}{1-n};$$

$$\Rightarrow W_B = \frac{(0.8)(0.2598)(368.04-300)}{1-1.3};$$

$$\Rightarrow W_B = -47.13 \text{ kJ};$$

From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(W_B + \cancel{W_O}^0\right);$$

$$\Rightarrow Q = m\left(u_2 - u_1\right) + W_B;$$

$$\Rightarrow Q = mc_v\left(T_2 - T_1\right) + W_B;$$

$$\Rightarrow Q = (0.8)(0.643)(368.04-300) - 47.13;$$

$$\Rightarrow Q = -12.13 \text{ kJ} \therefore Q_{\text{out}} = 12.13 \text{ kJ}$$

(b) The amount of entropy transfer into the atmosphere

$$\frac{Q_{\text{out}}}{T_B} = \frac{12.13}{300} = 0.0404 \frac{\text{kJ}}{\text{K}}$$

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

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

$$\Rightarrow S_{\text{gen,univ}} = -0.0368 + 0.0404;$$

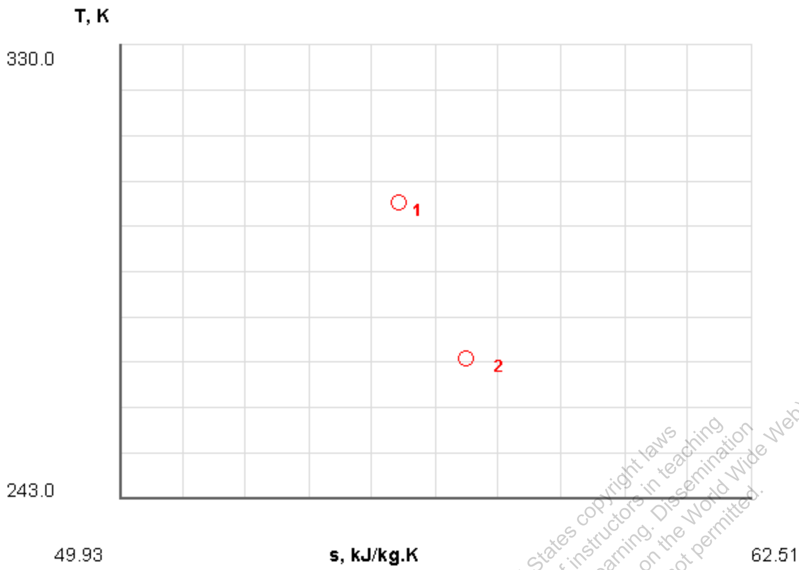
$$\Rightarrow S_{\text{gen,univ}} = 0.00363 \frac{\text{kJ}}{\text{K}}$$

TEST Solution and What-if Scenario:

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

5-1-54 [BED] A piston-cylinder device contains 0.1 kg of hydrogen gas (PG model: c_v = 10.18, k = 1.4, R= 4.12 kJ/kg-K) at 1000 kPa and 300 K. The gas undergoes an expansion process and the final conditions are 500 kPa, 270 K. If 10 kJ of heat is transferred into the gas from the surroundings at 300 K, determine (a) the boundary work, and (b) the entropy generated during the process.

SOLUTION



Given:

$$c_v = 10.18 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 4.12 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.4;$$

$$k = \frac{c_p}{c_v}; \qquad \Rightarrow c_p = 14.3 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$T_B = 300 \text{ K};$$

State-1 (given p_1, T_1)

State-2 (given p_2, T_2)

(a) From the energy balance equation

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(W_B + \cancel{W_O}^0\right);$$

$$\Rightarrow W_B = Q - m(u_2 - u_1);$$
$$\Rightarrow W_B = Q - mc_v(T_2 - T_1);$$
$$\Rightarrow W_B = (10) - (0.1)(10.18)(270 - 300);$$
$$\Rightarrow W_B = 40.54 \text{ kJ}$$

(b) From the entropy balance equation

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$
$$\Rightarrow m\Delta s = \frac{Q}{T_B} + S_{\text{gen,univ}};$$
$$\Rightarrow S_{\text{gen,univ}} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right) - \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = (0.1)\left[(14.3)\left(\ln\frac{270}{300}\right) - (4.12)\left(\ln\frac{500}{1000}\right)\right] - \left(\frac{10}{300}\right);$$
$$\Rightarrow S_{\text{gen,univ}} = 0.102 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-55 [BVW] Nitrogen at 300 K, 100 kPa is compressed in a piston-cylinder device of volume 1 m^3 in a polytropic manner. If the volumetric compression ratio is 15 and the final pressure after compression is measured as 3000 kPa, determine (a) the boundary work transfer (W_B) and (b) the entropy generated during the process (S_{gen}). Use the PG model.

SOLUTION

Given:

$$R = 0.269 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad c_v = 0.734 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$m_1 = \frac{p_1 V_1}{RT_1} = 1.126 \text{ kg};$$

State-2 (given p_2, V_2):

$$T_2 = \frac{p_2 V_2}{m_2 R} = 600 \text{ K};$$

For a polytropic process:

$$p_1 V_1^n = p_2 V_2^n; \quad \Rightarrow n = 1.256$$

The boundary work is given as:

$$W_B = \int_1^2 p dV = \frac{p_2 V_2 - p_1 V_1}{1-n} = -390.6 \text{ kJ}$$

The energy equation for this closed process yields:

$$\Delta U = Q - W_{\text{ext}};$$
$$\Rightarrow Q = mc_v\left(T_2 - T_1\right) + W_B = -143.4\text{ kJ}$$

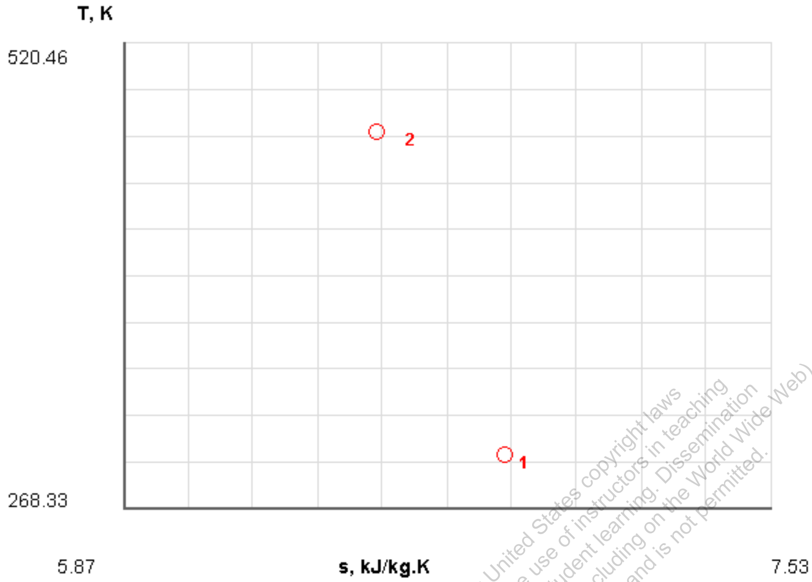
(b) The entropy equation for this closed process produces

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B} = m\left(s_2 - s_1\right) - \frac{Q}{T_0} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}\right) = 0.15\ \frac{\text{kJ}}{\text{K}}$$

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

5-1-56 [OAK] A cylinder fitted with a piston has an initial volume of 0.1 m^3 and contains nitrogen at 100 kPa, 25°C. The piston is moved, compressing the nitrogen until the pressure is 1.5 MPa and the temperature is 200°C. During this compression process heat is transferred from nitrogen to the atmosphere at 25°C, and the work done on the nitrogen is 30 kJ. Determine (a) the amount of this heat transfer, and (b) the entropy generation during the process. Use the PG model for nitrogen.

SOLUTION



Given:

$$c_v = 0.734 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_p = 1.031 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

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

$$m_1 = \frac{\cancel{V}_1 p_1}{RT_1} = \frac{(0.1)(100)}{(0.297)(298)} = 0.1122 \text{ kg};$$

State-2 (given p_2, T_2)

The energy equation for this closed process yields:

$$\Delta U = Q - W_{\text{ext}};$$

$$\Rightarrow Q = mc_v\left(T_2 - T_1\right) + W_B = -15.5 \text{ kJ}$$

The change in entropy

$\Delta S = m\Delta s;$

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

$$\Rightarrow \Delta S = (0.1133)\left[(1.031)\left(\ln\frac{473}{298}\right) - (0.297)\left(\ln\frac{1500}{100}\right)\right];$$

$$\Rightarrow \Delta S = -0.037\frac{\text{kJ}}{\text{K}};$$

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

$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B} = \Delta S - \frac{Q}{T_0};$$

$$\Rightarrow S_{\text{gen,univ}} = -0.037 - \left(\frac{-15.5}{298}\right);$$

$$\Rightarrow S_{\text{gen,univ}} = 0.015\frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-57 [OAP] A rubber ball of mass m is dropped from a height h on a rigid floor. It bounces back and forth and finally comes to rest on the floor. What is the entropy generation in the universe due to this irreversible phenomenon? Assume the atmospheric temperature to be T_0.

SOLUTION

Mass of rubber ball = m

Force required to drop the ball is mg

Work done will be

$$W_B = -\frac{mgh}{1000};$$

$\Delta S = 0;$ (As there is no entropy change)

$$Q = m(u_2 - u_1) + W_B;$$

$$\Rightarrow Q = (0) + \left(-\frac{mgh}{1000}\right);$$

$$\Rightarrow Q = -\frac{mgh}{1000};$$

The atmospheric temperature is given as T_0

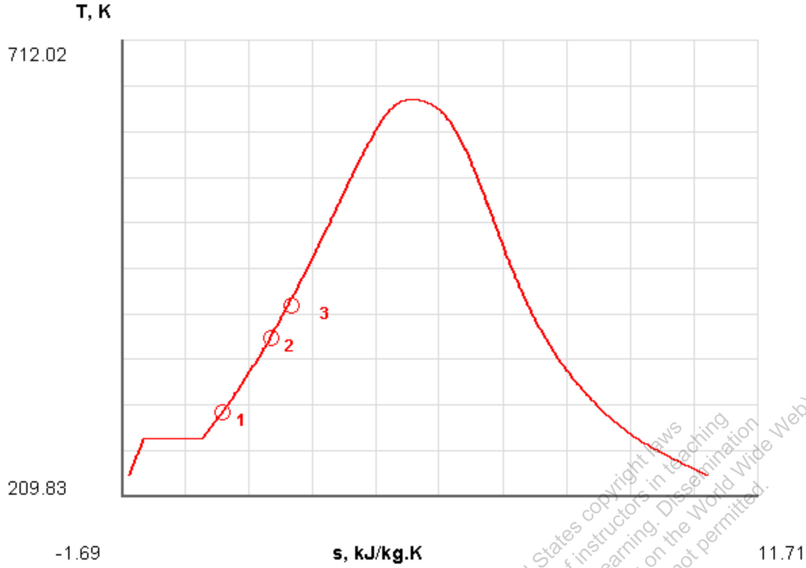
$$S_{\text{gen,univ}} = \Delta S - \frac{Q}{T_B};$$

$$\Rightarrow S_{\text{gen,univ}} = -\frac{\left(-\frac{mgh}{1000}\right)}{T_0};$$

$$\Rightarrow S_{\text{gen,univ}} = \frac{mgh}{1000T_0}\ \frac{\text{kJ}}{\text{K}}$$

5-1-58 [OAC] A piston-cylinder device contains 40 kg of water at 150 kPa and 30^o C. The cross-sectional area of the piston is 0.1 m^2. Heat is now added causing part of the water to evaporate. When the volume reaches 0.2 m^3, the piston reaches a linear spring with a spring constant of 120 kN/m. More heat is added until the piston moves by another 25 cm. Determine (a) the final pressure, (b) temperature, and (c) the total heat transfer.

SOLUTION



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

$$v_1 = 0.0010 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_1 = 125.78 \ \frac{\text{kJ}}{\text{kg}}; \qquad s_1 = 0.4369 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\mathcal{V}_1 = m_1 v_1 = (40)(0.0010) = 0.04 \text{ m}^3;$$

State-2 (given $p_2 = p_1, m_2 = m_1, \mathcal{V}_2$):

$$T_2 = T_{\text{sat@150 kPa}} = 384.37 \text{ K};$$

$$v_2 = \frac{\mathcal{V}_2}{m_2} = \frac{0.2}{40} = 0.005 \ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.005 - 0.001053}{1.158} = 0.0034;$$

$$u_f = 464.94 \ \frac{\text{kJ}}{\text{kg}}; \qquad u_{fg} = 2052.76 \ \frac{\text{kJ}}{\text{kg}};$$

$$u_2 = u_f + x_2 u_{fg} = (466.94) + (0.0034)(2052.76) = 473.91 \ \frac{\text{kJ}}{\text{kg}};$$

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

$$\mathcal{V}_3 = \mathcal{V}_2 + (0.25)(0.1) = 0.225 \text{ m}^3;$$

$$v_3 = \frac{\cancel{V}_3}{m_3} = \frac{0.225}{40} = 0.005625 \ \frac{\text{m}^3}{\text{kg}};$$

$$x_3 = \frac{v_3 - v_f}{v_{fg}} = \frac{0.005625 - 0.001088}{0.4129} = 0.01098;$$

$$u_f = 622.77 \ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 1934.83 \ \frac{\text{kJ}}{\text{kg}};$$

$$u_3 = u_f + x_3 u_{fg} = (622.77) + (0.01098)(1934.83) = 644.01 \ \frac{\text{kJ}}{\text{kg}};$$

Force applied by a linear spring at the final state is determined from

$$F = kx;$$

$$\Rightarrow F = (120000)(0.25);$$

$$\Rightarrow F = 30 \text{ kN};$$

Pressure applied by the spring on the gas at this state is

$$p = \frac{F}{A};$$

$$\Rightarrow p = \frac{30000}{0.1};$$

$$\Rightarrow p = 300000 \ \frac{\text{N}}{\text{m}^2} = 300 \text{ kPa};$$

(a) Due to the spring, the final pressure will be

$$p_3 = p_2 + p;$$

$$\Rightarrow p_3 = 150 + 300;$$

$$\Rightarrow p_3 = 450 \text{ kPa}$$

(b) The final temperature will be

$$T_3 = T_{\text{sat@450 kPa}} = 420.93 \text{ K} = 147.93°\text{C}$$

$$\Delta E_{1\to 2} = Q_{1\to 2} - W_{B,1\to 2};$$

$$\Rightarrow m\left(\Delta u + \cancel{\Delta \text{ke}}^{\,0} + \cancel{\Delta \text{pe}}^{\,0}\right) = Q_{1\to 2} - W_{B,1\to 2};$$

$$\Rightarrow m\left(u_2 - u_1\right) = Q_{1\to 2} - p\Delta\cancel{V};$$

$$\Rightarrow Q_{1\to 2} = (40)(473.91 - 125.79) + (150)(0.2 - 0.04);$$

$$\Rightarrow Q_{1\to 2} = 13948.8 \text{ kJ};$$

Work done can be calculated from the area of the trapezoid as

$$W_{B,2\to3} = \frac{1}{2}(\cancel{V}_3 - \cancel{V}_2)(p_3 + p_2);$$

$$\Rightarrow W_{B,2\to3} = \frac{1}{2}(0.225 - 0.2)(450 + 150);$$

$$\Rightarrow W_{B,2\to3} = 7.5 \text{ kJ};$$

$$\Delta E_{2\to3} = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow m\left(\Delta u + \cancel{\Delta \text{ke}}^{0} + \cancel{\Delta \text{pe}}^{0}\right) = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow m\left(u_3 - u_2\right) = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow Q_{2\to3} = (40)(644.01 - 473.91) + 7.5;$$

$$\Rightarrow Q_{2\to3} = 6811.6 \text{ kJ};$$

(c) Total heat transfer

$$Q_{\text{total}} = Q_{1\to2} + Q_{2\to3};$$

$$\Rightarrow Q_{\text{total}} = 13948.8 + 6811.5;$$

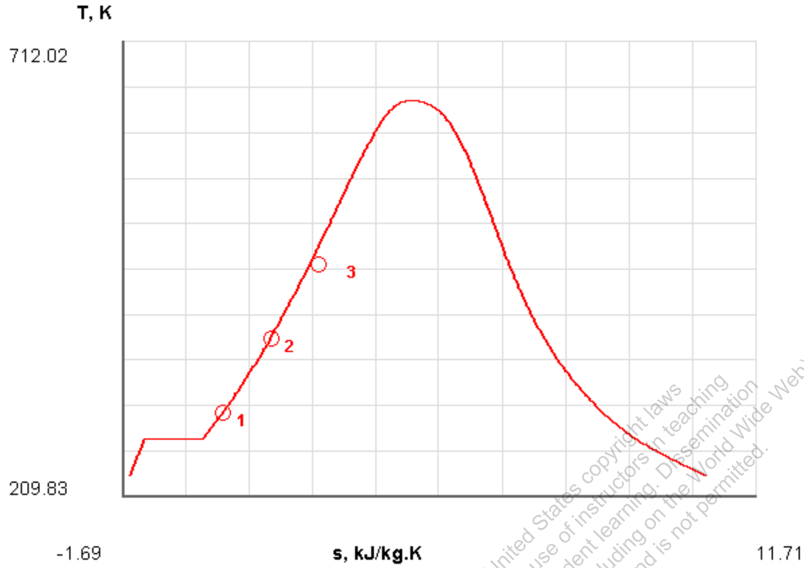
$$\Rightarrow Q_{\text{total}} = 20760.3 \text{ kJ} = 20.8 \text{ MJ}$$

TEST Solution:

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

5-1-59 [OAU] A piston-cylinder device contains 40 kg of water at 150 kPa and 30^{o} C. The cross-sectional area of the piston is 0.1 m^2. Heat is now added causing part of the water to evaporate. When the volume reaches 0.2 m^3, the piston reaches a spring with a constant spring constant. More heat is added until the volume increases to 0.3 m^3 and the pressure increases to 1.35 MPa. Determine (a) the spring constant, (b) the final temperature, and (c) the total heat transfer.

SOLUTION



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

$$v_1 = 0.0010\ \frac{\text{m}^3}{\text{kg}}; \quad u_1 = 125.78\ \frac{\text{kJ}}{\text{kg}}; \quad s_1 = 0.4369\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\mathcal{V}_1 = m_1 v_1 = (40)(0.0010) = 0.04\ \text{m}^3;$$

State-2 (given $p_2 = p_1, m_2 = m_1, \mathcal{V}_2$):

$$T_2 = T_{\text{sat@150 kPa}} = 384.37\ \text{K};$$

$$v_2 = \frac{\mathcal{V}_2}{m_2} = \frac{0.2}{40} = 0.005\ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.005 - 0.001053}{1.158} = 0.0034;$$

$$u_f = 464.94\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 2052.76\ \frac{\text{kJ}}{\text{kg}};$$

$$u_2 = u_f + x_2 u_{fg} = (466.94) + (0.0034)(2052.76) = 473.91\ \frac{\text{kJ}}{\text{kg}};$$

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

$$v_3 = \frac{\cancel{V}_3}{m_3} = \frac{0.3}{40} = 0.0075\ \frac{\text{m}^3}{\text{kg}};$$

$$x_3 = \frac{v_3 - v_f}{v_{fg}} = \frac{0.0075 - 0.0011}{0.1449} = 0.044;$$

$$u_f = 821.07\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 1770.85\ \frac{\text{kJ}}{\text{kg}};$$

$$u_3 = u_f + x_3 u_{fg} = (821.07) + (0.044)(1770.85) = 898.99\ \frac{\text{kJ}}{\text{kg}};$$

The fore applied can be calculated as

$$F = (p_3 - p_2)A;$$

$$\Rightarrow F = (1350 - 150)(0.1);$$

$$\Rightarrow F = 120 \text{ kN};$$

The spring constant can be calculated as

$$x = \frac{\cancel{V}_3 - \cancel{V}_2}{A};$$

$$\Rightarrow x = \frac{0.3 - 0.2}{0.1};$$

$$\Rightarrow x = 1\text{m};$$

(a) $k = \frac{F}{x};$

$$\Rightarrow k = \frac{120}{1};$$

$$\Rightarrow k = 120\ \frac{\text{kN}}{\text{m}}$$

(b) The final temperature will be

$$T_3 = T_{\text{sat@1350 kPa}} = 466.35 \text{ K} = 193.35°\text{C}$$

$$\Delta E_{1\to 2} = Q_{1\to 2} - W_{B,1\to 2};$$

$$\Rightarrow m\left(\Delta u + \cancel{\Delta \text{ke}}^{0} + \cancel{\Delta \text{pe}}^{0}\right) = Q_{1\to 2} - W_{B,1\to 2};$$

$$\Rightarrow m\left(u_2 - u_1\right) = Q_{1\to 2} - p\Delta \cancel{V};$$

$$\Rightarrow Q_{1\to 2} = (40)(473.91 - 125.78) + (150)(0.2 - 0.04);$$

$$\Rightarrow Q_{1\to 2} = 13948.8 \text{ kJ};$$

Work done can be calculated from the area of the trapezoid as

$$W_{B,2\to3} = \frac{1}{2}(\cancel{V}_3 - \cancel{V}_2)(p_3 + p_2);$$

$$\Rightarrow W_{B,2\to3} = \frac{1}{2}(0.3 - 0.2)(1350 + 150);$$

$$\Rightarrow W_{B,2\to3} = 75 \text{ kJ};$$

$$\Delta E_{2\to3} = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow m\left(\Delta u + \cancel{\Delta \text{ke}}^{0} + \cancel{\Delta \text{pe}}^{0}\right) = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow m\left(u_3 - u_2\right) = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow Q_{2\to3} = (40)(898.99 - 473.91) + 75;$$

$$\Rightarrow Q_{2\to3} = 17.078 \text{ MJ};$$

(c) Total heat transfer

$$Q_{\text{total}} = Q_{1\to2} + Q_{2\to3};$$

$$\Rightarrow Q_{\text{total}} = 13.949 + 17.078;$$

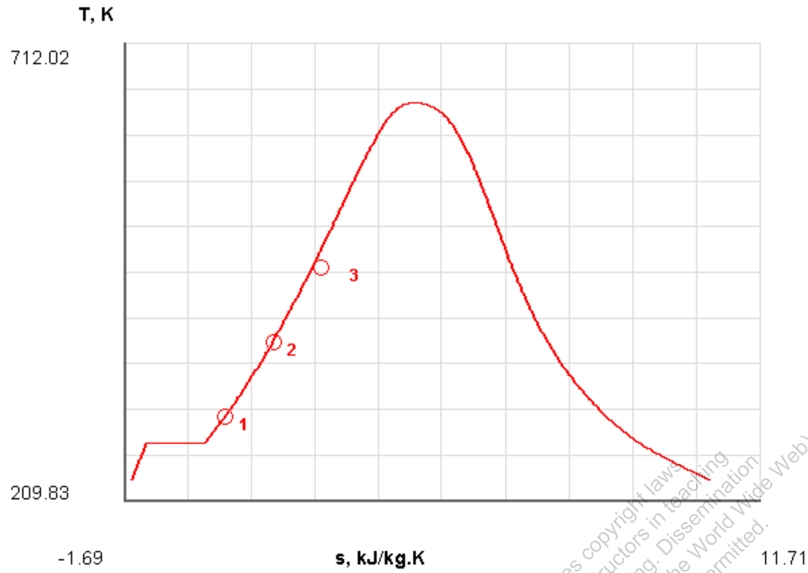
$$\Rightarrow Q_{\text{total}} = 31.03 \text{ MJ}$$

TEST Solution:

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

5-1-60 [OAT] If the heat addition takes place from a source at 500°C during the entire process in the above problem, determine (a) the change of entropy of the steam, (b) entropy transfer from the source, and (c) entropy generated in the universe during the process.

SOLUTION



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

$$v_1 = 0.0010\ \frac{\text{m}^3}{\text{kg}};\qquad u_1 = 125.78\ \frac{\text{kJ}}{\text{kg}};\qquad s_1 = 0.4369\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\mathcal{V}_1 = m_1 v_1 = (40)(0.0010) = 0.04\ \text{m}^3;$$

State-2 (given $p_2 = p_1, m_2 = m_1, \mathcal{V}_2$):

$$T_2 = T_{\text{sat@150 kPa}} = 384.37\ \text{K};$$

$$v_2 = \frac{\mathcal{V}_2}{m_2} = \frac{0.2}{40} = 0.005\ \frac{\text{m}^3}{\text{kg}};$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.005 - 0.001053}{1.158} = 0.0034;$$

$$u_f = 464.94\ \frac{\text{kJ}}{\text{kg}};\qquad u_{fg} = 2052.76\ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 1.4336\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\qquad s_{fg} = 5.789\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$s_2 = s_f + x_2 s_{fg} = (1.4336) + (0.0034)(5.789) = 1.453\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$u_2 = u_f + x_2 u_{fg} = (466.94) + (0.0034)(2052.76) = 473.91\ \frac{\text{kJ}}{\text{kg}};$$

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

$$v_3 = \frac{\cancel{V}_3}{m_3} = \frac{0.3}{40} = 0.0075\ \frac{\text{m}^3}{\text{kg}};$$

$$x_3 = \frac{v_3 - v_f}{v_{fg}} = \frac{0.0075 - 0.0011}{0.1449} = 0.044;$$

$$u_f = 821.07\ \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 1770.85\ \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 2.267\ \frac{\text{kJ}}{\text{kg}}; \quad s_{fg} = 4.228\ \frac{\text{kJ}}{\text{kg}};$$

$$s_3 = s_f + x_3 s_{fg} = (2.267) + (0.044)(4.228) = 2.453\ \frac{\text{kJ}}{\text{kg}};$$

$$u_3 = u_f + x_3 u_{fg} = (821.07) + (0.044)(1770.85) = 898.99\ \frac{\text{kJ}}{\text{kg}};$$

$$\Delta E_{1\to2} = Q_{1\to2} - W_{B,1\to2};$$

$$\Rightarrow m\left(\Delta u + \cancel{\Delta \text{ke}}^{0} + \cancel{\Delta \text{pe}}^{0}\right) = Q_{1\to2} - W_{B,1\to2};$$

$$\Rightarrow m\left(u_2 - u_1\right) = Q_{1\to2} - p\Delta\cancel{V};$$

$$\Rightarrow Q_{1\to2} = (40)(473.91 - 125.78) + (150)(0.2 - 0.04);$$

$$\Rightarrow Q_{1\to2} = 13948.8\ \text{kJ};$$

Work done can be calculated from the area of the trapezoid as

$$W_{B,2\to3} = \frac{1}{2}(\cancel{V}_3 - \cancel{V}_2)(p_3 + p_2);$$

$$\Rightarrow W_{B,2\to3} = \frac{1}{2}(0.3 - 0.2)(1350 + 150);$$

$$\Rightarrow W_{B,2\to3} = 75\ \text{kJ};$$

$$\Delta E_{2\to3} = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow m\left(\Delta u + \cancel{\Delta \text{ke}}^{0} + \cancel{\Delta \text{pe}}^{0}\right) = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow m\left(u_3 - u_2\right) = Q_{2\to3} - W_{B,2\to3};$$

$$\Rightarrow Q_{2\to3} = (40)(898.99 - 473.91) + 75;$$

$$\Rightarrow Q_{2\to3} = 17.078\ \text{MJ};$$

Total heat transfer

$$Q_{\text{total}} = Q_{1\to2} + Q_{2\to3};$$

$$\Rightarrow Q_{\text{total}} = 13.949 + 17.078;$$
$$\Rightarrow Q_{\text{total}} = 31.03\ \text{MJ};$$

The change in entropy

$$\Delta S_{1\to 2} = m(s_2 - s_1);$$
$$\Rightarrow \Delta S_{1\to 2} = (40)(1.453 - 0.4369);$$
$$\Rightarrow \Delta S_{1\to 2} = 40.64\ \frac{\text{kJ}}{\text{K}};$$

$$\Delta S_{2\to 3} = m(s_3 - s_2);$$
$$\Rightarrow \Delta S_{2\to 3} = (40)(2.453 - 1.453);$$
$$\Rightarrow \Delta S_{2\to 3} = 40\ \frac{\text{kJ}}{\text{K}};$$

(a) $\Delta S_{\text{total}} = \Delta S_{1\to 2} + \Delta S_{2\to 3};$

$$\Rightarrow \Delta S_{\text{total}} = 40.64 + 40;$$
$$\Rightarrow \Delta S_{\text{total}} = 80.64\ \frac{\text{kJ}}{\text{K}}$$

(b) The amount of entropy transfer into the atmosphere

$$\frac{Q_{1\to 2}}{T_B} = \frac{13949}{773} = 18.05\ \frac{\text{kJ}}{\text{K}};$$
$$\frac{Q_{2\to 3}}{T_B} = \frac{17424}{773} = 22.54\ \frac{\text{kJ}}{\text{K}};$$

$$\sum \frac{Q}{T_B} = \frac{Q_{1\to 2}}{T_B} + \frac{Q_{2\to 3}}{T_B};$$
$$\Rightarrow \sum \frac{Q}{T_B} = 18.05 + 22.54;$$
$$\Rightarrow \sum \frac{Q}{T_B} = 40.59\ \frac{\text{kJ}}{\text{K}}$$

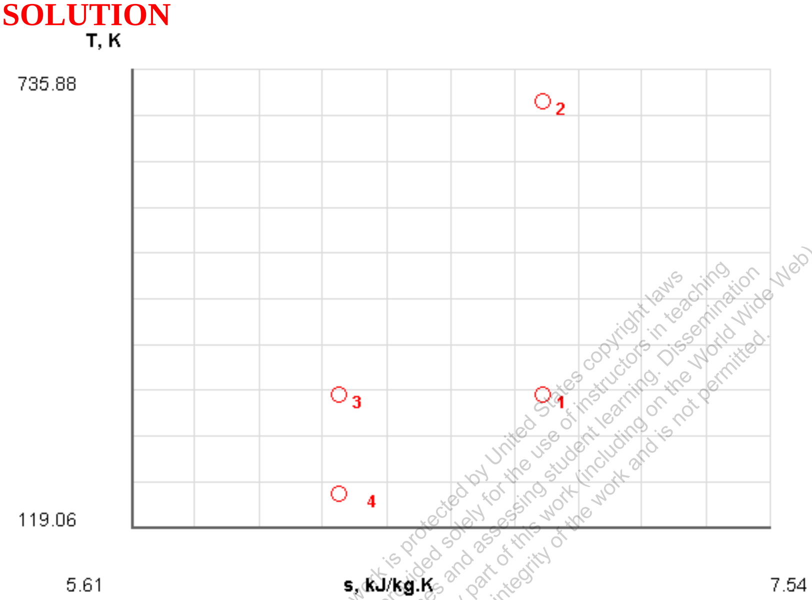
(c) The entropy equation, applied over the system’s universe, produces

$$S_{\text{gen,univ}} = \Delta S_{\text{total}} - \sum \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = 80.64 - 40.59;$$
$$\Rightarrow S_{\text{gen,univ}} = 40.05\ \frac{\text{kJ}}{\text{K}}$$

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

5-1-61 [OAX] A piston-cylinder device contains 1 m^3 of N2 at 100 kPa and 300 K (atmospheric conditions). (a) Determine the mass of N2(in kg). The trapped N2 is now rapidly compressed (adiabatically) with negligible friction (reversibly) to one eighth its original volume. Determine (b) the temperature and (c) pressure (kPa) right after the compression process is over. The volume is now held constant while the air cools down to the atmospheric temperature of 300 K. Determine (d) the pressure at the end of this cooling process. Finally, the gas is allowed to expand back to its original pressure of 100 kPa in an isentropic manner. (e) Determine the final temperature right after the expansion (K). Also determine (f) the work required for compression, and (g) work produced by expansion. Use the PG model for N2.

SOLUTION



Given:

$$c_v = 0.734 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_p = 1.031 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

$$k = 1.404;$$

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

(a) $$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)(1)}{(0.297)(300)} = 1.122 \text{ kg}$$

State-2 (given $s_2 = s_1, m_2 = m_1, \cancel{V}_2 = \cancel{V}_1 / 8$):

(b) $T_2 = T_1\left(\dfrac{v_1}{v_2}\right)^{k-1} = 300(8)^{0.404} = 695\ \text{K}$

(c) $p_2 = p_1\left(\dfrac{v_1}{v_2}\right)^{k} = 100(8)^{1.404} = 1853.3\ \text{kPa}$

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

(d) $p_3 = \dfrac{m_3}{\cancel{V}_3} RT_3 = \left(\dfrac{1.122}{0.125}\right)(0.297)(300) = 800\ \text{kPa}$

State-4 (given $p_4, s_4 = s_3, m_4 = m_1$):

(e) $T_4 = T_3\left(\dfrac{p_4}{p_3}\right)^{\frac{k-1}{k}} = 300\left(\dfrac{100}{800}\right)^{\frac{0.404}{1.404}} = 164.9\ \text{K}$

(f) For the compression process

$$\Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} = \cancel{Q}^{0} - \left(W_B + \cancel{W_O}^{0}\right);$$
$$\Rightarrow W_{B,1\to2} = -m\Delta u_{1\to2};$$
$$\Rightarrow W_{B,1\to2} = mc_v\left(T_1 - T_2\right);$$
$$\Rightarrow W_{B,1\to2} = (1.122)(0.734)(300-695);$$
$$\Rightarrow W_{B,1\to2} = -325.3\ \text{kJ}$$

(g) For the expansion process

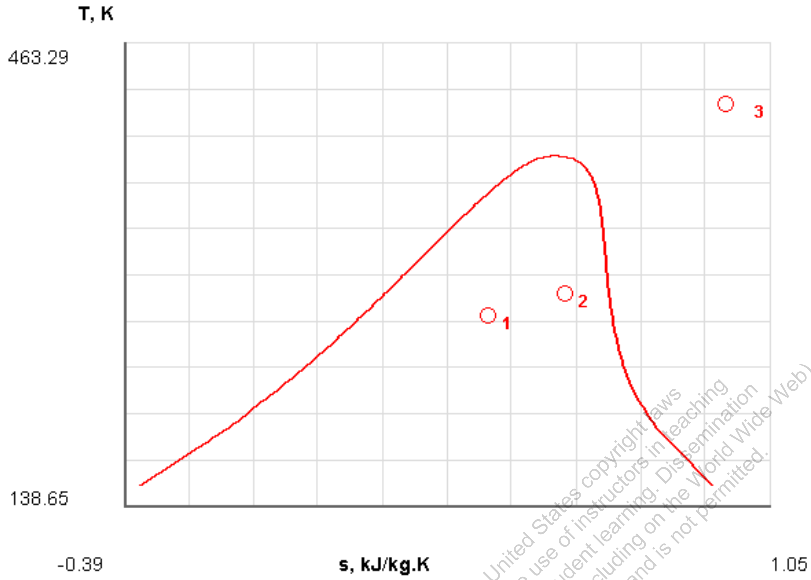
$$\Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} = \cancel{Q}^{0} - \left(W_B + \cancel{W_O}^{0}\right);$$
$$\Rightarrow W_{B,3\to4} = -m\Delta u_{3\to4};$$
$$\Rightarrow W_{B,3\to4} = mc_v\left(T_3 - T_4\right);$$
$$\Rightarrow W_{B,3\to4} = (1.122)(0.734)(300-164.9);$$
$$\Rightarrow W_{B,3\to4} = 111.3\ \text{kJ}$$

TEST Solution:

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

5-1-62 [OAV] A mass of 10 kg of saturated liquid-vapor mixture of R-12 is contained in a piston-cylinder device at 0°C. Initially half of the mixture is in the liquid phase. Heat is now transferred, and the piston, which is resting on a stop-ring, starts moving when the pressure reaches 500 kPa. Heat transfer continues until the total volume doubles. Determine (a) the final pressure, (b) work, and (c) heat transfer in the entire process. Also, show the process on a p-v diagram.

SOLUTION



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

$$v_f = 0.000716 \ \frac{\text{kJ}}{\text{kg}}; \qquad v_{fg} = 0.0546 \ \frac{\text{kJ}}{\text{kg}};$$

$$v_1 = v_f + x_1 v_{fg} = (0.000716) + (0.5)(0.0546) = 0.02805 \ \frac{\text{kJ}}{\text{kg}};$$

$$\cancel{V}_1 = m_1 v_1 = (10)(0.02805) = 0.2805 \ \text{m}^3;$$

$$u_f = 35.83 \ \frac{\text{kJ}}{\text{kg}}; \qquad u_{fg} = 134.61 \ \frac{\text{kJ}}{\text{kg}};$$

$$u_1 = u_f + x_1 u_{fg} = (35.83) + (0.5)(134.61) = 103.13 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2, m_2 = m_1, \cancel{V}_2 = \cancel{V}_1$):

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.02805 - 0.000744}{0.0346} = 0.79;$$

$$u_f = 50.28 \ \frac{\text{kJ}}{\text{kg}}; \qquad u_{fg} = 126.33 \ \frac{\text{kJ}}{\text{kg}};$$

$$u_2 = u_f + x_2 u_{fg} = (50.28) + (0.79)(126.33) = 150 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_2, m_3 = m_1, \cancel{V}_3 = 2\cancel{V}_2$):

$$v_3 = \frac{\cancel{V}_3}{m_3} = \frac{0.561}{10} = 0.0561 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_3 = 257.91 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $p_3 = 500 \text{ kPa}$

(b) Work done can be calculated from the area of the trapezoid as

$$W_{B,2\to3} = \frac{1}{2}(\cancel{V}_3 - \cancel{V}_2)(p_3 + p_2);$$

$$\Rightarrow W_{B,2\to3} = \frac{1}{2}(0.561 - 0.2805)(500 + 500);$$

$$\Rightarrow W_{B,2\to3} = 140.25 \text{ kJ}$$

The heat transfer for each process

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(\cancel{W_B}^0 + \cancel{W_O}^0\right);$$

$$\Rightarrow Q_{1\to2} = m(u_2 - u_1);$$

$$\Rightarrow Q_{1\to2} = (10)(150 - 103.13);$$

$$\Rightarrow Q_{1\to2} = 468.7 \text{ kJ};$$

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(W_B + \cancel{W_O}^0\right);$$

$$\Rightarrow Q_{2\to3} = m(u_3 - u_2) + W_{B,2\to3};$$

$$\Rightarrow Q_{2\to3} = (10)(257.91 - 150) + 140.25;$$

$$\Rightarrow Q_{2\to3} = 1219.35 \text{ kJ};$$

(c) The total heat transfer

$$Q_{\text{total}} = Q_{1\to2} + Q_{2\to3};$$

$$\Rightarrow Q_{\text{total}} = (468.7) + (1219.35);$$

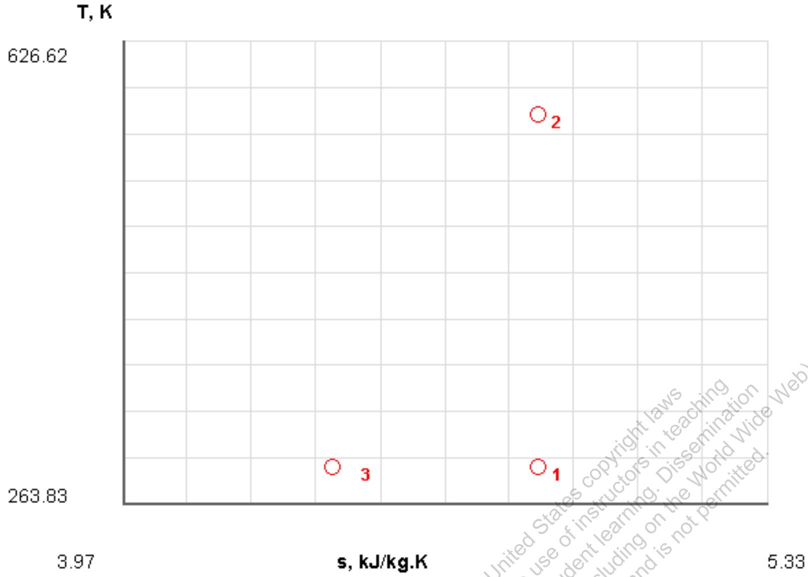
$$\Rightarrow Q_{\text{total}} = 1688.05 \text{ kJ}$$

TEST Solution:

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

5-1-63 [OAQ] An insulated cylinder with a frictionless piston contains 10 L of CO_2 at ambient conditions, 100 kPa and 20^{o}C. A force is now applied on the piston, compressing the gas until it reaches a set of stops, at which point the cylinder volume is 1 L. The insulation is now removed from the walls, and the gas cools down to the ambient temperature of 20^{o}C. Calculate the (a) work and (b) heat transfer for the overall process. Also, show the process on a T-s diagram. Use the PG model.

SOLUTION



Given:

$$c_v = 0.655 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R = 0.189 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$k = 1.289;$$

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

$$m_1 = \frac{p_1 \cancel{V}_1}{RT_1} = \frac{(100)(0.01)}{(0.189)(293)} = 0.0181 \text{ kg};$$

State-2 (given $m_2 = m_1, \cancel{V}_2$):

$$p_2 = p_1 \left(\frac{v_1}{v_2} \right)^k = 100(10)^{1.289} = 1945.36 \text{ kPa};$$

$$T_2 = T_1 \left(\frac{v_1}{v_2} \right)^{k-1} = 293(10)^{0.289} = 570 \text{ K};$$

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

(a) For the first process

$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = \cancel{Q}^0 - \left(W_B + \cancel{W_O}^0\right);$$

$$\Rightarrow W_{B,1\to 2} = -m\Delta u_{1\to 2};$$

$$\Rightarrow W_{B,1\to 2} = mc_v\left(T_1 - T_2\right);$$

$$\Rightarrow W_{B,1\to 2} = (0.0181)(0.655)(293 - 570);$$

$$\Rightarrow W_{B,1\to 2} = -3.28 \text{ kJ}$$

(b) For the second process

$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \left(\cancel{W_B}^0 + \cancel{W_O}^0\right);$$

$$\Rightarrow Q_{2\to 3} = m\Delta u_{2\to 3};$$

$$\Rightarrow Q_{2\to 3} = mc_v\left(T_3 - T_2\right);$$

$$\Rightarrow Q_{2\to 3} = (0.0181)(0.655)(293 - 570);$$

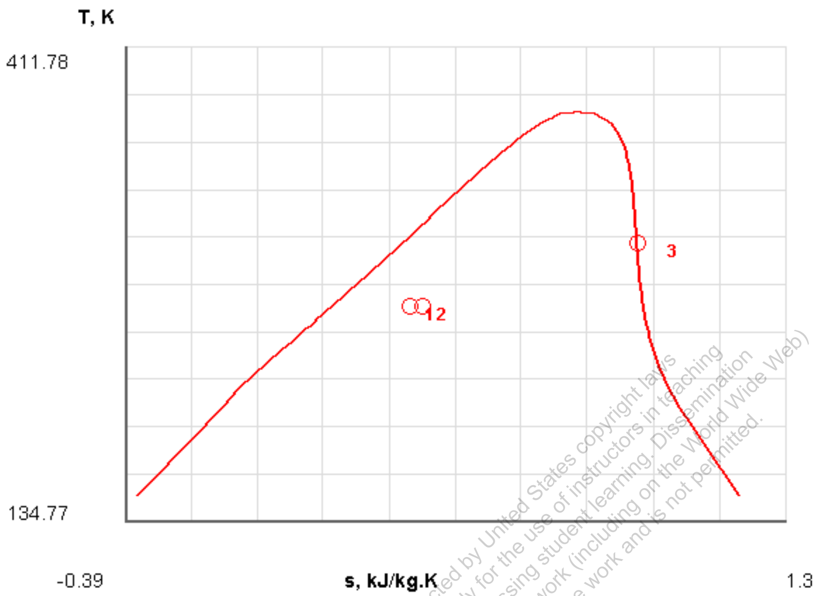
$$\Rightarrow Q_{2\to 3} = -3.28 \text{ kJ}$$

TEST Solution:

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

5-1-64 [OAD] A piston-cylinder device with a set of stops contains 12 kg of refrigerant-134a. Initially 9 kg of refrigerant is in the liquid form, and the temperature is -12°C. Now heat is transferred from the atmosphere at 25°C to the refrigerant until the piston hits the stop, at which point the volume is 380 L. Heating is continued until the temperature of the refrigerant reaches the atmospheric value. Determine (a) the final pressure, (b) the work transfer, (c) the heat transfer, and (d) the entropy generation during the entire process.

SOLUTION



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

$$p_1 = p_{\text{sat}@-12°\text{C}} = 185.40 \text{ kPa};$$

$$v_f = 0.0007498 \frac{\text{kJ}}{\text{kg}}; \quad v_{fg} = 0.1060 \frac{\text{kJ}}{\text{kg}};$$

$$v_1 = v_f + x_1 v_{fg} = (0.0007498) + (0.25)(0.1060) = 0.02726 \frac{\text{kJ}}{\text{kg}};$$

$$\mathcal{V}_1 = m_1 v_1 = (12)(0.02726) = 0.327 \text{ m}^3;$$

$$u_f = 34.25 \frac{\text{kJ}}{\text{kg}}; \quad u_{fg} = 186.11 \frac{\text{kJ}}{\text{kg}};$$

$$u_1 = u_f + x_1 u_{fg} = (34.25) + (0.25)(186.11) = 80.77 \frac{\text{kJ}}{\text{kg}};$$

$$s_f = 0.1388 \frac{\text{kJ}}{\text{kg}}; \quad s_{fg} = 0.7879 \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_f + x_1 s_{fg} = (0.1388) + (0.25)(0.7879) = 0.335 \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = p_1, m_2 = m_1, \mathcal{V}_2$):

$$v_2 = \frac{\cancel{V}_2}{m_2} = \frac{0.38}{12} = 0.03166 \ \frac{\text{m}^3}{\text{kg}};$$
$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.03166 - 0.0007498}{0.1060} = 0.2916;$$
$$u_2 = u_f + x_2 u_{fg} = (34.25) + (0.2916)(186.11) = 88.52 \ \frac{\text{kJ}}{\text{kg}};$$
$$s_2 = s_f + x_2 s_{fg} = (0.1388) + (0.2916)(0.7879) = 0.368 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $T_3, m_3 = m_1, \cancel{V}_3 = \cancel{V}_2$):
$$u_3 = 243.10 \ \frac{\text{kJ}}{\text{kg}}; \ s_3 = 0.9199 \ \frac{\text{kJ}}{\text{kg}}$$

(a) $p_3 = 654.15 \text{ kPa}$

(b) Work done can be calculated from the area of the trapezoid as
$$W_{B,1\to 2} = (p_2 \cancel{V}_2 - p_1 \cancel{V}_1);$$
$$\Rightarrow W_{B,1\to 2} = (185.4)(0.38) - (185.4)(0.327);$$
$$\Rightarrow W_{B,1\to 2} = 9.82 \text{ kJ};$$

As $\cancel{V}_3 = \cancel{V}_2, W_{B,2\to 3} = 0$
$$W_B = W_{B,1\to 2} + W_{B,2\to 3};$$
$$\Rightarrow W_B = 9.82 \text{ kJ}$$

The heat transfer is as follows
$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(W_B + \cancel{W_O}^0\right);$$
$$\Rightarrow Q_{1\to 2} = m(u_2 - u_1) + W_{B,1\to 2};$$
$$\Rightarrow Q_{1\to 2} = (12)(88.52 - 80.77) + 9.82;$$
$$\Rightarrow Q_{1\to 2} = 102.82 \text{ kJ};$$

$$\Delta U + \cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 = Q - \left(\cancel{W_B}^0 + \cancel{W_O}^0\right);$$
$$\Rightarrow Q_{2\to 3} = m(u_3 - u_2);$$
$$\Rightarrow Q_{2\to 3} = (12)(243.10 - 88.52);$$
$$\Rightarrow Q_{2\to 3} = 1854.96 \text{ kJ};$$

(c) The total heat transfer will be

$$Q_{\text{total}} = Q_{1\to2} + Q_{2\to3};$$
$$\Rightarrow Q_{\text{total}} = (102.82) + (1854.96);$$
$$\Rightarrow Q_{\text{total}} = 1957.78 \text{ kJ}$$

The change in entropy

$$\Delta S_{1\to2} = m(s_2 - s_1);$$
$$\Rightarrow \Delta S_{1\to2} = (12)(0.368 - 0.335);$$
$$\Rightarrow \Delta S_{1\to2} = 0.4026 \ \frac{\text{kJ}}{\text{K}};$$

$$\Delta S_{2\to3} = m(s_3 - s_2);$$
$$\Rightarrow \Delta S_{2\to3} = (12)(0.9199 - 0.368);$$
$$\Rightarrow \Delta S_{2\to3} = 6.62 \ \frac{\text{kJ}}{\text{K}};$$

$$\Delta S_{\text{total}} = \Delta S_{1\to2} + \Delta S_{2\to3};$$
$$\Rightarrow \Delta S_{\text{total}} = 7.0254 \ \frac{\text{kJ}}{\text{K}};$$

The amount of entropy transfer into the atmosphere

$$\frac{Q_{1\to2}}{T_B} = \frac{102.82}{298} = 0.345 \ \frac{\text{kJ}}{\text{K}};$$
$$\frac{Q_{2\to3}}{T_B} = \frac{1854.96}{296} = 6.225 \ \frac{\text{kJ}}{\text{K}};$$

$$\sum \frac{Q}{T_B} = \frac{Q_{1\to2}}{T_B} + \frac{Q_{2\to3}}{T_B};$$
$$\Rightarrow \sum \frac{Q}{T_B} = 0.345 + 6.225;$$
$$\Rightarrow \sum \frac{Q}{T_B} = 6.57 \ \frac{\text{kJ}}{\text{K}};$$

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

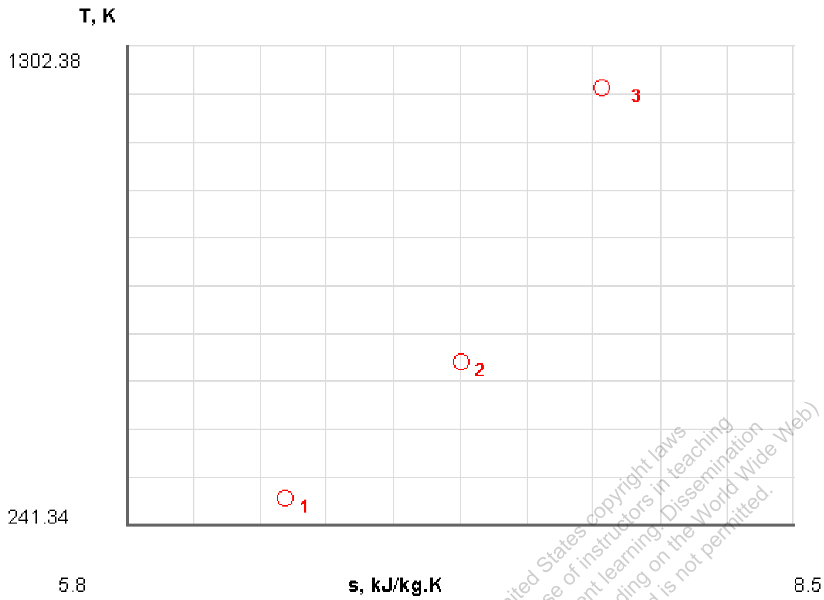
$$S_{\text{gen,univ}} = \Delta S_{\text{total}} - \sum \frac{Q}{T_B};$$
$$\Rightarrow S_{\text{gen,univ}} = 7.0254 - 6.57;$$
$$\Rightarrow S_{\text{gen,univ}} = 0.455 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

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

5-1-65 [OAY] A piston-cylinder device has a ring to limit the expansion stroke. Initially, the mass of air is 2 kg at 500 kPa, 30°C. Heat is now transferred until the piston touches the stop, at which point the volume is twice the original volume. More heat is transferred until the pressure inside also doubles. Using the IG model, determine (a) the amount of heat transfer, and (b) the final temperature.

SOLUTION



Given:

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

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

$$\mathcal{V}_1 = \frac{m_1 R T_1}{p_1} = \frac{(2)(0.287)(303)}{(500)} = 0.348 \text{ m}^3;$$

$$u_1 = -81.96 \ \frac{\text{kJ}}{\text{kg}};$$

State-2 (given $p_2 = p_1, m_2 = m_1, \mathcal{V}_2 = 2\mathcal{V}_1$):

$$u_2 = 143.17 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3, m_3 = m_1, \mathcal{V}_3 = \mathcal{V}_2$):

$$v_3 = \frac{\mathcal{V}_3}{m_3} = \frac{0.696}{2} = 0.348 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_3 = 646.72 \ \frac{\text{kJ}}{\text{kg}};$$

Work done can be calculated from the area of the trapezoid as

$$W_{B,1\to 2} = (p_2\cancel{V}_2 - p_1\cancel{V}_1);$$
$$\Rightarrow W_{B,1\to 2} = (500)(0.696 - 0.348);$$
$$\Rightarrow W_{B,1\to 2} = 174 \text{ kJ};$$

As $\cancel{V}_3 = \cancel{V}_2, W_{B(2-3)} = 0$

$$W_B = W_{B,1\to 2} + W_{B,2\to 3};$$
$$\Rightarrow W_B = 174 \text{ kJ};$$

The heat transfer in each process

$$\Delta U + \cancel{\Delta \mathrm{KE}}^{0} + \cancel{\Delta \mathrm{PE}}^{0} = Q - \left(W_B + \cancel{W_O}^{0}\right);$$
$$\Rightarrow Q_{1\to 2} = m(u_2 - u_1) + W_{B,1\to 2};$$
$$\Rightarrow Q_{1\to 2} = (2)\left[143.17 - (-81.96)\right] + 174;$$
$$\Rightarrow Q_{1\to 2} = 624.26 \text{ kJ};$$

$$\Delta U + \cancel{\Delta \mathrm{KE}}^{0} + \cancel{\Delta \mathrm{PE}}^{0} = Q - \left(\cancel{W_B}^{0} + \cancel{W_O}^{0}\right);$$
$$\Rightarrow Q_{2\to 3} = m(u_3 - u_2);$$
$$\Rightarrow Q_{2\to 3} = (2)(646.72 - 143.17);$$
$$\Rightarrow Q_{2\to 3} = 1007.1 \text{ kJ};$$

(a) The total heat transfer will be

$$Q_{\text{total}} = Q_{1\to 2} + Q_{2\to 3};$$
$$\Rightarrow Q_{\text{total}} = (624.26) + (1007.1);$$
$$\Rightarrow Q_{\text{total}} = 1631.36 \text{ kJ}$$

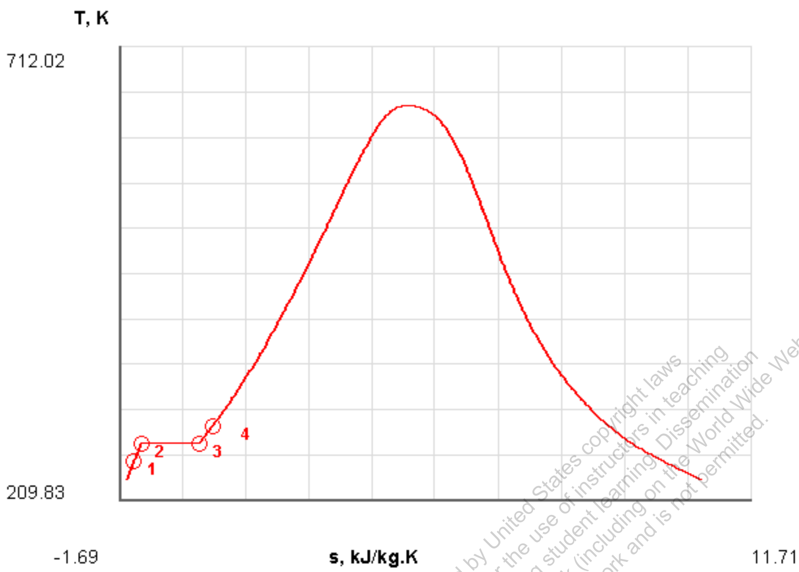
(b) $T_3 = \dfrac{p_3\cancel{V}_3}{m_3 R} = \dfrac{(1000)(0.696)}{(2)(0.287)} = 1212.54 \text{ K} = 939.54°\text{C}$

TEST Solution:

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

5-1-66 [OAF] An insulated container contains a block of ice of mass 1 ton (US) (1 US ton is 907.2 kg) at -20°C. The insulation is removed, and the ice gradually melts to water and comes to thermal equilibrium with the surroundings at 20°C. Assuming the pressure to remain constant at 100 kPa, determine the heat transfer during (a) the sensible heating of ice, (b) the melting of ice, and (c) the sensible heating of water. (d) ***What-if scenario:*** If the melting of ice in part (b) takes a period of 24 hours, what is the rate of heat transfer in kW?

SOLUTION



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

$$v_1 = 0.0010874 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_1 = -374.03 \ \frac{\text{kJ}}{\text{kg}};$$

$$\cancel{V}_1 = m_1 v_1 = 0.986 \ \text{m}^3;$$

State-2 (given $p_2 = p_1,\ m_2 = m_1, T_2 = -0.01°\text{C}$):

$$v_2 = 0.0010908 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_2 = -333.45 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (given $p_3 = p_1,\ m_3 = m_1, T_3 = 0.01°\text{C}$):

$$v_3 = 0.001 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_3 = -0.021 \ \frac{\text{kJ}}{\text{kg}};$$

State-4 (given $p_4 = p_1,\ m_4 = m_1, T_4$):

$$v_4 = 0.00102 \ \frac{\text{m}^3}{\text{kg}}; \qquad u_4 = 83.96 \ \frac{\text{kJ}}{\text{kg}};$$

(a) Looking at the sensible heating of ice

$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \left(W_B - \cancel{W_O}^0\right);$$

$$\Rightarrow Q_{1\to 2} = \Delta U_{1\to 2} + W_{B,1\to 2};$$

$$\Rightarrow Q_{1\to 2} = m(u_2 - u_1) + mp(v_2 - v_1);$$

$$\Rightarrow Q_{1\to 2} = (907.2)\left[-333.45 - (-374.03)\right] + (907.2)(100)(0.0010908 - 0.0010874);$$

$$\Rightarrow Q_{1\to 2} = 36814.48 \text{ kJ} = 36.81 \text{ MJ}$$

(b) Looking at the melting of ice

$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \left(W_B - \cancel{W_O}^0\right);$$

$$\Rightarrow Q_{2\to 3} = \Delta U_{2\to 3} + W_{B,2\to 3};$$

$$\Rightarrow Q_{2\to 3} = m(u_3 - u_2) + mp(v_3 - v_2);$$

$$\Rightarrow Q_{2\to 3} = (907.2)\left[-0.021 - (-333.45)\right] + (907.2)(100)(0.001 - 0.0010908);$$

$$\Rightarrow Q_{2\to 3} = 302478.55 \text{ kJ} = 302.48 \text{ MJ}$$

(c) Looking at the sensible heating of water

$$\Delta U + \cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 = Q - \left(W_B - \cancel{W_O}^0\right);$$

$$\Rightarrow Q_{3\to 4} = \Delta U_{3\to 4} + W_{B,3\to 4};$$

$$\Rightarrow Q_{3\to 4} = m(u_4 - u_3) + mp(v_4 - v_3);$$

$$\Rightarrow Q_{3\to 4} = (907.2)\left[83.96 - (-0.021)\right] + (907.2)(100)(0.00102 - 0.001);$$

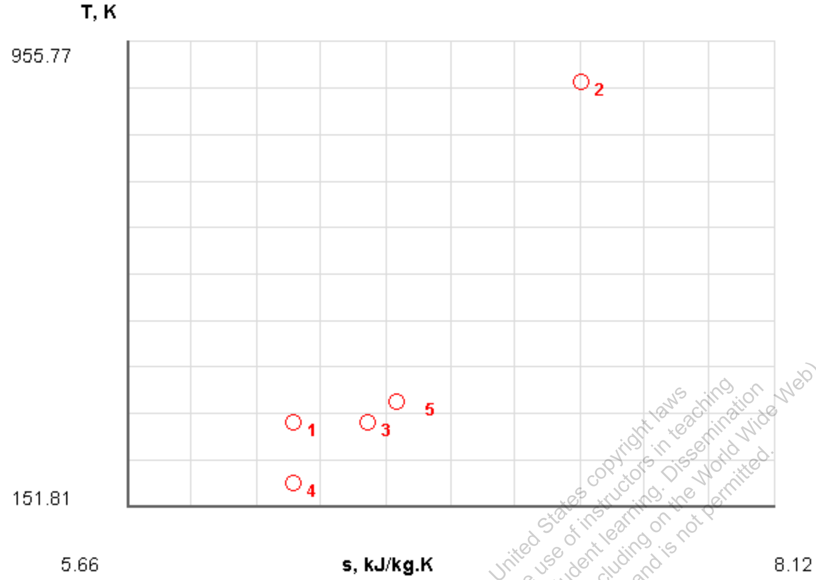
$$\Rightarrow Q_{3\to 4} = 76189.38 \text{ kJ} = 76.19 \text{ MJ}$$

TEST Solution and What-if Scenario:

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

5-1-67 [OAM] Three alternative processes shown in the accompanying figure are suggested to change the state of one kg of air from 0.8 MPa, 25°C (state-1) to 0.3 MPa, 60°C (state-5). Process 1-2-5 consists of a constant pressure expansion followed by a constant volume cooling, process 1-3-5 an isothermal expansion followed by a constant pressure expansion, and process 1-4-5 an isentropic expansion followed by a constant volume heating. Determine the work and heat transfer for each alternative.

SOLUTION



Given:

$c_v = 0.717 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$

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

$k = 1.4;$

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

$$\mathcal{V}_1 = \frac{m_1 R T_1}{p_1} = \frac{(1)(0.287)(298)}{(800)} = 0.106 \text{ m}^3;$$

State-2 (given $p_2 = p_1, m_2 = m_1, \mathcal{V}_2 = \mathcal{V}_5$):

$$T_2 = \frac{p_2 \mathcal{V}_2}{m_2 R} = \frac{(800)(0.318)}{(1)(0.287)} = 886.4 \text{ K};$$

State-3 (given $p_3 = p_5, T_3 = T_1, m_3 = m_1$):

$$\mathcal{V}_3 = \frac{m_3 R T_3}{p_3} = \frac{(1)(0.287)(298)}{(300)} = 0.285 \text{ m}^3;$$

State-4 (given $m_4 = m_1, s_4 = s_1, \cancel{V}_4 = \cancel{V}_5$):

$$T_4 = T_1\left(\frac{v_1}{v_4}\right)^{k-1} = T_1\left(\frac{\cancel{V}_1}{\cancel{V}_4}\right)^{k-1} = 298\left(\frac{0.106}{0.318}\right)^{0.4} = 192 \text{ K};$$

$$p_4 = p_1\left(\frac{v_1}{v_4}\right)^{k} = p_4\left(\frac{\cancel{V}_1}{\cancel{V}_4}\right)^{k} = 800\left(\frac{0.106}{0.318}\right)^{1.4} = 171.8 \text{ kPa};$$

State-5 (given $p_5, T_5, m_5 = m_1$):

$$\cancel{V}_5 = \frac{m_5RT_5}{p_5} = \frac{(1)(0.287)(333)}{(300)} = 0.318 \text{ m}^3;$$

The heat transfer is follows

$$\Delta U + \cancel{\Delta \text{KE}}^{\,0} + \cancel{\Delta \text{PE}}^{\,0} = Q - \left(W_B + \cancel{W_O}^{\,0}\right);$$

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

Process 1-2-5

(a.1) $Q_{1\to2} = m(u_2 - u_1) + W_{B,1\to2} = mc_v(T_2 - T_1) + W_{B,1\to2} = (1)(0.717)(886.4 - 298) + 170 = 591.88 \text{ kJ};$

$Q_{2\to5} = m(u_5 - u_2) + \cancel{W_{B,2\to5}}^{\,0} = mc_v(T_5 - T_2) = (1)(0.717)(333 - 886.4) = -396.79 \text{ kJ};$

$Q_{1\to2\to5} = Q_{1\to2} + Q_{2\to5} = 195.09 \text{ kJ}$

(a.2) $W_{B,1\to2} = p_1(\cancel{V}_2 - \cancel{V}_1);$

$\Rightarrow W_{B,1\to2} = (800)(0.318 - 0.106);$

$\Rightarrow W_{B,1\to2} = 170 \text{ kJ};$

As $\cancel{V}_5 = \cancel{V}_2$, $W_{B,2\to5} = 0$

$W_{B,1\to2\to5} = W_{B,1\to2} + W_{B,2\to5};$

$\Rightarrow W_{B,1\to2\to5} = 170 \text{ kJ}$

Process 1-3-5

(b.1) $Q_{1\to3} = m(u_3 - u_1) + W_{B,1\to3} = mc_v\,\cancel{(T_3 - T_1)}^{\,0} + W_{B,1\to3} = 83.87 \text{ kJ};$

$Q_{3\to5} = m(u_5 - u_3) + W_{B,3\to5} = mc_v(T_5 - T_3) + W_{B,3\to5} = (1)(0.717)(333 - 298) + 9.9 = 35 \text{ kJ};$

$Q_{1\to3\to5} = Q_{1\to3} + Q_{3\to5} = 118.87 \text{ kJ}$

(b.2) $W_{B,1\to3} = p_1 V_1 \ln\dfrac{V_3}{V_1};$

$$\Rightarrow W_{B,1\to3} = (800)(0.106)\ln\frac{(0.285)}{(0.106)};$$

$$\Rightarrow W_{B,1\to3} = 83.87 \text{ kJ};$$

$$W_{B,3\to5} = p_5(V_5 - V_3);$$

$$\Rightarrow W_{B,3\to5} = (300)(0.318-0.285);$$

$$\Rightarrow W_{B,3\to5} = 9.9 \text{ kJ};$$

$$W_{B,1\to3\to5} = W_{B,1\to3} + W_{B,3\to5};$$

$$\Rightarrow W_{B,1\to3\to5} = 93.77 \text{ kJ}$$

Process 1-4-5

(c.1) $Q_{1\to4} = 0$ kJ;

$$Q_{4\to5} = m(u_5 - u_4) + \cancel{W_{B,4\to5}}^{0} = mc_v(T_5 - T_4) = (1)(0.717)(333-192) = 101.1 \text{ kJ};$$

$$Q_{1\to4\to5} = Q_{1\to4} + Q_{4\to5} = 101.1 \text{ kJ}$$

(c.2) $W_{B,1\to4} = \dfrac{(p_4 V_4 - p_1 V_1)}{1-n};$

$$\Rightarrow W_{B,1\to4} = \frac{(171.8)(0.318)-(800)(0.106)}{1-1.4};$$

$$\Rightarrow W_{B,1\to4} = 75.42 \text{ kJ};$$

As $V_5 = V_4, W_{B,4\to5} = 0$

$$W_{B,1\to4\to5} = W_{B,1\to4} + W_{B,4\to5};$$

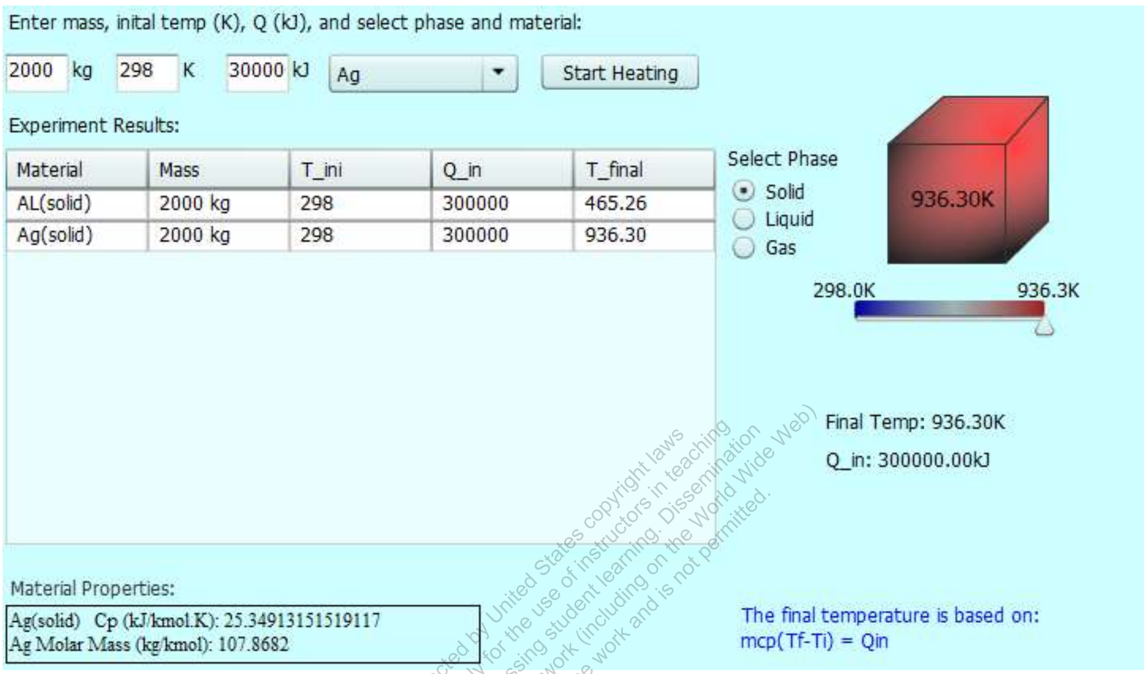
$$\Rightarrow W_{B,1\to4\to5} = 75.42 \text{ kJ}$$

TEST Solution:

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

5-1-68 [BVX] An aluminum (Al) block of mass 2000 kg is heated from a temperature of 25°C. Using the SL Simulator RIA (linked from left margin), (a) determine the final temperature (T_2) of the block if the heat input is 300 MJ. (b) **What-if Scenario:** How would the answer change if the block were made of silver (Ag)?

SOLUTION



5-1-69 [BVV] A container containing 5 kg of CO2 is heated from a temperature of 300 K. Using the SL Simulator RIA (linked from left margin), (a) determine the final temperature (T_2) of the block if the heat input is 1 MJ. (b) **What-if Scenario:** What would be the final temperature if heat input was 5 MJ?

SOLUTION