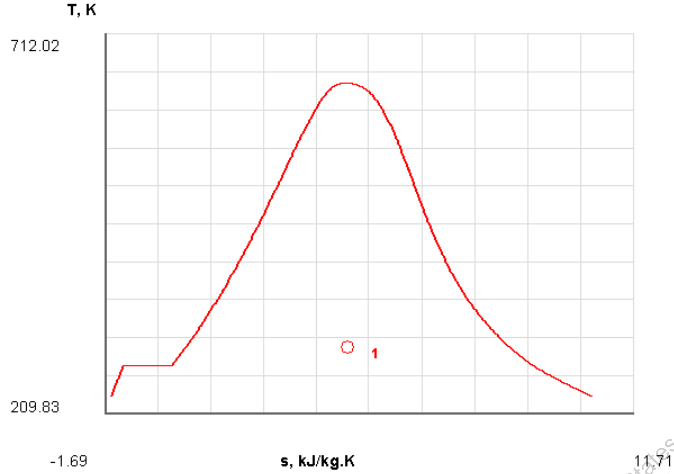
3-3-1 [YL] A cylinder contains H_2O (and nothing else). The outside temperature is 298 K. To analytically determine the pressure inside, you figure that the temperature of H_2O must be also 298 K. Also, you shake the cylinder and realize that it is only partially filled with liquid water. You say, "Aha", consult a chart, and come up with the answer. What is the pressure (in kPa)?

SOLUTION



After shaking the cylinder containing only H_2O and realizing that it is only partially filled with liquid water, it can be concluded that the H_2O inside the cylinder is a saturated mixture and therefore the pressure is

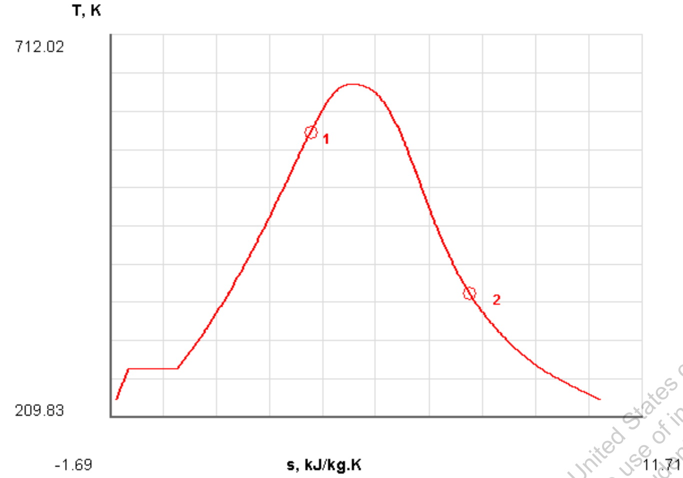
$$p_{sat@298K} = 3.17 \text{ kPa}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-2 [YZ] Saturated liquid water flows through a pipe at 10 MPa. Assuming thermodynamic equilibrium to exist at any given cross-section, (a) determine the temperature (*T*) and (b) the quality of water. A small leak develops and as water jets out, it quickly equilibrates with the pressure outside, which is at 100 kPa. Some of the water evaporates and the composition of the jet is observed as a mixture of saturated liquid and vapor. Determine (c) the temperature of the jet in ^{o}C.

SOLUTION



(a) Looking at the Pressure Saturation Chart for water (Table-B.1)

$$T_{\text{sat@10MPa}} = 311°\text{C}$$

(b) The quality of the water

$$x = \frac{m_v}{m}; \quad \Rightarrow x = \frac{0}{m}; \quad \Rightarrow x = 0$$

(c) When a leak develops, the pressure inside equalizes to the outside pressure.
Looking at the Pressure Saturation Chart for water (Table-B.1)

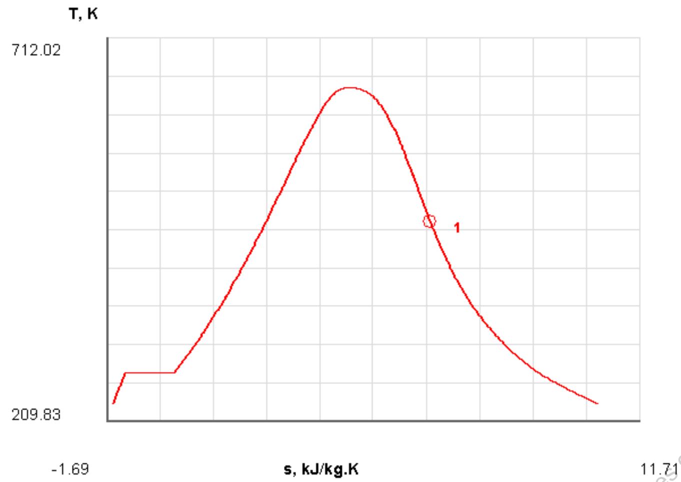
$$T_{\text{sat@100kPa}} = 99.63°\text{C}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-3 [YU] A 30-cm diameter pipe carries H_2O at a rate of 10 kg/s. At a certain cross-section, steam is found to be saturated vapor at 200°C. Determine (a) the pressure (kPa) and (b) velocity (m/s).

SOLUTION



(a) Using Table B.2

$$P_{sat} \ @ \ 200^\circ\mathrm{C} = 1553.8 \text{ kPa}$$

(b) Using Table B.2

$$v_g = 0.12736 \frac{\mathrm{m}^3}{\mathrm{kg}}; \quad \Rightarrow \rho = \frac{1}{v_g}; \quad \Rightarrow \rho = 7.85175 \frac{\mathrm{kg}}{\mathrm{m}^3};$$

$$\dot{m} = \rho A V; \quad \Rightarrow V = \frac{\dot{m}}{\rho A}; \quad \Rightarrow V = \frac{10}{(7.85175)\left(\frac{\pi}{4}(0.3)^2\right)}; \quad \Rightarrow V = 18.02 \frac{\mathrm{m}}{\mathrm{s}}$$

TEST Solution:

Launch the PC open steady state single-flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-4 [YK] For H_2O, locate (qualitatively) the following states on a *T-s* and a *p-v* diagram. State-1: p = 100 kPa, T = 50°C; State-2: p = 5 kPa, T = 50°C; State-3: p = 500 kPa, x = 50%.

SOLUTION

State-1: $p = 100$ kPa, $T = 50^\circ$C

Using Table-B.1

T_{sat} @ 100 kPa $= 99.63^\circ$C;

Since $T_1 < T_{sat}$ @ 100 kPa, we can determine that State-1 is a sub-cooled liquid located on the 100 kPa constant pressure line.

State-2: $p = 5$ kPa, $T = 50^\circ$C

Using Table-B.1

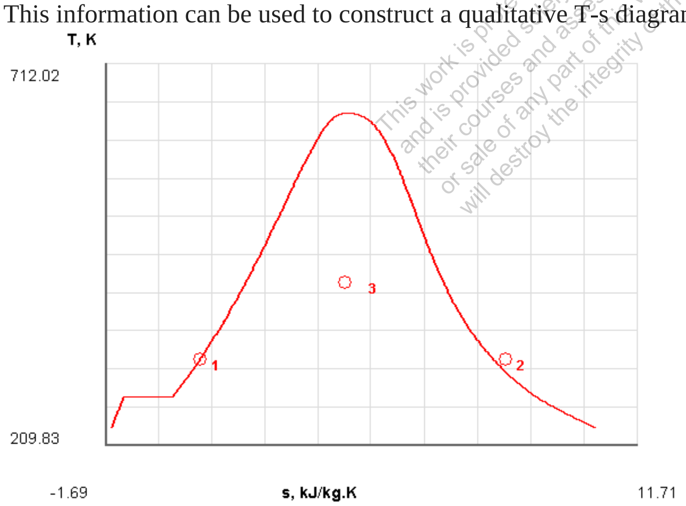
T_{sat} @ 5 kPa $= 32.88^\circ$C;

Since $T_2 > T_{sat}$ @ 5 kPa, we can determine that State-2 is a super-heated vapor located on the 5 kPa constant pressure line.

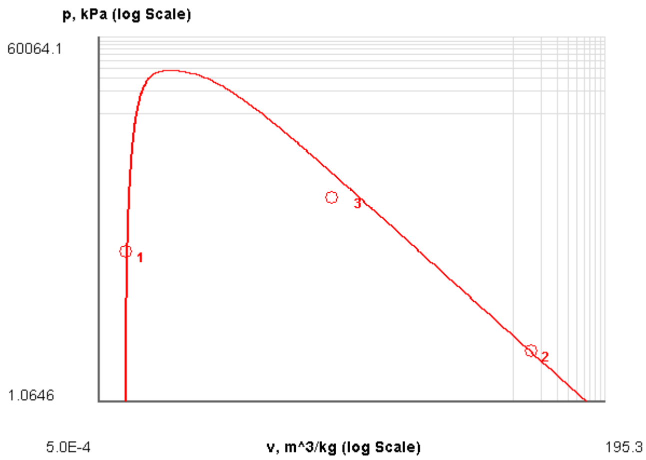
State-3: $p = 500$ kPa, x=0.5

Since the pressure is given, State-3 will lie on the 500 kPa constant pressure line. The second known property, x = 0.5, tells us the state's exact location, halfway between the f and g points at this pressure.

This information can be used to construct a qualitative T-s diagram displaying these states.



This information can be used to construct a qualitative p-v diagram displaying these states.



TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-5 [YP] For H_2O, locate (qualitatively) the following states on a *T-s* and a *p-v* diagram. State-1: p = 10 kPa, saturated liquid; State-2: p = 1 MPa, $s = s_1$; State-3: $p = p_2$, T = 500°C State-4: $p = p_1$, saturated vapor.

SOLUTION

State-1: $p = 10$ kPa, saturated liquid

The first property, *p*, tells us that State-1 will be located on the 10 kPa constant pressure line. The second known property is that State-1 is a saturated liquid or x = 0 which means that State-1 will be located at the f point on the T-s diagram for this pressure.

State-2: $p = 1$ MPa, $s = s_1$

The first property, *p*, tells us that State-2 will be located on the 1 MPa constant pressure line. Knowing that $s = s_1$ tells us that State-2 is vertically aligned with State-1.

State-3: $p = p_2$, $T = 500^\circ$C

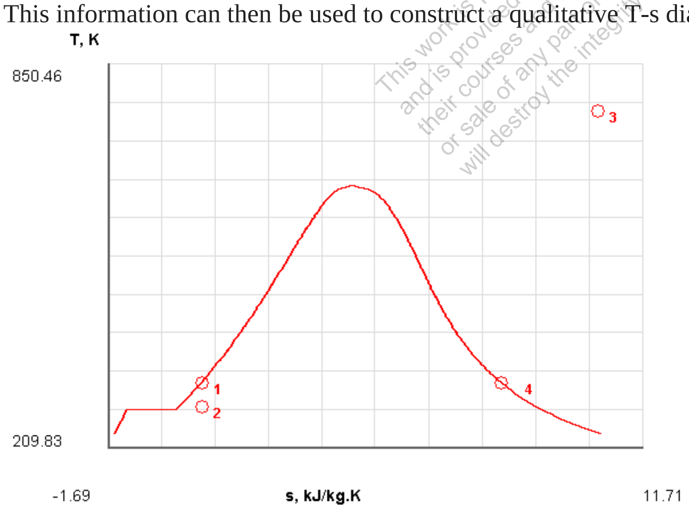
Using TableB.1, T_{sat} @ 1 MPa $= 179.91^\circ$C

Since $T_3 > T_{sat}$ @ 1 MPa, it can be determined that State-3 is a super-heated vapor and knowing that $p = p_2$, it will be located on the 1 MPa constant pressure line.

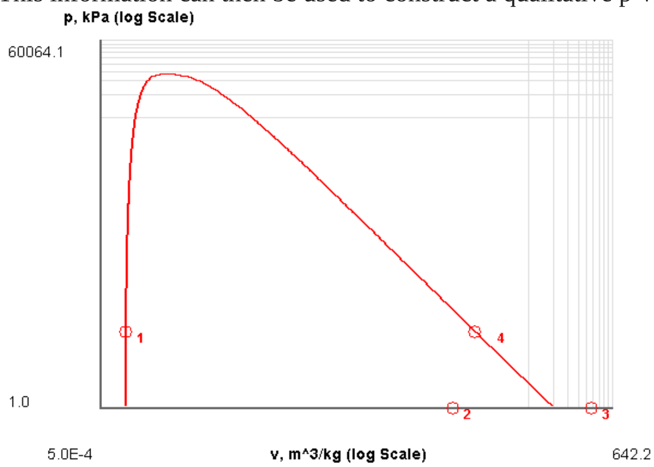
State-4: $p = p_1$, saturated vapor

The first property, *p*, tells us that State-4 will be located on the 10 kPa constant pressure line. The second known property is that State-4 is a saturated vapor or x = 1 which means that State-4 will be located at the g point on the T-s diagram for this pressure.

This information can then be used to construct a qualitative T-s diagram displaying these states.



This information can then be used to construct a qualitative p-v diagram displaying these states.



TEST Solution:

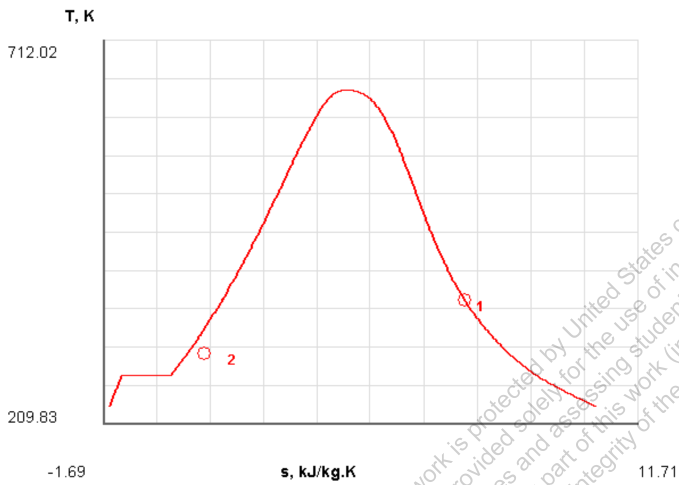
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-6 [YX] A sealed rigid tank contains saturated steam at 100 kPa. As the tank cools down to the temperature of the surrounding atmosphere, the quality of the steam drops to 5%. Using a *T-s* diagram, explain why the pressure in the tank must decrease drastically to satisfy thermodynamic equilibrium.

SOLUTION

Observation of a *T-s* diagram reveals that all constant pressure lines lie in horizontal fashion under the saturation dome (constant temperature). Therefore, a decrease in temperature must be accompanied by a decrease in pressure.

The second property, x = 0.05, identifies the final states position between the f and g points at the final pressure.



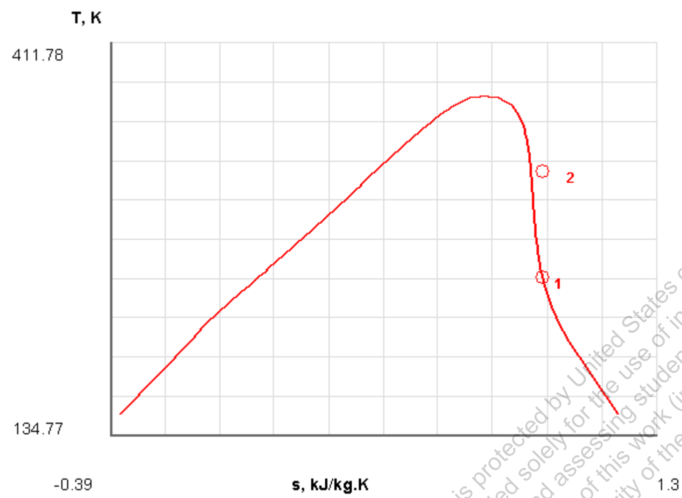
TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-7 [YC] An isentropic compressor is used to raise the pressure of a refrigerant, entering the compressor as saturated vapor. Using a *T-s* diagram, explain why the temperature at the exit can be expected to be higher than that at the inlet.

SOLUTION

On a *T-s* diagram, an isentropic process is represented as a change in the vertical direction only $(\Delta s = 0)$. Raising the pressure of a refrigerant from p_i to p_f with a pump tells us that this change will be in the positive vertical direction. Since the dependent axis of a *T-s* diagram measures the temperature, it can be concluded that an increase in temperature will take place.



TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-8 [YV] A pipe carries saturated liquid water at a pressure of 500 kPa. Some water squirts out from the pipe through a small leak. As the water is expelled, it quickly achieves mechanical equilibrium with the atmosphere at 100 kPa. (a) Estimate the temperature of water inside and outside the pipe. What-if Scenario: What would the answers be if the fluid were (b) R-134a or (c) R-12 instead?

SOLUTION

(a) H20

State-1: (inside the pipe) $p_1 = 500$ kPa, saturated liquid (x = 0)

Using Table-B.1

$$T_1 = T_{sat} \ @\ 500 \text{ kPa} = 151.86^\circ\text{C} \text{ and } s_1 = s_f \ @\ 500 \text{ kPa} = 1.8607 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: (outside the pipe) $p_2 = 100$ kPa, $s_2 = s_1 = 1.8607 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table=B.1

$$s_f = 1.3026 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \text{ and } s_g = 7.3594 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\Rightarrow s_f < s_2 < s_g; \quad \Rightarrow \text{State-2 is a mixture (L + V);}$$

$$T_2 = T_{sat} \ @\ 100 \text{ kPa} = 99.63^\circ\text{C}$$

(b) R-134a

State-1: (inside the pipe) $p_1 = 500$ kPa, saturated liquid (x = 0)

Using Table-B.5

$$T_1 = T_{sat} \ @\ 500 \text{ kPa} = 15.65^\circ\text{C} \text{ and } s_1 = s_f \ @\ 500 \text{ kPa} = 0.276 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: (outside the pipe) $p_2 = 100$ kPa, $s_2 = s_1 = 0.276 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.5

$$s_f = 0.0684 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \text{ and } s_g = 0.9465 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\Rightarrow s_f < s_2 < s_g; \quad \Rightarrow \text{State-2 is a mixture (L + V);}$$

$$T_2 = T_{sat} \ @\ 100 \text{ kPa} = -26.5866^\circ\text{C}$$

(c) R-12

State-1: (inside the pipe) $p_1 = 500$ kPa, saturated liquid (x = 0)

$$T_1 = T_{sat} \ @\ 500 \text{ kPa} = 15.58^\circ\text{C} \text{ and } s_1 = s_f \ @\ 500 \text{ kPa} = 0.1934 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: (outside the pipe) $p_2 = 100 \text{ kPa}, \ s_2 = s_1 = 0.1934 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$

$s_f = 0.0367 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$; and $s_g = 0.717 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$;

$\Rightarrow s_f < s_2 < s_g$; $\Rightarrow$ State-2 is a mixture (L + V);

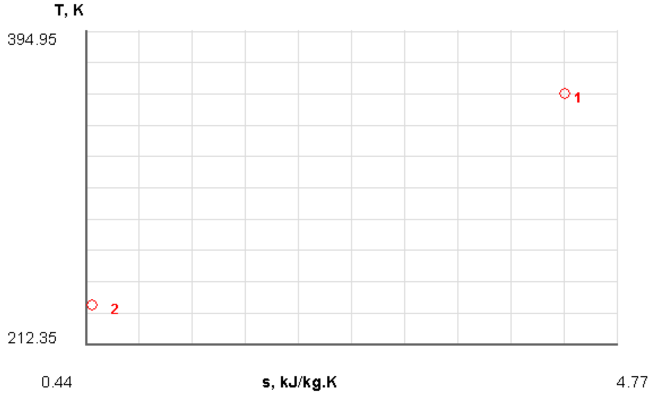
$T_2 = T_{\text{sat}}$ @ 100 kPa $= -30.097^\circ\text{C}$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-9 [YY] An insulated piston inside an insulated rigid cylinder, closed at both ends, creates two chambers: one containing a two-phase mixture of H_2O and another containing a two-phase mixture of R-134a. If the temperature inside the chamber containing H2O is 85.9^{o}C, determine the temperature inside the other chamber. Assume mechanical equilibrium.

SOLUTION



Using Table B.2

P_{sat} @ 85.9°C $= 59.83$ kPa;

Since there is an insulated piston inside an insulated rigid cylinder, the pressure of the R-134a is equal to the pressure of the H_2O. Therefore,

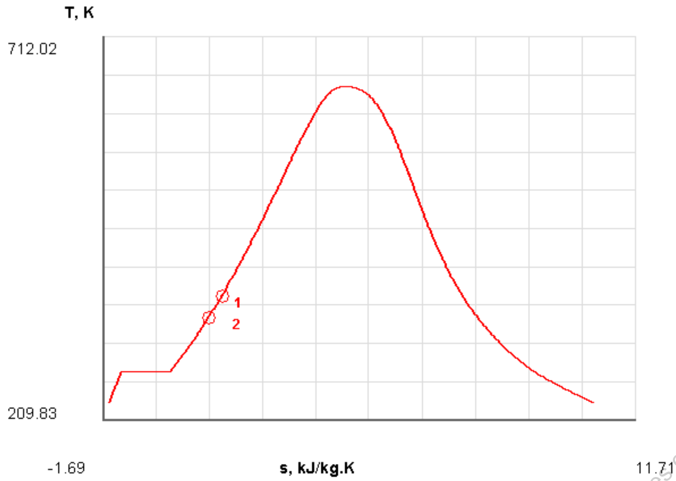
T_{sat} @59.83 kPa = -37.2°C

TEST Solution:

Launch the PC/PC non-uniform non-mixing closed system TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-10 [YQ] Determine the boiling temperature of water (a) at sea level and (b) atop Mount Everest (elevation 8,848 m). Use Table H-3 to look up the pressure of atmosphere at different altitudes.

SOLUTION



(a) Using Table H-3, the air pressure at sea level is found to be
$p_{0\,\mathrm{m}} = 101.33\ \mathrm{kPa};$

Using Table-B.1, the boiling temperature of water at sea level is found to be
$T_{\mathrm{sat}} = 99.98^{\circ}\mathrm{C}$

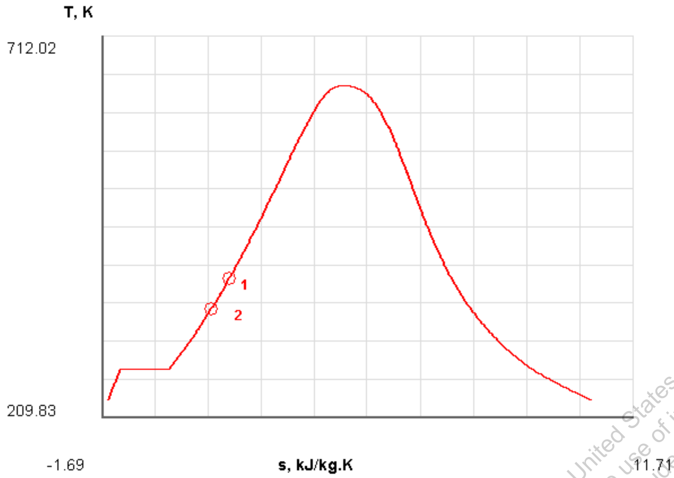
(b) Using Table H-3, the air pressure atop Mount Everest is found to be
$p_{8848\,\mathrm{m}} = 31.53\ \mathrm{kPa};$

Using Table-B.1, the boiling temperature of water atop Mount Everest is found to be
$T_{\mathrm{sat}} = 70.24^{\circ}\mathrm{C}$

TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-11 [YT] A vertical piston-cylinder assembly contains water. The piston has a mass of 2 kg and a diameter of 10 cm. Determine the vertical force necessary on the piston to ensure that water inside the cylinder boils at (a) 120°C or (b) 80°C. Assume atmospheric pressure to be 101 kPa. (c) What-if Scenario: What would the answer in part (a) be if the piston mass were neglected?

SOLUTION



Using Table-B.2

p_{sat} @ $120^\circ\text{C} = 198.53$ kPa;

p_{sat} @ $80^\circ\text{C} = 47.39$ kPa;

At saturation pressure, pressure equilibrium is defined as

$$p_{sat} = p_o + \frac{F_{app} + \dfrac{m_{piston}g}{1000}}{A_{piston}};$$

$$\Rightarrow F_{app} = (p_{sat} - p_o)\pi r^2 - \frac{m_{piston}g}{1000};$$

(a) At 120°C

$$F_{app} = (198.53 - 101)\pi(0.05)^2 - \frac{2(9.81)}{1000}; \qquad \Rightarrow F_{app} = 0.746 \text{ kN}$$

(b) At 80°C

$$F_{app} = (47.39 - 101)\pi(0.05)^2 - \frac{2(9.81)}{1000}; \qquad \Rightarrow F_{app} = -0.441 \text{ kN}$$

(c) If the piston mass was neglected

$$\Rightarrow \mathrm{F}_{\mathrm{app}} = \left(p_{\mathrm{sat}} - p_{\mathrm{o}}\right)\pi \mathrm{r}^2 - \frac{\cancel{m}^{0}_{\mathrm{piston}}\, g}{1000};$$

$$\Rightarrow \mathrm{F}_{\mathrm{app}} = \left(p_{\mathrm{sat}} - p_{\mathrm{o}}\right)\pi \mathrm{r}^2;$$

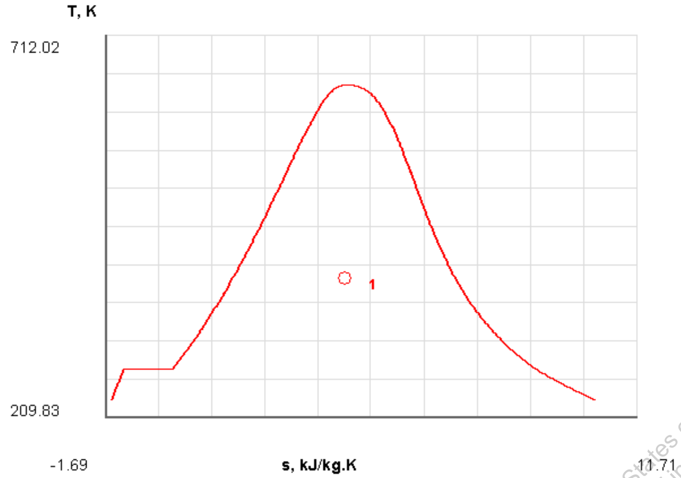
$$\mathrm{F}_{\mathrm{app}} = (198.53 - 101)\pi(0.05)^2; \qquad \Rightarrow \mathrm{F}_{\mathrm{app}} = 0.766 \text{ kN}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-12 [YF] A vertical piston-cylinder assembly contains a saturated mixture of water at 120°C and a gauge pressure of 108.5 kPa. The piston has a mass of 5 kg and a diameter of 12 cm. Determine (a) the atmospheric pressure outside and (b) the external force exerted on the piston to maintain a constant pressure.

SOLUTION



Using Table-B.2

p_{sat} @ $120^{\circ}\mathrm{C} = 198.53$ kPa;

(a) $p_{inside} = p_{sat} = p_o + p_{gauge}$;

$$\Rightarrow p_o = p_{sat} - p_{gauge};$$

$$p_o = 198.53 - 108.5; \quad \Rightarrow p_o = 90.03 \text{ kPa}$$

(b) Under equilibrium conditions, the pressure balance on this system can be described as

$$p_{sat} = p_o + \frac{\mathrm{F_{app}} + \dfrac{m_{piston}g}{1000}}{\mathrm{A_{piston}}};$$

$$\Rightarrow \mathrm{F_{app}} = \left(p_{sat} - p_o\right)\pi r^2 - \frac{m_{piston}g}{1000};$$

$$\Rightarrow \mathrm{F_{app}} = p_{gage}\pi r^2 - \frac{m_{piston}g}{1000};$$

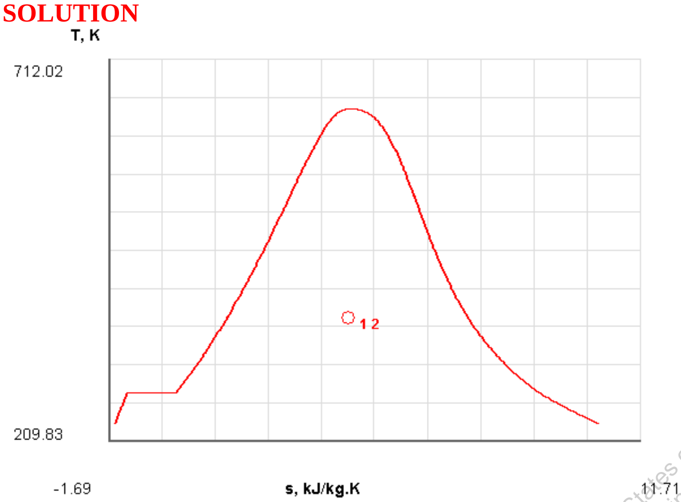
$$\mathrm{F_{app}} = 108.5\pi\left(0.06\right)^2 - \frac{5(9.81)}{1000}; \quad \Rightarrow \mathrm{F_{app}} = 1.178 \text{ kN}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-13 [YD] A cooking pan with an inner diameter of 20 cm is filled with water and covered with a lid of mass 5 kg. If the atmospheric pressure is 100 kPa, determine (a) the boiling temperature of water. (b) What-if Scenario: What would the boiling temperature be if a 5 kg block were placed on top of the lid?

SOLUTION



(a) By treating the lid as a piston-like device, the pressure of the water can be determined as

$$p_i = p_o + \frac{m_{lid} g}{1000 A_{lid}}; \quad \Rightarrow p_i = 100 + \frac{5(9.81)}{1000\pi(0.1)^2}; \quad \Rightarrow p_i = 101.56 \text{ kPa};$$

Using Table-B.1

T_{sat} @ 101.56 kPa = 100.04°C

(b) If a mass of 5 kg were placed on top of the lid, the pressure equilibrium equation would become

$$p_i = p_o + \frac{(m_{lid} + m_{weight}) g}{1000 A_{lid}}; \quad \Rightarrow p_i = 100 + \frac{(5+5)(9.81)}{1000\pi(0.1)^2}; \quad \Rightarrow p_i = 103.123 \text{ kPa};$$

Using Table-B.1

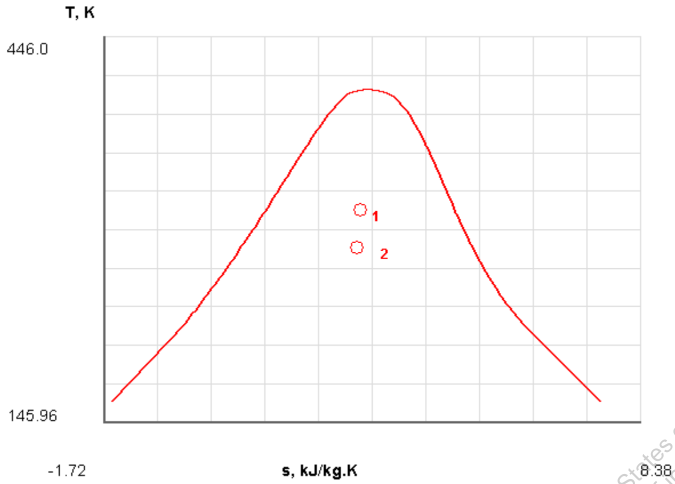
T_{sat} @ 103.123 kPa = 100.46°C

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-14 [YM] A heat engine cycle is executed with ammonia in the saturation dome. The pressure of ammonia is 1.5 MPa during heat addition and 0.6 MPa during heat rejection. What is the highest possible thermal efficiency? Based on the temperatures of heat addition and rejection, could you comment on possible application of such a low-efficiency cycle?

SOLUTION



Under the saturation dome, the highest efficiency possible will occur when 2 intermediate isentropic processes are executed.

$$\eta_{\text{th, max}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}};$$

$$q = T\Delta s;$$

The efficiency can now be rewritten as

$$\eta_{\text{th, max}} = 1 - \frac{T_{\text{L}}\Delta s}{T_{\text{H}}\Delta s}; \qquad \Rightarrow \eta_{\text{th, max}} = 1 - \frac{T_{\text{L}}}{T_{\text{H}}};$$

Where

$$T_{\text{L}} = T_{\text{sat}} \text{ @ } 0.6 \text{ MPa} = 282.41 \text{ K};$$

$$T_{\text{H}} = T_{\text{sat}} \text{ @ } 1.5 \text{ MPa} = 311.84 \text{ K};$$

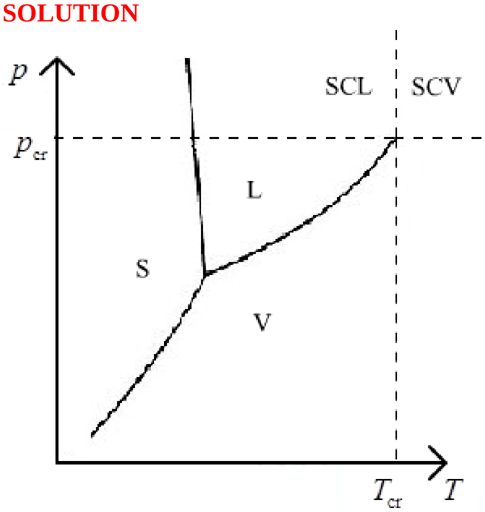
$$\eta_{\text{th, max}} = 1 - \frac{282.41}{311.84}; \qquad \Rightarrow \eta_{\text{th, max}} = 0.0944; \qquad \Rightarrow \eta_{\text{th, max}} = 9.44\%$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-15 [FR] Plot how the saturation temperature of water increases with pressure. Use the full range - from the triple point to critical point.

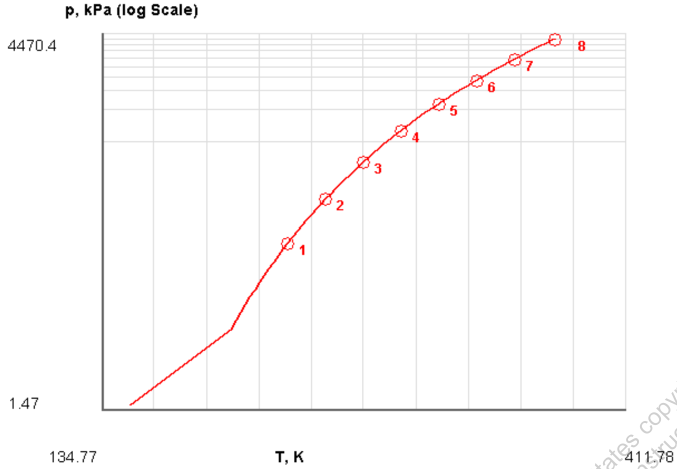
SOLUTION



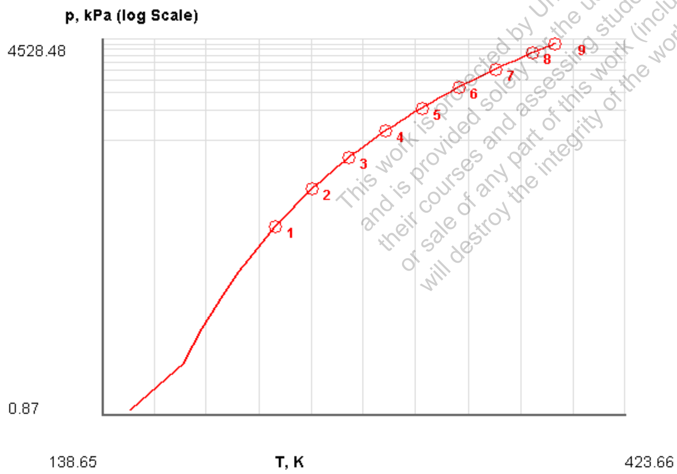
3-3-16 [YJ] Plot the phase diagram (p-T) for the following refrigerants for a temperature range from -40°C to the critical temperature: (a) R-134a, (b) R-12 and (c) NH_3. Use a log scale for pressure and linear scale for temperature.

SOLUTION

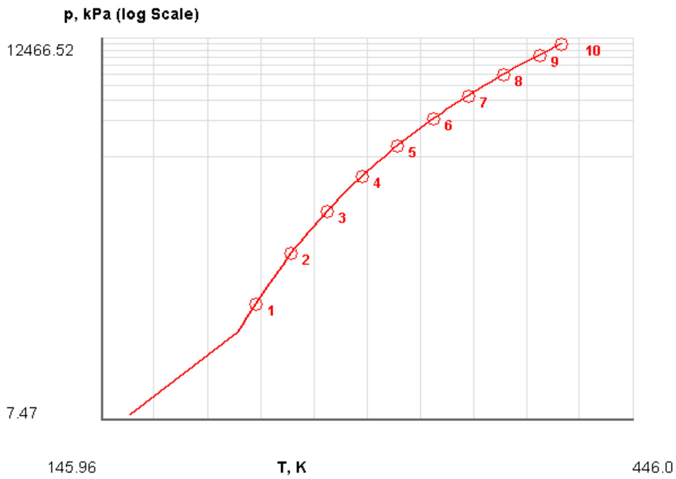
(a) R-134a



(b) R-12



(c) NH_3



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-17 [YW] Complete the following property table for H_2O. Also locate the states on a *T-s* diagram (qualitatively).

SOLUTION

State-1: $p_1 = 100$ kPa; $T_1 = 20^\circ\text{C}$

Using Table-B.1,

$T_{\text{sat @ 100 kPa}} = 99.63^\circ\text{C}$;

Since $T_1 < T_{\text{sat @ 100 kPa}}$, State-1 is a sub-cooled liquid, therefore the CL sub-model assumptions can be made. $x_1 = \text{N/A}$

Using Table-B.2,

$$v_1 = v_{f\ @\ 20^\circ\text{C}} = 0.001002\ \frac{\text{m}^3}{\text{kg}}$$

$$u_1 = u_{f\ @\ 20^\circ\text{C}} = 83.95\ \frac{\text{kJ}}{\text{kg}}$$

$$h_1 = u_1 + p_1 v_1; \quad \Rightarrow h_1 = 83.95 + 100(0.001002); \quad \Rightarrow h_1 = 84.05\ \frac{\text{kJ}}{\text{kg}}$$

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

State-2: $p_2 = 100$ kPa, $h_2 = 209.42\ \frac{\text{kJ}}{\text{kg}}$

Using Table-B.2

$h_2 \cong h_{f\ @\ 50^\circ\text{C}}; \quad \Rightarrow T_2 \cong 50^\circ\text{C}$

Using Table-B.1

$T_{\text{sat @ 100 kPa}} = 99.63^\circ\text{C}$; Since $T_2 < T_{\text{sat @ 100 kPa}}$, State-2 is a sub-cooled liquid, therefore the CL sub-model assumptions can be made. $x_2 = \text{N/A}$

Using Table-B.2

$$v_2 = v_{f\ @\ 50^\circ\text{C}} = 0.001012\ \frac{\text{m}^3}{\text{kg}}$$

$$u_2 = u_{f\ @\ 50^\circ\text{C}} = 209.32\ \frac{\text{kJ}}{\text{kg}}$$

$$s_2 = s_{f\ @\ 50^\circ\text{C}} = 0.7038\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

State-3: $x_3 = 0.5$, $v_3 = 0.8475\ \frac{\text{m}^3}{\text{kg}}$

Since x_3 is given, State-3 is a saturated mixture.

Neglecting v_f, $v_3 \cong x_3 v_g$; $\quad \Rightarrow v_g \cong \dfrac{v_3}{x_3}$; $\quad \Rightarrow v_g = \dfrac{0.8475}{0.5}$; $\quad \Rightarrow v_g = 1.695\ \dfrac{\text{m}^3}{\text{kg}}$;

Using Table-B.2

$v_g \cong v_{g\ @\ 100^\circ\text{C}}$; $\quad \Rightarrow T_3 = 100^\circ\text{C}$

$p_3 = p_{\text{sat}\ @\ 100^\circ\text{C}}$; $\quad \Rightarrow p_3 = 101.35\ \text{kPa}$

$$\left.\begin{aligned} u_{f\ @\ 100^\circ\text{C}} &= 418.94\ \frac{\text{kJ}}{\text{kg}} \\ u_{g\ @\ 100^\circ\text{C}} &= 2506.5\ \frac{\text{kJ}}{\text{kg}} \end{aligned}\right\rangle\ u_3 = u_f + x_3\left(u_g - u_f\right); \quad \Rightarrow u_3 = 1462.72\ \frac{\text{kJ}}{\text{kg}}$$

$$\left.\begin{aligned} h_{f\ @\ 100^\circ\text{C}} &= 419.04\ \frac{\text{kJ}}{\text{kg}} \\ h_{g\ @\ 100^\circ\text{C}} &= 2676.1\ \frac{\text{kJ}}{\text{kg}} \end{aligned}\right\rangle\ h_3 = h_f + x_3\left(h_g - h_f\right); \quad \Rightarrow h_3 = 1574.57\ \frac{\text{kJ}}{\text{kg}}$$

$$\left.\begin{aligned} s_{f\ @\ 100^\circ\text{C}} &= 1.3067\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \\ s_{g\ @\ 100^\circ\text{C}} &= 7.3549\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \end{aligned}\right\rangle\ s_3 = s_f + x_3\left(s_g - s_f\right); \quad \Rightarrow s_3 = 4.3308\ \frac{\text{kJ}}{\text{kg}}$$

State-4: $T_4 = 100^\circ\text{C}$, $u_4 = 2297.2\ \dfrac{\text{kJ}}{\text{kg}}$

Using Table-B.2

$u_{f\ @\ 100^\circ\text{C}} = 418.94\ \dfrac{\text{kJ}}{\text{kg}}$;

$u_{g\ @\ 100^\circ\text{C}} = 2506.5\ \dfrac{\text{kJ}}{\text{kg}}$;

Since $u_f < u_4 < u_g$, State-4 is a saturated mixture.

$\Rightarrow p_4 = p_{\text{sat}\ @100^\circ\text{C}}$; $\quad \Rightarrow p_4 = 101.35\ \text{kPa}$

$x_4 = \dfrac{u_4 - u_f}{u_g - u_f}$; $\quad \Rightarrow x_4 = \dfrac{2297.2 - 418.94}{2506.5 - 418.94}$; $\quad \Rightarrow x_4 = 0.8997$

$$\left.\begin{aligned} v_{f\ @\ 100^\circ\text{C}} &= 0.001044\ \frac{\text{m}^3}{\text{kg}} \\ v_{g\ @\ 100^\circ\text{C}} &= 1.6729\ \frac{\text{m}^3}{\text{kg}} \end{aligned}\right\rangle\ v_4 = v_f + x_4\left(v_g - v_f\right); \quad \Rightarrow v_4 = 1.5052\ \frac{\text{m}^3}{\text{kg}}$$

$$\left.\begin{array}{l} h_{f\ @\ 100^\circ\mathrm{C}} = 419.04\ \dfrac{\mathrm{kJ}}{\mathrm{kg}} \\ h_{g\ @\ 100^\circ\mathrm{C}} = 2676.1\ \dfrac{\mathrm{kJ}}{\mathrm{kg}} \end{array}\right\rangle h_4 = h_f + x_4\left(h_g - h_f\right); \qquad \Rightarrow h_4 = 2449.72\ \frac{\mathrm{kJ}}{\mathrm{kg}}$$

$$\left.\begin{array}{l} s_{f\ @\ 100^\circ\mathrm{C}} = 1.3067\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}} \\ s_{g\ @\ 100^\circ\mathrm{C}} = 7.3549\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}} \end{array}\right\rangle s_4 = s_f + x_4\left(s_g - s_f\right); \qquad \Rightarrow s_4 = 6.7483\ \frac{\mathrm{kJ}}{\mathrm{kg}}$$

State-5: $T_5 = 200^\circ\mathrm{C},\ s_5 = 7.8342\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}}$

Using Table-B.2

$s_{g\ @\ 200^\circ\mathrm{C}} = 6.4323\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}};$

Since $s_5 > s_{g\ @\ 200^\circ\mathrm{C}}$, State-5 is a superheated vapor. $x_5 = \mathrm{N/A}$

Using Table-B.3

$\Rightarrow p_5 = 100\ \mathrm{kPa}$

$v_5 = v_{200^\circ\mathrm{C},\ 100\ \mathrm{kPa}}; \qquad \Rightarrow v_5 = 2.172\ \dfrac{\mathrm{m^3}}{\mathrm{kg}}$

$u_5 = u_{200^\circ\mathrm{C},\ 100\ \mathrm{kPa}}; \qquad \Rightarrow u_5 = 2658.1\ \dfrac{\mathrm{kJ}}{\mathrm{kg}}$

$h_5 = h_{200^\circ\mathrm{C},\ 100\ \mathrm{kPa}}; \qquad \Rightarrow h_5 = 2875.3\ \dfrac{\mathrm{kJ}}{\mathrm{kg}}$

State-6: $v_6 = 3.5654\ \dfrac{\mathrm{m^3}}{\mathrm{kg}},\ u_6 = 3131.5\ \dfrac{\mathrm{kJ}}{\mathrm{kg}}$

Using Table-B.3

$p_6 = 100\ \mathrm{kPa}$

$\Rightarrow x = \mathrm{N/A}$

$T_6 = 500^\circ\mathrm{C}$

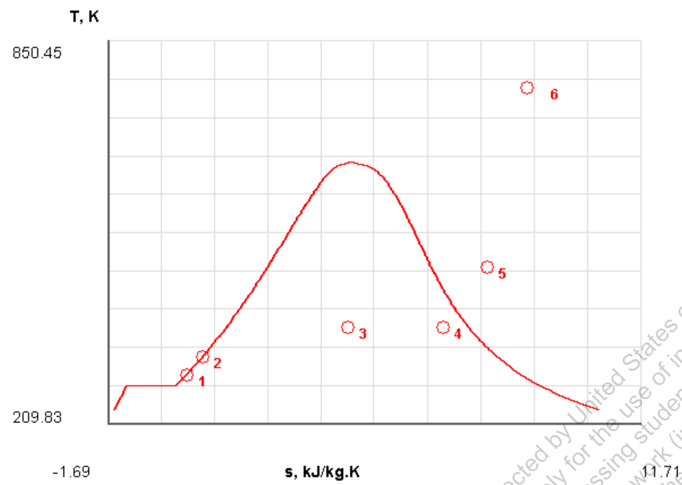
$h_6 = h_{100\ \mathrm{kPa},\ 500^\circ\mathrm{C}}; \qquad \Rightarrow h_6 = 3488.1\ \dfrac{\mathrm{kJ}}{\mathrm{kg}}$

$s_6 = s_{100\ \mathrm{kPa},\ 500^\circ\mathrm{C}}; \qquad \Rightarrow s_6 = 8.8342\ \dfrac{\mathrm{kJ}}{\mathrm{kg\cdot K}}$

These values can be used to complete the property table and draw a qualitative T-s diagram.

State	p (kPa)	T (°C)	x (%)	v (m³/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg.K)

1	100	20	N/A	0.001002	83.95	84.05	0.2966
2	100	50	N/A	0.001012	209.32	209.42	0.7038
3	101.35	100	50	0.8475	1462.72	1574.57	4.3308
4	101.35	100	89.97	1.5052	2297.2	2449.72	6.7483
5	100	200	N/A	2.172	2658.1	2875.3	7.8342
6	100	500	N/A	3.5654	3131.5	3448.1	8.8342



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-18 [FO] Complete the following property table for Refrigerant-134a. Also locate the states on a *T-s* diagram (qualitatively).

SOLUTION

State-1: $T_1 = -20^\circ\text{C},\ x_1 = 1$

With $x_1 = 1,$ state-1 is a saturated vapor.

Using Table-B.6

$p_1 = p_{\text{sat @ -20}^\circ\text{C}};\quad \Rightarrow p_1 = 132.99\ \text{kPa}$

$v_1 = v_{g\ @\ \text{-20}^\circ\text{C}};\quad \Rightarrow v_1 = 0.1464\ \dfrac{\text{m}^3}{\text{kg}}$

$u_1 = u_{g\ @\ \text{-20}^\circ\text{C}};\quad \Rightarrow u_1 = 215.84\ \dfrac{\text{kJ}}{\text{kg}}$

$h_1 = h_{g\ @\ \text{-20}^\circ\text{C}};\quad \Rightarrow h_1 = 235.31\ \dfrac{\text{kJ}}{\text{kg}}$

$s_1 = s_{g\ @\ \text{-20}^\circ\text{C}};\quad \Rightarrow s_1 = 0.9322\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$

State-2: $p_2 = 1000\ \text{kPa},\ s_2 = s_1 = 0.9322\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$

With a higher pressure and no change in specific entropy from State-1, State-2 is a superheated vapor. $x_2 = \text{N/A}$

Using Table-B.7

$s_2 \cong s_{1000\ \text{kPa, 50}^\circ\text{C}};\quad \Rightarrow T_2 = 50^\circ\text{C}$

$v_2 = v_{1000\ \text{kPa, 50}^\circ\text{C}};\quad \Rightarrow v_2 = 0.02171\ \dfrac{\text{m}^3}{\text{kg}}$

$u_2 = u_{1000\ \text{kPa, 50}^\circ\text{C}};\quad \Rightarrow u_2 = 258.48\ \dfrac{\text{kJ}}{\text{kg}}$

$h_2 = h_{1000\ \text{kPa, 50}^\circ\text{C}};\quad \Rightarrow h_2 = 280.19\ \dfrac{\text{kJ}}{\text{kg}}$

State-3: $p_3 = p_2 = 1000\ \text{kPa},\ x_3 = 0$

Since $x_3 = 0,$ State-3 is a saturated liquid.

Using Table-B.5

$T_3 = T_{\text{sat @ 1000 kPa}};\quad \Rightarrow T_3 = 39.39^\circ\text{C}$

$v_3 = v_{f\ @\ 1000\ \text{kPa}};\quad \Rightarrow v_3 = 0.00087\ \dfrac{\text{m}^3}{\text{kg}}$

$$u_3 = u_{f\ @\ 1000\ \text{kPa}}; \qquad \Rightarrow u_3 = 104.42\ \frac{\text{kJ}}{\text{kg}}$$

$$h_3 = h_{f\ @\ 1000\ \text{kPa}}; \qquad \Rightarrow h_3 = 105.29\ \frac{\text{kJ}}{\text{kg}}$$

$$s_3 = s_{f\ @\ 1000\ \text{kPa}}; \qquad \Rightarrow s_3 = 0.3838\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

State-4: $p_4 = p_1 = 139.99\ \text{kPa},\ h_4 = h_3 = 105.29\ \frac{\text{kJ}}{\text{kg}}$

Using Table-B.5

$$\left.\begin{array}{l} h_{f\ @\ 132.99\ \text{kPa}} = 24.6\ \frac{\text{kJ}}{\text{kg}} \\ h_{g\ @\ 132.99\ \text{kPa}} = 237.02\ \frac{\text{kJ}}{\text{kg}} \end{array}\right\rangle h_f < h_6 < h_g; \qquad \Rightarrow \text{State-6 is a saturated mixture}$$

$$T_4 = T_{\text{sat}\ @\ 132.99\ \text{kPa}} = -20.13^\circ\text{C}$$

$$x_4 = \frac{h_4 - h_f}{h_g - h_f}; \qquad \Rightarrow x_4 = \frac{105.29 - 24.6}{237.02 - 24.6}; \qquad \Rightarrow x_4 = 0.38$$

$$\left.\begin{array}{l} v_{f\ @\ 132.99\ \text{kPa}} = 0.00074\ \frac{\text{m}^3}{\text{kg}} \\ v_{g\ @\ 132.99\ \text{kPa}} = 0.1473\ \frac{\text{m}^3}{\text{kg}} \end{array}\right\rangle v_4 = v_f + x_4\left(v_g - v_f\right); \qquad \Rightarrow v_4 = 0.0567\ \frac{\text{m}^3}{\text{kg}}$$

$$\left.\begin{array}{l} u_{f\ @\ 132.99\ \text{kPa}} = 24.5\ \frac{\text{kJ}}{\text{kg}} \\ u_{g\ @\ 132.99\ \text{kPa}} = 217.44\ \frac{\text{kJ}}{\text{kg}} \end{array}\right\rangle u_4 = u_f + x_4\left(u_g - u_f\right); \qquad \Rightarrow u_4 = 107.13\ \frac{\text{kJ}}{\text{kg}}$$

$$\left.\begin{array}{l} s_{f\ @\ 132.99\ \text{kPa}} = 0.101\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \\ s_{g\ @\ 132.99\ \text{kPa}} = 0.941\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \end{array}\right\rangle s_4 = s_f + x_4\left(s_g - s_f\right); \qquad \Rightarrow s_4 = 0.456\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

These values can be used to complete the property table and draw a qualitative T-s diagram.

State	P (kPa)	T (°C)	x (%)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
1	132.99	-20	100	0.1464	215.84	235.31	0.9322
2	1000	50	N/A	0.02171	258.48	280.19	0.9322
3	1000	39.39	0	0.00087	104.42	105.29	0.3838

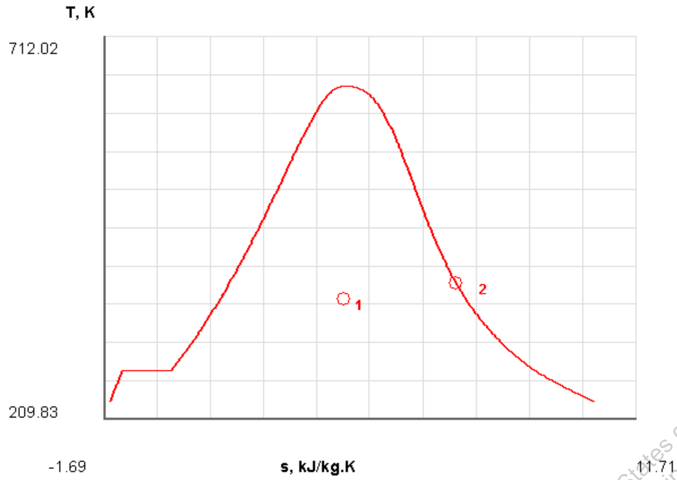
4	**132.99**	**-20.13**	**38**	**0.0567**	**107.13**	**107.13**	**0.456**

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-19 [FB] A 10 L rigid tank contains 0.01 kg of steam. Determine (a) the pressure (p), (b) stored energy (E), and (c) entropy (S), of steam if the quality is 50%. Neglect kinetic and potential energy. What-if Scenario: What would the (d) pressure, (e) stored energy, (f) entropy of steam be if the steam quality were 100%?

SOLUTION



(a) Specific volume

$$v = \frac{\cancel{V}}{m}; \quad \Rightarrow v = \frac{\left(\frac{10}{1000}\right)}{.01}; \quad \Rightarrow v = 1\ \frac{\text{m}^3}{\text{kg}};$$

$$v = v_f + x\left(v_g - \cancel{v_f}^{0,\text{ neg}}\right); \quad \Rightarrow v_g \cong \frac{v}{x} = \frac{1}{0.5} = 2;$$

Using Table-B.2

$$v_g \cong v_{g\ @\ 95^\circ\text{C}};$$

$$p = p_{\text{sat}\ @\ 95^\circ\text{C}}; \quad \Rightarrow p = 84.55\ \text{kPa}$$

(b) Energy

$$\left.\begin{aligned} u_{f\ @\ 95^\circ\text{C}} &= 397.88\ \frac{\text{kJ}}{\text{kg}}; \\ u_{g\ @\ 95^\circ\text{C}} &= 2500.6\ \frac{\text{kJ}}{\text{kg}}; \end{aligned}\right\rangle \quad u = u_f + x\left(u_g - u_f\right); \quad \Rightarrow u = 1449.24\ \frac{\text{kJ}}{\text{kg}};$$

$$E = m\left(u + \cancel{ke}^0 + \cancel{pe}^0\right); \quad \Rightarrow E = mu; \quad \Rightarrow E = 0.01(1449.24);$$

$$\Rightarrow E = 14.49\ \text{kJ}$$

(c) Entropy

$$\left.\begin{array}{l} s_{f\,@\,95^\circ\text{C}} = 1.25\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}; \\ s_{g\,@\,95^\circ\text{C}} = 7.4159\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}; \end{array}\right\rangle\ s = s_f + x\left(s_g - s_f\right); \qquad \Rightarrow s = 4.333\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$S = ms; \qquad \Rightarrow S = 0.01\left(4.333\right); \qquad \Rightarrow S = 0.04333\ \frac{\text{kJ}}{\text{K}}$$

(d) If $x = 1$

$$v = v_g = 1\ \frac{\text{m}^3}{\text{kg}};$$

Using Table-B.2

$$v_g \cong v_{g\,@\,115^\circ\text{C}};$$

$$\Rightarrow p = p_{\text{sat}\,@\,115^\circ\text{C}} = 170\ \text{kPa}$$

(e) $u_{g\,@\,115^\circ\text{C}} = 2523.7\ \dfrac{\text{kJ}}{\text{kg}};$

$$E = mu; \qquad \Rightarrow E = 0.01\left(2523.7\right); \qquad \Rightarrow E = 25.24\ \text{kJ}$$

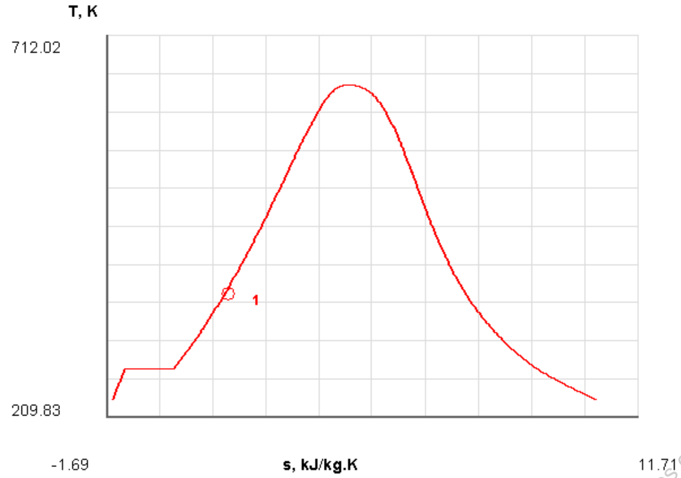
(f) $s_{g\,@\,115^\circ\text{C}} = 7.1833\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$$S = ms; \qquad \Rightarrow S = 0.01\left(7.1833\right); \qquad \Rightarrow S = 0.071833\ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-20 [FS] A liquid-vapor mixture of water at 100 kPa has a quality of 1%. (a) Determine the volumetric quality of the mixture. (b) What-if Scenario: What would the volumetric quality be if the working fluid were R-134a?

SOLUTION



(a) Using Table-B.1

$$v_{\text{liquid}} = v_{f\ @\ 100\ \text{kpa}}; \qquad \Rightarrow v_{\text{liquid}} = 0.00143\ \frac{\text{m}^3}{\text{kg}};$$

$$v_{\text{vapor}} = v_{g\ @\ 100\ \text{kpa}}; \qquad \Rightarrow v_{\text{vapor}} = 1.694\ \frac{\text{m}^3}{\text{kg}};$$

The overall specific volume of this mixture can be found as

$$v_{\text{total}} = v_f + x\left(v_g - v_f\right); \qquad \Rightarrow v_{\text{total}} = 0.001043 + 0.01(1.694 - 0.001043);$$

$$\Rightarrow v_{\text{total}} = 0.018\ \frac{\text{m}^3}{\text{kg}};$$

The volume fraction of vapor can be calculated as

$$y = \frac{V_{\text{vapor}}}{V_{\text{total}}}; \qquad \Rightarrow y = \frac{v_{\text{vapor}}}{v_{\text{total}}}; \qquad \Rightarrow y = \frac{v_{\text{total}} - v_{\text{liquid}}}{v_{\text{total}}};$$

$$\Rightarrow \ y = 1 - \frac{v_{\text{liquid}}}{v_{\text{total}}}; \qquad \Rightarrow y = 1 - \frac{0.001043}{0.018}; \qquad \Rightarrow y = 0.942; \qquad \Rightarrow y = 94.2\%$$

(b) If the working fluid was R-134a
Using Table-B.5

$$v_{\text{liquid}} = v_{f\ @\ 100\ \text{kpa}}; \qquad \Rightarrow v_{\text{liquid}} = 0.00073\ \frac{\text{m}^3}{\text{kg}};$$

$$v_{\text{vapor}} = v_{g\ @\ 100\ \text{kpa}}; \qquad \Rightarrow v_{\text{vapor}} = 0.19269\ \frac{\text{m}^3}{\text{kg}};$$

$$v_{\text{total}} = v_f + x\left(v_g - v_f\right); \qquad \Rightarrow v_{\text{total}} = 0.00073 + 0.01\left(0.19269 - 0.00073\right);$$

$$\Rightarrow v_{\text{total}} = 0.00265\ \frac{\text{m}^3}{\text{kg}};$$

$$y = 1 - \frac{v_{\text{liquid}}}{v_{\text{total}}}; \qquad \Rightarrow y = 1 - \frac{0.00073}{0.00265}; \qquad \Rightarrow y = 0.725; \qquad \Rightarrow y = 72.5\%$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-21 [FA] A 0.4 m^3 vessel contains 10 kg of refrigerant-134a at 25°C. Determine the (a) phase composition (b) pressure (p) (c) total internal energy (U) and (d) total entropy (S) of the refrigerant.

SOLUTION

(a) Specific volume

$$v = \frac{\mathcal{V}}{m}; \quad \Rightarrow v = \frac{0.4}{10}; \quad \Rightarrow v = 0.04 \ \frac{\text{m}^3}{\text{kg}};$$

Using Table-B.6

$$v_{g\,@\,25^\circ\text{C}} = 0.03 \ \frac{\text{m}^3}{\text{kg}};$$

Since $v > v_g$, this refrigerant is in the superheated vapor state.

(b) Using Table-B.7

$$p = p(T, v); \quad \Rightarrow p = p\left(25^\circ\text{C}, 0.04 \ \frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow p \cong 536 \text{ kPa}$$

(c) Total Internal Energy
Using Table B-7

$$u = u(T, v); \quad \Rightarrow u = u\left(25^\circ\text{C}, 0.04 \ \frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow u \cong 245.15 \ \frac{\text{kJ}}{\text{kg}};$$

$$U = mu; \quad \Rightarrow U = 10(245.15); \quad \Rightarrow U = 2451.5 \text{ kJ}$$

(d) Total Entropy

$$s = s(T,v); \quad \Rightarrow s = s\left(25^\circ\mathrm{C}, 0.04\ \frac{\mathrm{m}^3}{\mathrm{kg}}\right); \quad \Rightarrow s \cong 0.943\ \frac{\mathrm{kJ}}{\mathrm{kg}\cdot\mathrm{K}};$$

$$S = ms; \quad \Rightarrow S = 10(0.943); \quad \Rightarrow S = 9.43\ \frac{\mathrm{kJ}}{\mathrm{K}}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-22 [FE] A tank contains 1 L of saturated liquid and 99 L of saturated vapor of water at 200 kPa. Determine (a) the mass, (b) quality and (c) stored energy (*E*) of the steam.

SOLUTION

Volume

$$\mathcal{V}_{\text{liquid}} = 1\ \text{L}; \qquad \Rightarrow \mathcal{V}_{\text{liquid}} = 0.001\ \text{m}^3;$$

$$\mathcal{V}_{\text{vapor}} = 99\ \text{L}; \qquad \Rightarrow \mathcal{V}_{\text{vapor}} = 0.099\ \text{m}^3;$$

$$\mathcal{V}_{\text{total}} = \mathcal{V}_{\text{liquid}} + \mathcal{V}_{\text{vapor}}; \qquad \Rightarrow \mathcal{V}_{\text{total}} = 0.001 + 0.099; \qquad \Rightarrow \mathcal{V}_{\text{total}} = 0.1\ \text{m}^3;$$

Using Table-B.1

$$v_{\text{liquid}} = v_{f\ @\ 200\ \text{kPa}}; \qquad \Rightarrow v_{\text{liquid}} = 0.001061\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{\text{liquid}} = u_{f\ @\ 200\ \text{kPa}}; \qquad \Rightarrow u_{\text{liquid}} = 504.68\ \frac{\text{kJ}}{\text{kg}};$$

$$v_{\text{vapor}} = v_{g\ @\ 200\ \text{kPa}}; \qquad \Rightarrow v_{\text{vapor}} = 0.8863\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{\text{vapor}} = u_{g\ @\ 200\ \text{kPa}}; \qquad \Rightarrow u_{\text{vapor}} = 2529.5\ \frac{\text{kJ}}{\text{kg}};$$

Mass

$$m_{\text{liquid}} = \frac{\mathcal{V}_{\text{liquid}}}{v_{\text{liquid}}}; \qquad \Rightarrow m_{\text{liquid}} = \frac{0.001}{0.001061}; \qquad \Rightarrow m_{\text{liquid}} = 0.9425\ \text{kg};$$

$$m_{\text{vapor}} = \frac{\mathcal{V}_{\text{vapor}}}{v_{\text{vapor}}}; \qquad \Rightarrow m_{\text{vapor}} = \frac{0.099}{0.8863}; \qquad \Rightarrow m_{\text{vapor}} = 0.1117\ \text{kg};$$

(a) $m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}};\quad \Rightarrow m_{\text{total}} = 0.9425 + 0.1117;\quad \Rightarrow m_{\text{total}} = 1.054\text{ kg}$

(b) $x = \dfrac{m_{\text{vapor}}}{m_{\text{total}}};\quad \Rightarrow x = \dfrac{0.1117}{1.054};\quad \Rightarrow x = 0.1060;\quad \Rightarrow x = 10.60\%$

(c) $E_{\text{total}} = E_{\text{liquid}} + E_{\text{vapor}};\quad \Rightarrow E_{\text{total}} = m_{\text{liquid}} u_{\text{liquid}} + m_{\text{vapor}} u_{\text{vapor}};$

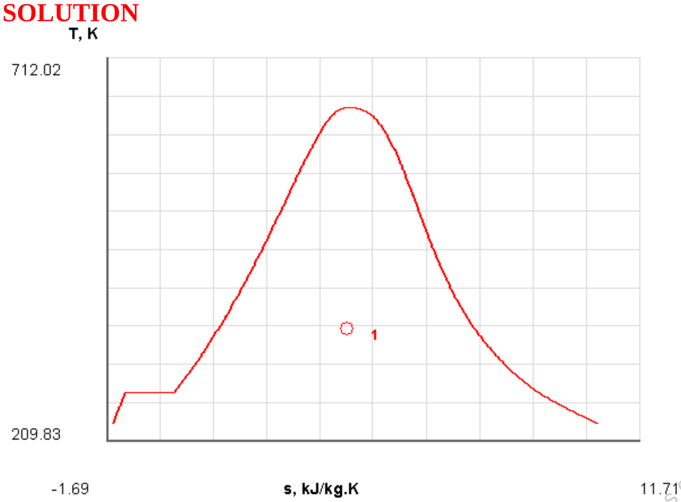
$\Rightarrow E_{\text{total}} = 0.9425(504.68) + 0.1117(2529.5);\quad \Rightarrow E_{\text{total}} = 758.21\text{ kJ}$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-23 [FH] A tank contains 20 kg of water at 85°C. If half of it (by mass) is in the liquid phase and the rest in vapor phase, determine (a) the volumetric quality, the stored energy (E) in (b) the liquid and (c) vapor phases.

SOLUTION



With half of the mass in the vapor phase, $x = 0.5$;
Using Table-B.2

$$v_{\text{liquid}} = v_{f\ @\ 85^\circ\text{C}}; \quad \Rightarrow v_{\text{liquid}} = 0.001033\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{\text{liquid}} = u_{f\ @\ 85^\circ\text{C}}; \quad \Rightarrow u_{\text{liquid}} = 355.84\ \frac{\text{kJ}}{\text{kg}};$$

$$v_{\text{vapor}} = v_{g\ @\ 85^\circ\text{C}}; \quad \Rightarrow v_{\text{vapor}} = 2.828\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{\text{vapor}} = u_{g\ @\ 85^\circ\text{C}}; \quad \Rightarrow u_{\text{vapor}} = 2488.4\ \frac{\text{kJ}}{\text{kg}};$$

Mass

$$m_{\text{liquid}} = m(1-x); \quad \Rightarrow m_{\text{liquid}} = 20(1-0.5); \quad \Rightarrow m_{\text{liquid}} = 10\ \text{kg};$$
$$m_{\text{vapor}} = mx; \quad \Rightarrow m_{\text{vapor}} = 20(0.5); \quad \Rightarrow m_{\text{vapor}} = 10\ \text{kg};$$

Volume

$$\cancel{V}_{\text{liquid}} = m_{\text{liquid}} v_{\text{liquid}}; \quad \Rightarrow \cancel{V}_{\text{liquid}} = 10(0.001033); \quad \Rightarrow \cancel{V}_{\text{liquid}} = 0.01033\ \text{m}^3;$$
$$\cancel{V}_{\text{vapor}} = m_{\text{vapor}} v_{\text{vapor}}; \quad \Rightarrow \cancel{V}_{\text{vapor}} = 10(2.828); \quad \Rightarrow \cancel{V}_{\text{vapor}} = 28.28\ \text{m}^3;$$

(a) $y = \dfrac{\cancel{V}_{\text{vapor}}}{\cancel{V}_{\text{total}}}; \quad \Rightarrow y = \dfrac{\cancel{V}_{\text{vapor}}}{\cancel{V}_{\text{vapor}} + \cancel{V}_{\text{liquid}}}; \quad \Rightarrow y = \dfrac{1}{1 + \dfrac{\cancel{V}_{\text{liquid}}}{\cancel{V}_{\text{vapor}}}};$

$\Rightarrow y = \dfrac{1}{1 + \dfrac{0.01033}{28.28}}; \quad \Rightarrow y = 0.9996; \quad \Rightarrow y = 99.96\%$

(b) Stored Energy- Liquid

$E_{\text{liquid}} = m_{\text{liquid}} u_{\text{liquid}}; \quad \Rightarrow E_{\text{liquid}} = 10(355.84); \quad \Rightarrow E_{\text{liquid}} = 3558.4 \text{ kJ}$

(c) Stored Energy- Vapor

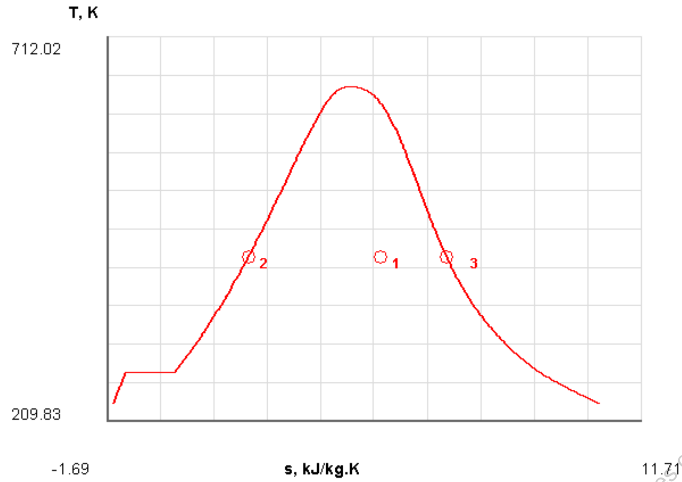
$E_{\text{vapor}} = m_{\text{vapor}} u_{\text{vapor}}; \quad \Rightarrow E_{\text{vapor}} = 10(2488.4); \quad \Rightarrow E_{\text{vapor}} = 24884 \text{ kJ}$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-24 [FN] A vessel having a volume of 0.5 m^3 contains a 2 kg saturated mixture of H_2O at 500 kPa. Calculate the (a) mass of liquid (b) mass of vapor and (c) volume of liquid (d) volume of vapor.

SOLUTION



Specific volume

$$v = \frac{\cancel{V}}{m}; \quad \Rightarrow v = \frac{0.5}{2}; \quad \Rightarrow v = 0.25 \ \frac{\text{m}^3}{\text{kg}};$$

Using Table-B.1

$$v_{\text{liquid}} = v_{f\ @\ 500\ \text{kpa}}; \quad \Rightarrow v_{\text{liquid}} = 0.001063 \ \frac{\text{m}^3}{\text{kg}};$$

$$v_{\text{vapor}} = v_{g\ @\ 500\ \text{kpa}}; \quad \Rightarrow v_{\text{vapor}} = 0.3749 \ \frac{\text{m}^3}{\text{kg}};$$

Mass fraction

$$x = \frac{v - v_f}{v_g - v_f}; \quad \Rightarrow x = \frac{0.25 - 0.001063}{0.3749 - 0.001063}; \quad \Rightarrow x = 0.6659;$$

(a) $m_{\text{liquid}} = m_{\text{total}}(1 - x); \quad \Rightarrow m_{\text{liquid}} = 2(1 - 0.6659); \quad \Rightarrow m_{\text{liquid}} = 0.67 \text{ kg}$

(b) $m_{\text{vapor}} = m_{\text{total}} x; \quad \Rightarrow m_{\text{vapor}} = 2(0.6659); \quad \Rightarrow m_{\text{vapor}} = 1.33 \text{ kg}$

(c) $\cancel{V}_{\text{liquid}} = m_{\text{liquid}} v_{\text{liquid}}; \quad \Rightarrow \cancel{V}_{\text{liquid}} = 0.67(0.001063); \quad \Rightarrow \cancel{V}_{\text{liquid}} = 0.000712 \text{ m}^3$

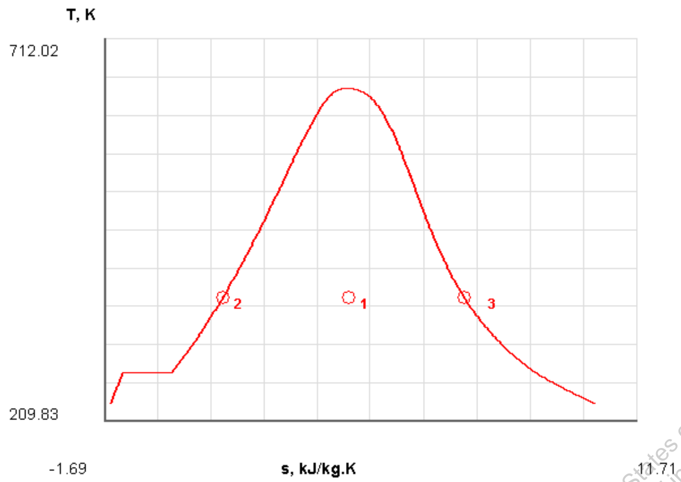
(d) $\cancel{V}_{\text{vapor}} = m_{\text{vapor}} v_{\text{vapor}}; \quad \Rightarrow \cancel{V}_{\text{vapor}} = 1.33(0.3747); \quad \Rightarrow \cancel{V}_{\text{vapor}} = 0.4986 \text{ m}^3$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-25 [FI] (a) What is the phase composition of H_2O at p = 100 kPa and u = 1500 kJ/kg? (b) How much volume does 2 kg of H_2O in that state occupy? (c) What-if Scenario: What would the volume be if mass of H_2O were 5 kg?

SOLUTION



Using Table-B.1

$$v_{\text{liquid}} = v_{f\ @\ 100\ \text{kPa}}; \qquad \Rightarrow v_{\text{liquid}} = 0.001043\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{\text{liquid}} = u_{f\ @\ 100\ \text{kPa}}; \qquad \Rightarrow u_{\text{liquid}} = 417.36\ \frac{\text{kJ}}{\text{kg}};$$

$$v_{\text{vapor}} = v_{g\ @\ 100\ \text{kPa}}; \qquad \Rightarrow v_{\text{vapor}} = 1.694\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{\text{vapor}} = u_{g\ @\ 100\ \text{kPa}}; \qquad \Rightarrow u_{\text{vapor}} = 2506.1\ \frac{\text{kJ}}{\text{kg}};$$

(a) Since $u_f < u < u_g$, the composition of this fluid is a saturated mixture.

(b) $x = \dfrac{u - u_f}{u_g - u_f}; \qquad \Rightarrow x = \dfrac{1500 - 417.36}{2506.1 - 417.36}; \qquad \Rightarrow x = 0.51832; \qquad \Rightarrow x = 51.832\%;$

$$\mathcal{V} = mv; \qquad \Rightarrow \mathcal{V} = m\left\lfloor v_f + x\left(v_g - v_f\right)\right\rfloor;$$

$$\Rightarrow \mathcal{V} = 2\left\lfloor 0.001043 + 0.51832\left(1.694 - 0.001043\right)\right\rfloor; \qquad \Rightarrow \mathcal{V} = 1.757\ \text{m}^3$$

(c) If mass of H_2O is 5 kg

$$\cancel{V} = mv; \quad \Rightarrow \cancel{V} = m\left\lfloor v_f + x\left(v_g - v_f\right)\right\rfloor;$$

$$\Rightarrow \cancel{V} = 5\left\lfloor 0.001043 + 0.51832\left(1.694 - 0.001043\right)\right\rfloor; \quad \Rightarrow \cancel{V} = 4.39 \text{ m}^3$$

TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-26 [FL] A rigid vessel contains 3 kg of refrigerant-12 at 890 kPa and 85°C. Determine (a) volume () of the vessel and (b) total internal energy (U).

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SOLUTION

Using the phase change volume state daemon with R-12 as the working fluid

$$v_{890\text{ kPa, }50^{\circ}\text{C}} = 0.02487\ \frac{\text{m}^3}{\text{kg}};$$

$$u_{890\text{ kPa, }50^{\circ}\text{C}} = 215.6\ \frac{\text{kJ}}{\text{kg}};$$

(a) $\mathcal{V} = mv; \quad \Rightarrow \mathcal{V} = 3(0.02487); \quad \Rightarrow \mathcal{V} = 0.0746\ \text{m}^3$

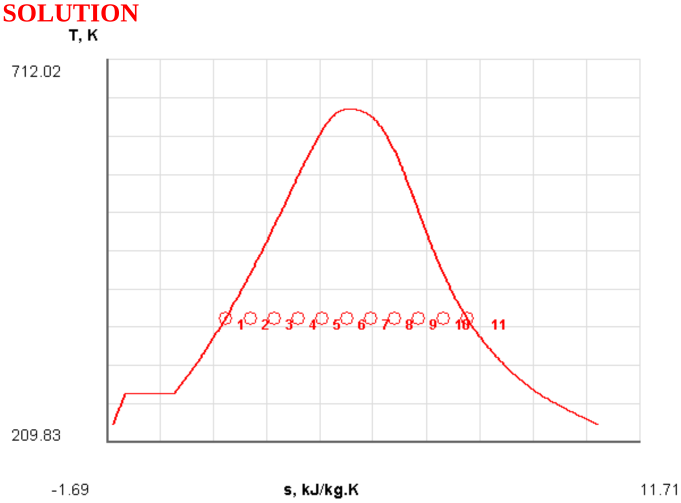
(b) $E = mu; \quad \Rightarrow E = 3(215.6); \quad \Rightarrow E = 646.8\ \text{kJ}$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-27 [FG] For H_2O, plot how the volume fraction, *y*, changes with quality, *x*, over the entire possible range at (a) *p* = 100 kPa and (b) *p* = 20 MPa.

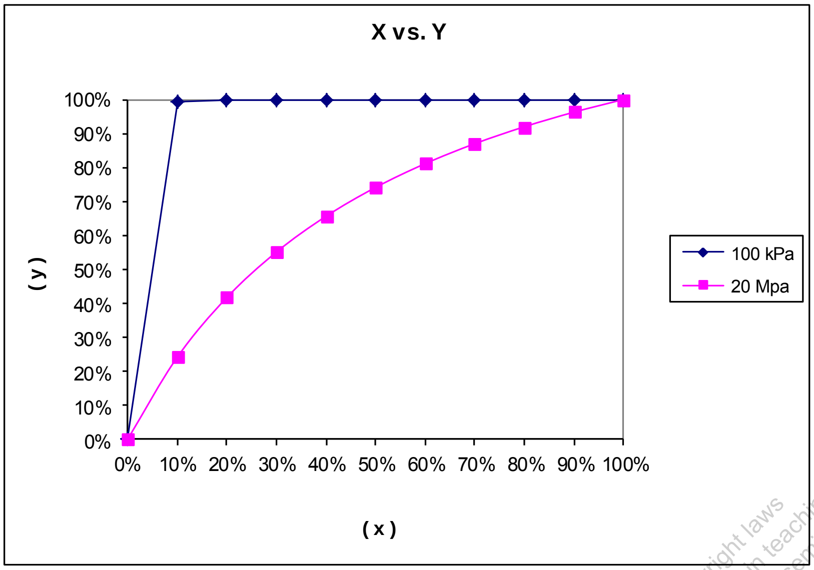
SOLUTION



Using, TEST, run the phase change volume state daemon to solve for the following values

At 100 kPa		At 20 MPa	
x = 0;	y = 0;	x = 0;	y = 0;
x = 0.1;	y = 0.99449;	x = 0.1;	y = 0.24137;
x = 0.2;	y = 0.99754;	x = 0.2;	y = 0.4172;
x = 0.3;	y = 0.99857;	x = 0.3;	y = 0.55101;
x = 0.4;	y = 0.99908;	x = 0.4;	y = 0.65624;
x = 0.5;	y = 0.99938;	x = 0.5;	y = 0.74117;
x = 0.6;	y = 0.99959;	x = 0.6;	y = 0.81115;
x = 0.7;	y = 0.99974;	x = 0.7;	y = 0.86982;
x = 0.8;	y = 0.99985;	x = 0.8;	y = 0.9197;
x = 0.9;	y = 0.99983;	x = 0.9;	y = 0.96265;
x = 1;	y = 1;	x = 1;	y = 1

The values for y can be plotted against the values for x at the two pressures.

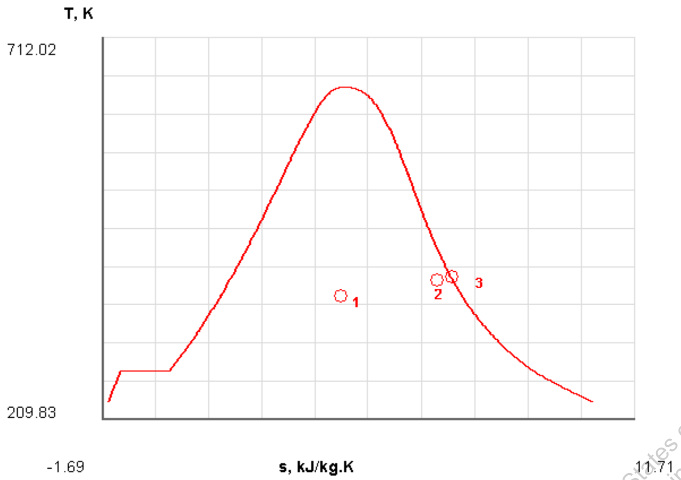


TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-28 [FZ] A rigid tank of volume 83 m^3 contains 100 kg of H_2O at 100°C. The tank is heated until the temperature inside reaches 120°C. Determine the pressure (p) inside the tank at (a) the beginning and (b) the end of the heating process. (c) What-if Scenario: What would the final pressure be if the tank temperature increased to 125°C?

SOLUTION



Since the tank is rigid, v is constant throughout any closed process.

$$v = \frac{\cancel{V}}{m}; \quad \Rightarrow v = \frac{83}{100}; \quad \Rightarrow v = 0.83 \ \frac{\text{m}^3}{\text{kg}};$$

(a) Using Table-B.2

$$v_{f\ @\ 100^\circ\text{C}} = 0.001044 \ \frac{\text{m}^3}{\text{kg}};$$

$$v_{g\ @\ 100^\circ\text{C}} = 1.6729 \ \frac{\text{m}^3}{\text{kg}};$$

Since $v_f < v < v_g$, the water in the tank is initially a saturated mixture.

$$\Rightarrow p_{\text{initial}} = p_{\text{sat @ 100}^\circ\text{C}} = 101.35 \text{ kPa}$$

(b) At 120°C

$$v_{f\ @\ 120^\circ\text{C}} = 0.00106 \ \frac{\text{m}^3}{\text{kg}};$$

$$v_{g\ @\ 120^\circ\text{C}} = 0.8919 \ \frac{\text{m}^3}{\text{kg}};$$

Since $v_f < v < v_g$, the water in the tank is initially a saturated mixture.

$$\Rightarrow p_{\text{final}} = p_{\text{sat @ 120}^\circ\text{C}} = 198.53 \text{ kPa}$$

(c) At 125°C

$$v_{g\ @\ 125^\circ\text{C}} = 0.7706\ \frac{\text{m}^3}{\text{kg}};$$

Since $v > v_g$, the water in the tank is in the superheated state at this temperature.

Using Table-B.3

$$v \cong v_{125^\circ\text{C},\ 215\ \text{kPa}};$$

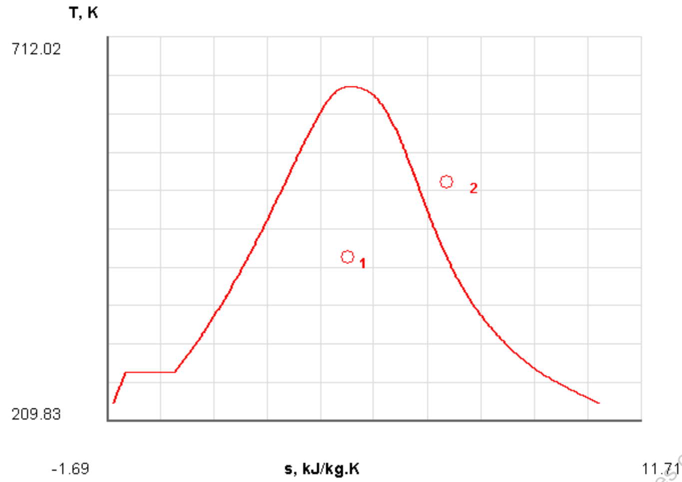
$$p_{\text{final}} = p(v,T); \qquad \Rightarrow p_{\text{final}} = p\left(0.83\ \frac{\text{m}^3}{\text{kg}},\ 125^\circ\text{C}\right); \qquad \Rightarrow p_{\text{final}} \cong 216\ \text{kPa}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-29 [FK] A tank contains 5 kg of saturated liquid and 5 kg of saturated vapor of H_2O at 500 kPa. Determine (a) its volume in m^3 an (b) its temperature (T) in Celcius. The tank is now heated to a temperature of 250^{o}C. (c) Determine the pressure in MPa.

SOLUTION



(a) Using Table B.1

$$v_{f\ @\ 500\text{kPa}} = 0.001093\ \frac{\text{m}^3}{\text{kg}};$$

$$v_{g\ @\ 500\text{kPa}} = 0.3749\ \frac{\text{m}^3}{\text{kg}};$$

$$V_{liquid} = mv; \qquad \Rightarrow V_{liquid} = (5)(0.001093); \qquad \Rightarrow V_{liquid} = 0.005465\ \text{m}^3;$$

$$V_{vapor} = mv; \qquad \Rightarrow V_{vapor} = (5)(0.3749); \qquad \Rightarrow V_{vapor} = 1.8745\ \text{m}^3;$$

$$V_{total} = V_{liquid} + V_{vapor}; \qquad \Rightarrow V_{total} = 0.005465 + 1.8745; \qquad \Rightarrow V_{total} = 1.88\ \text{m}^3$$

(b) $T_{\text{sat@500kPa}} = 151.86°\text{C}$

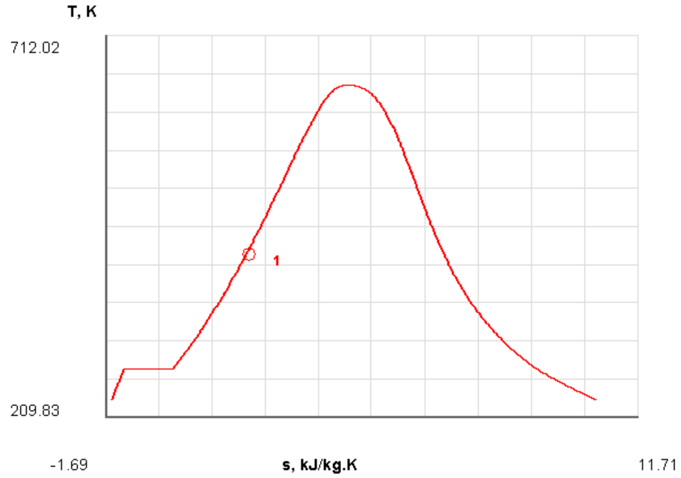
(c) $T_{\text{sat@250°C}} = 1.22\ \text{MPa}$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-30 [BEF] A tank contains 500 kg of saturated liquid and 5 kg of saturated vapor of H_2O at 500 kPa. Determine (a) the quality of the steam and (b) the volume of the tank.

SOLUTION



Using Table B.1

$$v_{f\ @\ 500\text{kPa}} = 0.001093\ \frac{\text{m}^3}{\text{kg}};$$

$$v_{g\ @\ 500\text{kPa}} = 0.3749\ \frac{\text{m}^3}{\text{kg}};$$

(a) $x = \dfrac{m_{\text{vapor}}}{m_{\text{total}}}; \quad \Rightarrow x = \dfrac{5}{500+5}; \quad \Rightarrow x = 0.0099; \quad \Rightarrow x = 0.99\%$

(b) $V_{liquid} = mv; \quad \Rightarrow V_{liquid} = (500)(0.001093); \quad \Rightarrow V_{liquid} = 0.5465\ \text{m}^3;$

$V_{vapor} = mv; \quad \Rightarrow V_{vapor} = (5)(0.3749); \quad \Rightarrow V_{vapor} = 1.8745\ \text{m}^3;$

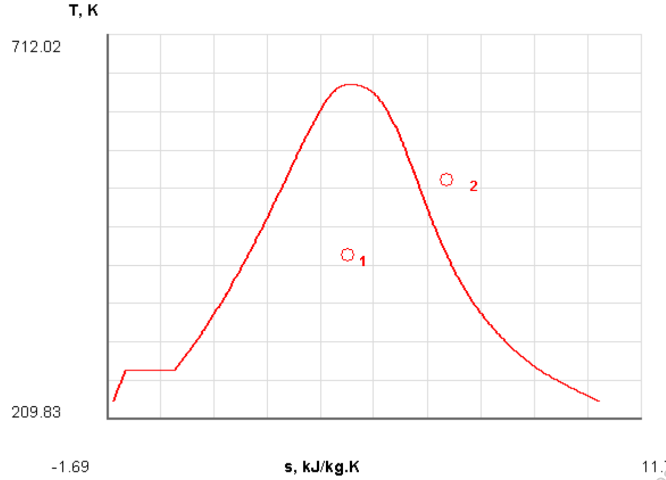
$V_{total} = V_{liquid} + V_{vapor}; \quad \Rightarrow V_{total} = 0.5465 + 1.8745; \quad \Rightarrow V_{total} = 2.421\ \text{m}^3$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-31 [FP] In problem 3-3-29 [FK], determine the change in (a) stored energy (ΔE) and (b) entropy (ΔS) of the system. (c) Using the entropy balance equation, explain why the entropy of the system increases.

SOLUTION



Using Table-B.1

$$u_{f\ @\ 500\text{kPa}} = 639.68\ \frac{\text{kJ}}{\text{kg}};\quad u_{g\ @\ 500\text{kPa}} = 2561.2\ \frac{\text{kJ}}{\text{kg}};$$

$$s_{f\ @\ 500\text{kPa}} = 1.8607\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};\quad s_{g\ @\ 500\text{kPa}} = 6.8213\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Using Table-B.3

$$u_{1.2\text{MPa}\ \&\ 250^\circ\text{C}} = 2704.2\ \frac{\text{kJ}}{\text{kg}};\quad s_{1.2\text{MPa}\ \&\ 250^\circ\text{C}} = 6.8294\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) Change in stored energy

$$E_i = E_{\text{liquid},\,i} + E_{\text{vapor},\,i};\quad \Rightarrow E_i = m_{\text{liquid}} u_{f\ @\ 500\text{kPa}} + m_{\text{vapor}} u_{g\ @\ 500\text{kPa}};$$

$$\Rightarrow E_i = 5(639.68) + 5(2561.2);\quad \Rightarrow E_i = 16004.4\ \text{kJ};$$

$$E_f = m_{\text{total}} u_{1.2\text{MPa}\ \&\ 250^\circ\text{C}};\quad \Rightarrow E_f = (5+5)(2704.2);\quad \Rightarrow E_f = 27042\ \text{kJ};$$

$$\Delta E = E_f - E_i;\quad \Rightarrow \Delta E = 27042 - 16004.4;\quad \Rightarrow \Delta E = 11037.6\ \text{kJ}$$

(b) Change in entropy

$$S_i = S_{\text{liquid},\,i} + S_{\text{vapor},\,i};\quad \Rightarrow S_i = m_{\text{liquid}} s_{f\ @\ 500\text{kPa}} + m_{\text{vapor}} s_{g\ @\ 500\text{kPa}};$$

$$\Rightarrow S_i = 5(1.8607) + 5(6.8213);\quad \Rightarrow S_i = 43.41\ \frac{\text{kJ}}{\text{K}};$$

$$S_f = m_{\text{total}} s_{1.2\text{MPa} \ \& \ 250^\circ\text{C}}; \quad \Rightarrow S_f = (5+5)(6.8294); \quad \Rightarrow S_f = 68.295 \ \frac{\text{kJ}}{\text{K}};$$

$$\Delta E = E_f - E_i; \quad \Rightarrow \Delta E = 68.295 - 43.41; \quad \Rightarrow \Delta E = 24.885 \ \frac{\text{kJ}}{\text{K}}$$

(c) Entropy balance

$$\Delta S = S_{\text{net}} + \frac{\cancel{Q}^{0}}{T_{\text{B}}} + S_{\text{gen}};$$

$$\Rightarrow \Delta S = S_{\text{gen}} \ \text{and} \ S_{\text{gen}} > 0;$$

$$\Rightarrow \Delta S > 0; \quad \Rightarrow S_f > S_i; \quad \Rightarrow \text{Entropy increases}$$

TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-32 [FU] A tank with a volume of 10 gallons contains a liquid-vapor mixture of propane at 30°C. Determine (a) the pressure and (b) the mass of propane inside. (c) If the tank is designed for a maximum pressure of 3000 kPa, determine the maximum temperature the tank will be able to withstand.

SOLUTION

(a) At $T = 30^\circ\text{C}, x = 0.5$:

$$p = p_{\text{sat @ }30^\circ\text{C}} = 1070.3 \text{ kPa}$$

(b) $v_{\text{f @ }30^\circ\text{C}} = 0.00207 \dfrac{\text{m}^3}{\text{kg}}; \quad v_{\text{g @ }30^\circ\text{C}} = 0.04288 \dfrac{\text{m}^3}{\text{kg}};$

$$v = v_f + x(v_g - v_f); \quad \Rightarrow v = 0.00207 + 0.5(0.04288 - 0.00207); \quad \Rightarrow v = 0.02247 \frac{\text{m}^3}{\text{kg}};$$

$$m = \frac{\cancel{V}}{v}; \quad \Rightarrow m = \frac{10}{0.02247}\left[0.003785 \frac{\text{m}^3}{\text{gal}}\right]; \quad \Rightarrow m = 1.684 \text{ kg}$$

(c) Maximum temperature

At $p = 3000 \text{ kPa}, v = 0.02247 \dfrac{\text{m}^3}{\text{kg}}$:

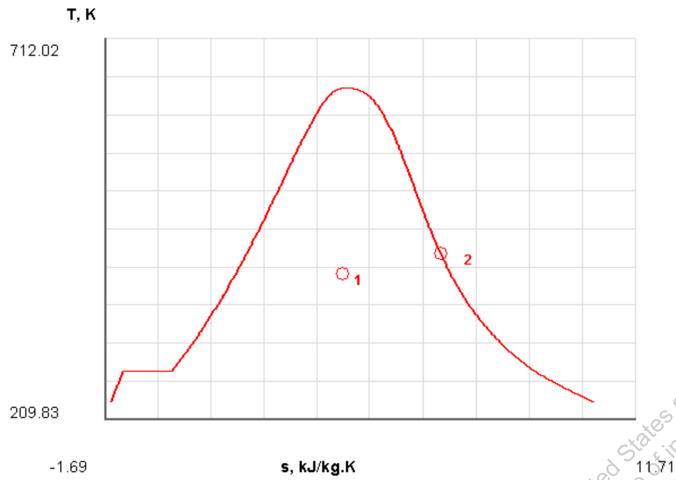
$$T_{\max} = T(p_{\max}, v); \quad \Rightarrow T_{\max} = T\left(3000 \text{ kPa}, 0.02247 \frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow T_{\max} \cong 154.95^\circ\text{C}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-33 [FX] A piston cylinder device of volume 1 m^3 contains 3 kg of water. The piston, which has an area of 100 cm^2, exerts a force of 1.7 kN on the pin to keep it stationary. Determine (a) the temperature and (b) quality of H_2O inside the cylinder. The water is now heated. (c) Determine the force on the pin when all the liquid in the tank vaporize. Assume the atmospheric pressure to be 100 kPa and neglect the piston's mass.

SOLUTION



Pressure equilibrium

$$p_i = p_o + \frac{\mathrm{F_{pin}}}{\mathrm{A}}; \qquad \Rightarrow p_i = 100 + \frac{1.7}{0.01}; \qquad \Rightarrow p_i = 270 \text{ kPa};$$

Specific volume

$$v = \frac{\mathcal{V}}{m}; \qquad \Rightarrow v = \frac{1}{3}; \qquad \Rightarrow v = 0.333 \ \frac{\mathrm{m^3}}{\mathrm{kg}};$$

Using Table-B.1

$$v_{\mathrm{f\ @\ 270\ kPa}} = 0.00107 \ \frac{\mathrm{m^3}}{\mathrm{kg}}; \qquad v_{\mathrm{g\ @\ 270\ kPa}} = 0.669 \ \frac{\mathrm{m^3}}{\mathrm{kg}};$$

Since $v_{\mathrm{f}} < v < v_{\mathrm{g}}$, this fluid is a saturated mixture.

(a) $T = T_{\mathrm{sat\ @\ 270\ kPa}} \cong 130^\circ\mathrm{C}$

(b) $x = \dfrac{v - v_{\mathrm{f}}}{v_{\mathrm{g}} - v_{\mathrm{f}}}; \qquad \Rightarrow x = \dfrac{0.333 - 0.00107}{0.669 - 0.00107}; \qquad \Rightarrow x = 0.497$

(c) When all liquid is evaporated, $x = 1$, and $v = v_{\mathrm{g\ @\ }p}$

Using Table-B.1

$v \cong v_{g\,@\,566\text{ kPa}};$

$\Rightarrow p_i = 566\text{ kPa};$

Pressure equilibrium

$$p_i = p_o + \frac{F_{pin}}{A};$$

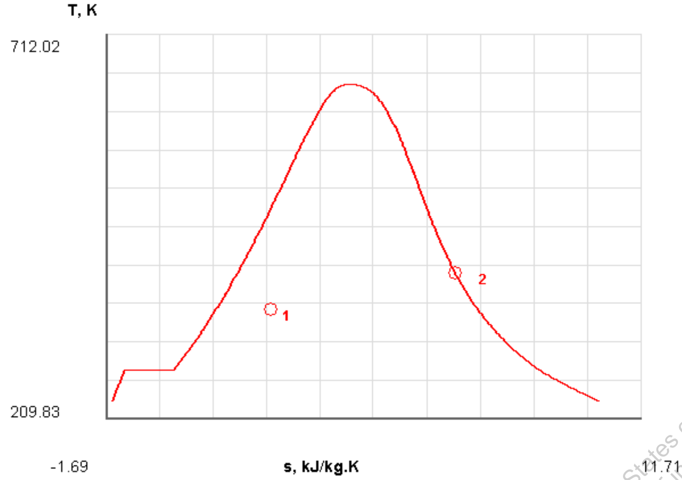
$$\Rightarrow F_{pin} = (p_i - p_o)A; \quad \Rightarrow F_{pin} = (566 - 100)0.01; \quad \Rightarrow F_{pin} = 4.66\text{ kN}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-34 [FC] A rigid tank with a volume of 3.5 m^3 contains 5 kg of saturated liquid-vapor mixture of H_2O at 80^{o}C. The tank is slowly heated until all the liquid in the tank is completely vaporized. Determine the temperature at which this process occurred. Also show the process on a *T*-*v* diagram with respect to saturation lines.

SOLUTION



Specific volume

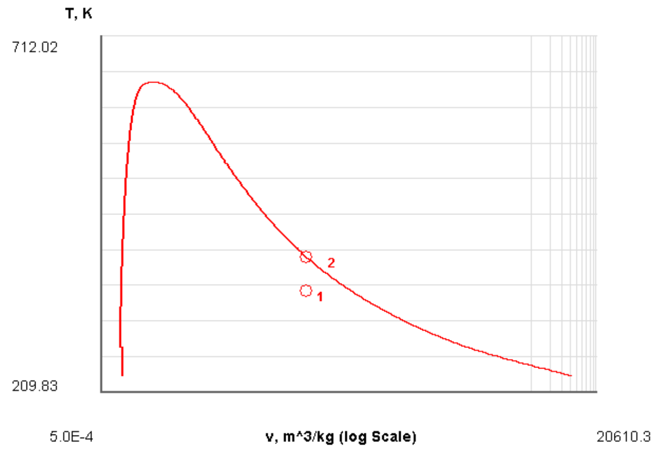
$$v=\frac{\cancel{V}}{m};\quad \Rightarrow v=\frac{3.5}{5};\quad \Rightarrow v=0.7\ \frac{\text{m}^3}{\text{kg}};$$

When all liquid is evaporated, $x=1$, and $v=v_{g\,@\,T}$

Using Table-B.2

$v\cong v_{g\,@\,128.3^\circ\text{C}}$;

$$\Rightarrow T_{\text{final}}=128.3^\circ\text{C}$$

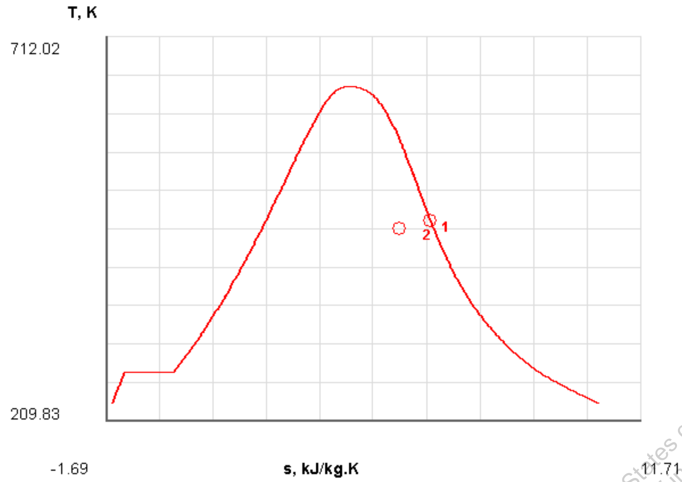


TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-35 [FV] A 10 m^3 rigid tank contains saturated vapor of H_2O at 200°C. The tank is cooled until the quality drops to 80%. Determine the (a) mass of H_2O in the tank, (b) drop in pressure (Δp), (c) drop in temperature (ΔT), and (d) drop in total entropy (ΔS). (e) What causes the entropy of this system to decrease?

SOLUTION



Using Table B.2

$$v_{g\ @\ 200°C} = 0.12736\ \frac{\text{m}^3}{\text{kg}};$$

(a) $m = \dfrac{V}{v}; \quad \Rightarrow m = \dfrac{10}{0.12736}; \quad \Rightarrow m = 78.52\text{ kg}$

(b) $p_i = p_{sat@200°C} = 1553.8\text{ kPa};$

$$p_f = p(x,v); \quad \Rightarrow p_f = p\left(80\%,\ 0.12736\frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow p_f = 1233.9\text{ kPa};$$

$$\Delta p = p_i - p_f; \quad \Rightarrow \Delta p = 1553.8 - 1233.9; \quad \Rightarrow \Delta p = 319.9\text{ kPa}$$

(c) $T_i = 200°\text{C};$

$$T_f = T(x,v); \quad \Rightarrow T_f = T\left(80\%,\ 0.12736\frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow T_f = 189.3°\text{C};$$

$$\Delta T = T_i - T_f; \quad \Rightarrow \Delta T = 200 - 189.3; \quad \Rightarrow \Delta T = 10.7°\text{C}$$

(d) $s_i = s(T,x); \quad \Rightarrow s_i = s(200°\text{C},\ 100\%); \quad \Rightarrow s_i = 6.4323\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}};$

$$s_f = s(x, v); \qquad \Rightarrow s_f = s\left(80\%,\ 0.12736\frac{\text{m}^3}{\text{kg}}\right); \qquad \Rightarrow s_f = 5.6566\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\Delta s = s_i - s_f; \qquad \Rightarrow \Delta s = 6.4323 - 5.6566; \qquad \Rightarrow \Delta s = 0.7757\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\Delta S = m\Delta s; \qquad \Rightarrow \Delta \text{S} = (78.52)(0.7757); \qquad \Rightarrow \Delta \text{S} = 60.91\ \frac{\text{kJ}}{\text{K}}$$

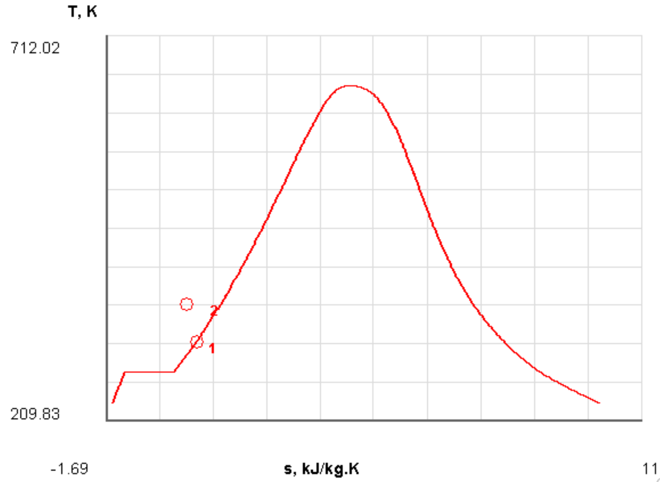
(e) Heat going out transfers energy as well as entropy.

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-36 [FT] A 1000 L rigid tank contains saturated liquid water at 40°C. (a) Determine the pressure (p) inside. The tank is now heated to 90°C. (b) Use the compressed liquid table to determine the pressure in the tank.

SOLUTION



(a) At 40°C, $x = 0$

Using Table-B.2

$$v = v_{\text{f @ 40}^\circ\text{C}} = 0.001008 \ \frac{\text{m}^3}{\text{kg}};$$

$$p = p_{\text{sat @ 40}^\circ\text{C}}; \quad \Rightarrow p = 7.384 \text{ kPa}$$

(b) At 90°C, $v = 0.001008 \ \frac{\text{m}^3}{\text{kg}}$

Using Table-B.4

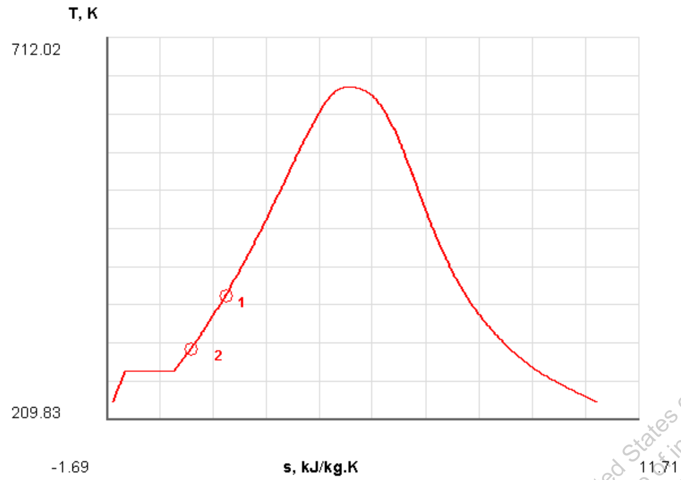
$$p = p(T, v); \quad \Rightarrow p = p\left(90^\circ\text{C}, 0.001008 \ \frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow p \cong 28.53 \text{ MPa}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-37 [FF] A lid with negligible weight is suddenly placed on a pan of boiling water and the heating is turned off. After about an hour, thermal equilibrium is reached between the water and the atmosphere, which is at 30°C and 101 kPa. If the inner diameter of the pan is 20 cm, determine (a) the force necessary to open the lid. (b) What-if Scenario: What would the force be if the weight of 1 kg lid were to be considered?

SOLUTION



The water is initially saturated $(x_1 = 0)$, and the tank is rigid $(v_1 = v_2 = v)$.

State-1: $x_1 = 0,\ p_1 = 101\text{ kPa}$

Using Table-B.1

$$v = v_{\text{f @ 101 kPa}}; \quad \Rightarrow v = 0.00104\ \frac{\text{m}^3}{\text{kg}};$$

State-2: $T = 30^\circ\text{C},\ v_2 = v_1 = 0.00104\ \dfrac{\text{m}^3}{\text{kg}}$

Using Table-B.4

$$p_2 = p_2(T, v); \quad \Rightarrow p_2 = p_2\left(30^\circ\text{C},\ 0.00104\ \frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow p_2 = 4.254\text{ kPa};$$

State-2 piston equilibrium

$$p_2 = p_o + \frac{\text{F}_{\text{lid}} - \text{F}_{\text{removal}}}{\text{A}};$$

$$\Rightarrow \text{F}_{\text{removal}} = -(p_2 - p_o)\text{A} + \text{F}_{\text{lid}};$$

(a) Neglecting the weight of the lid

$$F_{\text{removal}} = -(p_2 - p_o)A + \cancel{F_{\text{lid}}}^{\text{neg}}; \qquad \Rightarrow F_{\text{removal}} = -(4.254 - 101)\pi \frac{\left(\frac{20}{100}\right)^2}{4};$$

$$\Rightarrow F_{\text{removal}} = 3.04 \text{ kN}$$

(b) Including the weight of the lid

$$F_{\text{removal}} = -(p_2 - p_o)A + \frac{m_{\text{lid}} g}{1000}; \qquad \Rightarrow F_{\text{removal}} = 3.04 + \frac{1(9.81)}{1000}; \qquad \Rightarrow F_{\text{removal}} = 3.05 \text{ kN}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-38 [FQ] Superheated water vapor at 1.5 MPa and 280°C is allowed to cool at constant volume until the temperature drops to 130°C. At the final state, determine (a) the pressure (p_2), (b) the quality and (c) the specific enthalpy (h_2). Show the process on a *T-s* diagram.

SOLUTION

State-1: $p_1 = 1.5 \text{ MPa}, \; T_1 = 280^{\circ}\text{C}$

Using Table-B.3

$$v_1 = v_1(p,T); \quad \Rightarrow v_1 = v_1\left(1.5\text{MPa}, \, 280^{\circ}\text{C}\right); \quad \Rightarrow v_1 = 0.16257 \; \frac{\text{m}^3}{\text{kg}};$$

State-2: $T_2 = 130^{\circ}\text{C}, \; v_2 = v_1 = 0.16257 \; \dfrac{\text{m}^3}{\text{kg}}$

Using Table-B.2

$$v_{\text{f @ 130}^{\circ}\text{C}} = 0.00107 \; \frac{\text{m}^3}{\text{kg}}; \quad v_{\text{g @ 130}^{\circ}\text{C}} = 0.6685 \; \frac{\text{m}^3}{\text{kg}};$$

(a) Since $v_\text{f} < v_2 < v_\text{g}$, this fluid is now a saturated mixture. For pressure:

$$p_2 = p_{\text{sat @ 130}^{\circ}\text{C}} = 270.1 \text{ kPa}$$

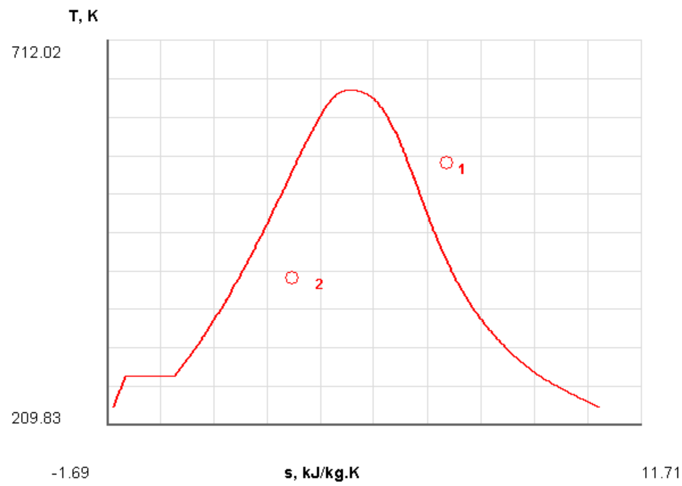
(b) Quality

$$x_2 = \frac{v_2 - v_\text{f}}{v_\text{g} - v_\text{f}}; \quad \Rightarrow x_2 = \frac{0.1625 - 0.00107}{0.6685 - 0.00107}; \quad \Rightarrow x_2 = 0.242; \quad \Rightarrow x_2 = 24.2\%$$

(c) Enthalpy

$$\left.\begin{aligned} h_{f \text{ @ 130}^{\circ}\text{C}} &= 546.31 \; \frac{\text{kJ}}{\text{kg}}; \\ h_{g \text{ @ 130}^{\circ}\text{C}} &= 2720.5 \; \frac{\text{kJ}}{\text{kg}}; \end{aligned}\right\rangle \; h = h_\text{f} + x_2\left(h_\text{g} - h_\text{f}\right); \quad \Rightarrow h = 1072 \; \frac{\text{kJ}}{\text{kg}}$$

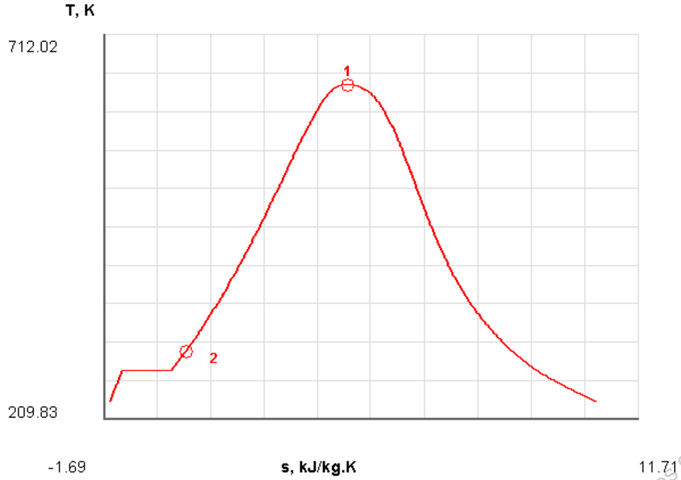
T-s diagram



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-39 [FY] A rigid tank contains steam at the critical state. Determine (a) the quality of the steam after the tank cools down to the atmospheric temperature, 25°C. (b) What percent of the volume is occupied by the vapor at the final state?

SOLUTION



State-1: (critical conditions)
Using Table-E.1

$$\bar{v}_1 = \bar{v}_{cr} = 0.0568 \frac{\text{m}^3}{\text{kmol}};$$

$$\bar{M}_{water} = 18.015 \frac{\text{kg}}{\text{kmol}};$$

Specific volume

$$v_1 = \frac{\bar{v}_{cr}}{\bar{M}}; \qquad \Rightarrow v_1 = \frac{0.0568}{18.015}; \qquad \Rightarrow v_1 = 0.003153 \frac{\text{m}^3}{\text{kg}};$$

State-2: $T_2 = 25^\circ\text{C}, v_2 = v_1 = 0.003153 \dfrac{\text{m}^3}{\text{kg}}$

Using Table-B.4

$$v_{f@25^\circ\text{C}} = 0.001003 \frac{\text{m}^3}{\text{kg}}; \qquad v_{g@25^\circ\text{C}} = 43.36 \frac{\text{m}^3}{\text{kg}};$$

Since $v_f < v_2 < v_g$, this fluid is now a saturated mixture.

(a) Quality

$$x_2 = \frac{v_2 - v_f}{v_g - v_f}; \quad \Rightarrow x_2 = \frac{0.003153 - 0.001003}{43.36 - 0.001003}; \quad \Rightarrow x_2 = 0.00005; \quad \Rightarrow x_2 = 0.005\%$$

(b) Volume fraction

$$y = \frac{\cancel{V}_{\text{vapor}}}{\cancel{V}_{\text{total}}}; \quad \Rightarrow y = \frac{\cancel{V}_{\text{vapor}}}{\cancel{V}_{\text{vapor}} + \cancel{V}_{\text{liquid}}}; \quad \Rightarrow y = \frac{1}{1 + \frac{\cancel{V}_{\text{liquid}}}{\cancel{V}_{\text{vapor}}}};$$

$$\Rightarrow y = \frac{1}{1 + \frac{\cancel{m}(x)v_f}{\cancel{m}(1-x)v_g}}; \quad \Rightarrow y = \frac{1}{1 + \frac{(1-x_2)v_f}{(x_2)v_g}};$$

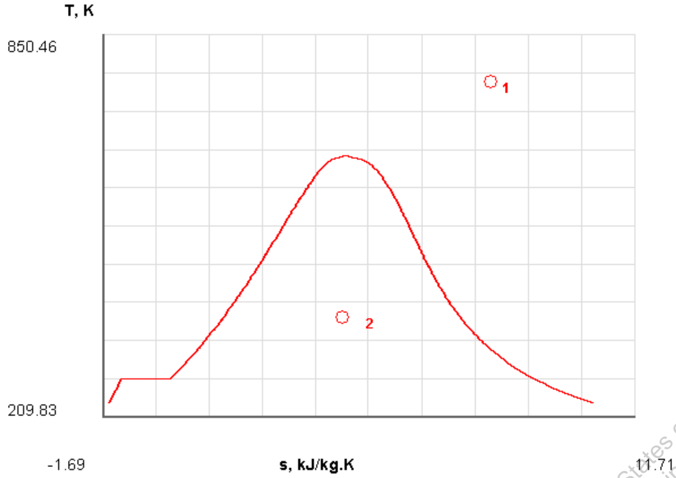
$$\Rightarrow y = \frac{1}{1 + \frac{(1-0.00005)(0.001003)}{(0.00005)(43.36)}}; \quad \Rightarrow y = 0.6837; \quad \Rightarrow y = 68.37\%$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-40 [FD] A rigid tank with a volume of 1 m^3 contains superheated steam at 500 kPa and 500^{o}C. Determine (a) the mass and (b) total internal energy (U) of the steam. The tank is now cooled until the total internal energy decreases to 2076.2 kJ. Determine (c) the pressure (p_2) and (d) temperature (T_2) in the final state.

SOLUTION



State-1: $p_1 = 500 \text{ kPa}, \ T_1 = 500^\circ\text{C},$

Using Table-B.3

$$v_1 = v_1(p,T); \quad \Rightarrow v_1 = v_1(500\text{kPa}, 500^\circ\text{C}); \quad \Rightarrow v_1 = 0.7109 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_1 = u_1(p,T); \quad \Rightarrow u_1 = u_1(500\text{kPa}, 500^\circ\text{C}); \quad \Rightarrow u_1 = 3128.4 \ \frac{\text{kJ}}{\text{kg}};$$

(a) Mass

$$m = \frac{\mathcal{V}}{v}; \quad \Rightarrow m = \frac{1}{0.7109}; \quad \Rightarrow m = 1.4067 \text{ kg}$$

(b) Internal energy

$$U_1 = mu_1; \quad \Rightarrow U_1 = 1.4067(3128.4); \quad \Rightarrow U_1 = 4400.6 \text{ kJ}$$

State-2:

$$v_2 = v_1 = 0.7109\ \frac{\mathrm{m^3}}{\mathrm{kg}};$$

$$u_2 = \frac{U_2}{m}; \qquad \Rightarrow u_2 = \frac{2076.2}{1.4067}; \qquad \Rightarrow u_2 = 1475.94\ \frac{\mathrm{kJ}}{\mathrm{kg}};$$

Using Table-B.2

$@\ 105^\circ\mathrm{C},\ x(v) \cong x(u) \cong 50\%;$

(c) $p_2 = p_{\mathrm{sat}\ @\ 105^\circ\mathrm{C}} = 120.82\ \mathrm{kPa}$

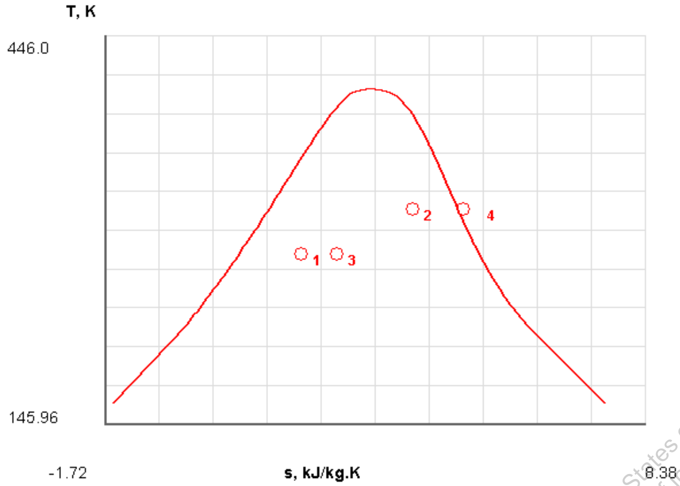
(d) $T_2 \cong 105^\circ\mathrm{C}$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-41 [FM] 10 kg of ammonia is stored in a rigid tank of volume 0.64 m^3. Determine the pressure variation (Δp) in the tank as the ambient temperature swings between (a) 5^{o}C in the night to (b) 40^{o}C in the day time. (c and d) What-if Scenario: What would the answers be if the volume of the tank were increased to 1 m^3?

SOLUTION



$$v=\frac{V}{m};\qquad \Rightarrow v=\frac{0.64}{10};\qquad \Rightarrow v=0.064\frac{\text{m}^3}{\text{kg}};$$

(a) $p=(v,T);\qquad \Rightarrow p=$ 515.9 kPa

(b) $p=(v,T);\qquad \Rightarrow p=$ 1554.9 kPa

(c) $v=\frac{V}{m};\qquad \Rightarrow v=\frac{1}{10};\qquad \Rightarrow v=0.1\frac{\text{m}^3}{\text{kg}};$

$p=(v,T);\qquad \Rightarrow p=$ 515.9 kPa

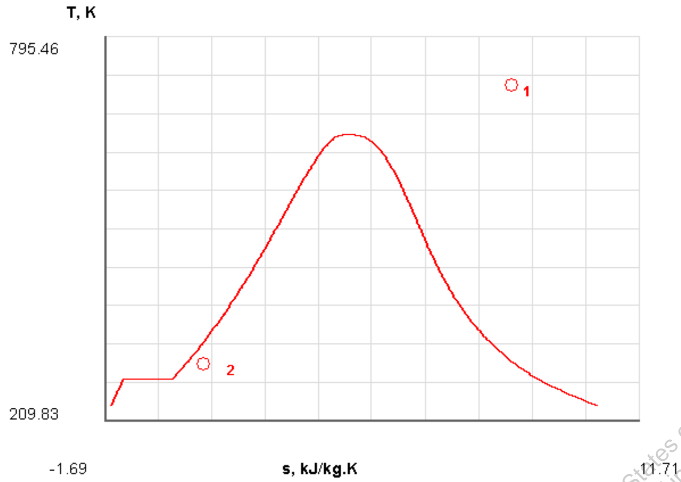
(d) $p=(v,T);\qquad \Rightarrow p=$ 1331.4 kPa

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-42 [FJ] A large industrial tank of volume 200 m^3 is filled with steam at 450^{o}C and 150 kPa. Determine (a) the pressure (p) and (b) quality of steam when the temperature drops to 25^{o}C due to heat loss. (c) If the heat transfer for this constant volume process is given by $Q = \Delta U$, determine the heat transfer.

SOLUTION



State-1: $p_1 = 150 \text{ kPa},\ T_1 = 450^\circ\text{C}$

Using Table-B.3

$$v_1 = v_1(p,T); \quad \Rightarrow v_1 = v_1(150\text{kPa},\ 450^\circ\text{C}); \quad \Rightarrow v_1 = 2.222\ \frac{\text{m}^3}{\text{kg}};$$

$$u_1 = u_1(p,T); \quad \Rightarrow u_1 = u_1(150\text{kPa},\ 450^\circ\text{C}); \quad \Rightarrow u_1 = 3049.2\ \frac{\text{kJ}}{\text{kg}};$$

Mass

$$m = \frac{\cancel{V}}{v}; \quad \Rightarrow m = \frac{200}{2.222}; \quad \Rightarrow m = 90.01 \text{ kg};$$

State-2: $T_2 = 25^\circ\text{C},\ v_2 = v_1 = 2.222\ \frac{\text{m}^3}{\text{kg}}$

Using Table-B.2

$$v_{\text{f @ 130}^\circ\text{C}} = 0.001003\ \frac{\text{m}^3}{\text{kg}}; \quad v_{\text{g @ 130}^\circ\text{C}} = 43.36\ \frac{\text{m}^3}{\text{kg}};$$

Since $v_f < v_2 < v_g$, this fluid is now a saturated mixture.

(a) Pressure

$$p_2 = p_{\text{sat @ 25}^\circ\text{C}} = 3.169 \text{ kPa}$$

(b) Quality

$$x_2 = \frac{v_2 - v_f}{v_g - v_f}; \qquad \Rightarrow x_2 = \frac{2.222 - 0.001003}{43.36 - 0.001003}; \qquad \Rightarrow x_2 = 0.0512; \qquad \Rightarrow x_2 = 5.12\%$$

(c) Internal energy

$$\left.\begin{aligned} u_{f\ @\ 25^\circ\mathrm{C}} &= 104.88\ \frac{\mathrm{kJ}}{\mathrm{kg}}; \\ u_{g\ @\ 25^\circ\mathrm{C}} &= 2409.8\ \frac{\mathrm{kJ}}{\mathrm{kg}}; \end{aligned}\right\rangle\ u = u_f + x_2\left(u_g - u_f\right) = 104.88 + 0.0512\left(2409.8 - 104.88\right) = 222.9\ \frac{\mathrm{kJ}}{\mathrm{kg}};$$

Heat transfer

$$Q = \Delta U; \qquad \Rightarrow Q = m\Delta u; \qquad \Rightarrow Q = 90.01\left(222.9 - 3049.2\right);$$

$$\Rightarrow Q = -254{,}395\ \mathrm{kJ}; \qquad \Rightarrow Q = -254.40\ \mathrm{MJ}$$

TEST Solution:

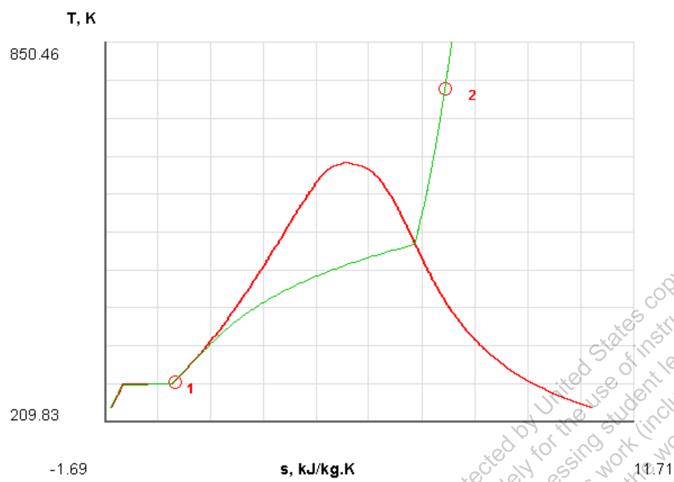
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-43 [FW] A rigid tank of volume 0.64 m^3 contains 10 kg of water at 5°C. (a) Plot how the state of water changes in a *T-s* diagram as the temperature is gradually increased to 500°C. (b) What-if Scenario: How would the plot change if the tank held 0.1 kg of water?

SOLUTION

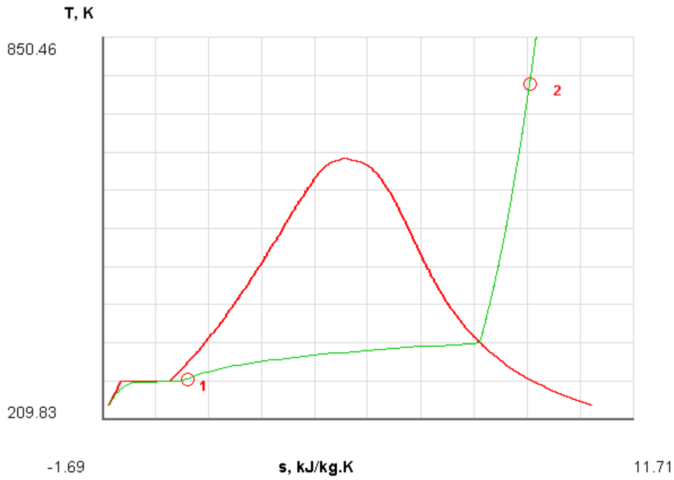
(a) $v = \frac{V}{m}; \quad \Rightarrow v = \frac{0.64}{10}; \quad \Rightarrow v = 0.064 \frac{\text{m}^3}{\text{kg}};$

Since the tank is rigid, *v* remains constant as the temperature is increased



(b) $v = \frac{V}{m}; \quad \Rightarrow v = \frac{0.64}{0.1}; \quad \Rightarrow v = 6.4 \frac{\text{m}^3}{\text{kg}};$

Since the tank is rigid, *v* remains constant as the temperature is increased



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-44 [DR] Draw a line of constant specific volume that passes through the critical point on a *T*-*s* diagram for R-134a. (b) What-if Scenario: How would the line shift if it passed through saturated vapor state at 50^{o}C?

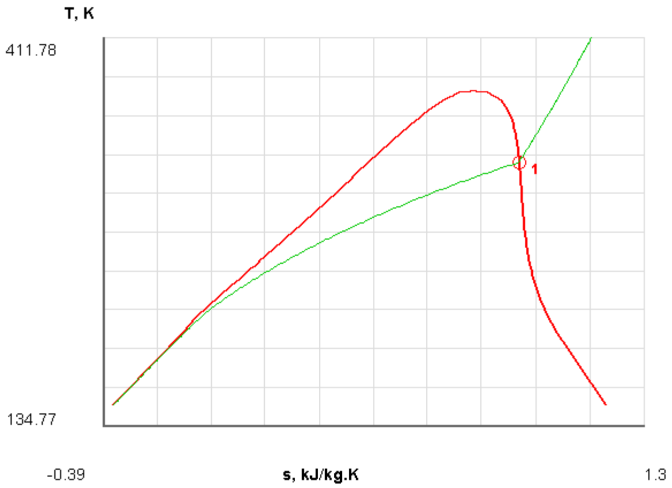
SOLUTION

(a) R-134a is at its critical state when $p = 4.06$ MPa, $T = 100.95°$C

$$v = v(p,T); \quad \Rightarrow v = v\left(4.06 \text{ MPa, } 100.95^{\circ}\text{C}\right); \quad \Rightarrow v = 0.0018 \ \frac{\text{m}^3}{\text{kg}};$$

(b) R-134a is a saturated vapor at 50°C which means $p = p_{sat@50°C} = 1.3181$ MPa

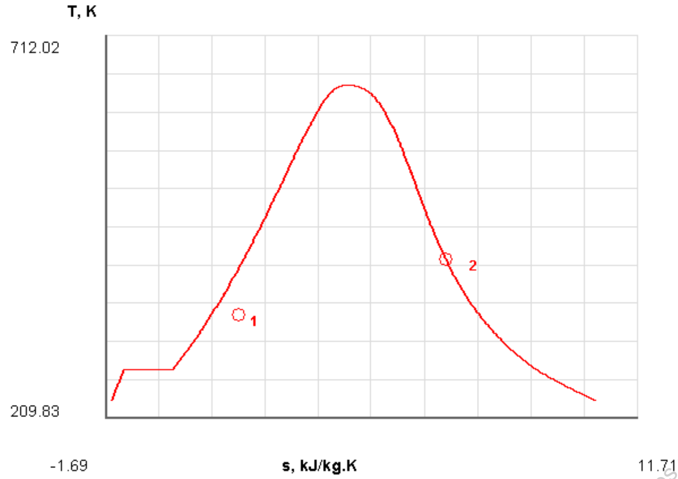
$$v_g = v_g\left(p,T\right); \quad \Rightarrow v_g = v_g\left(1.3181 \text{ MPa, } 50^{\circ}\text{C}\right); \quad \Rightarrow v = 0.01512 \ \frac{\text{m}^3}{\text{kg}};$$



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

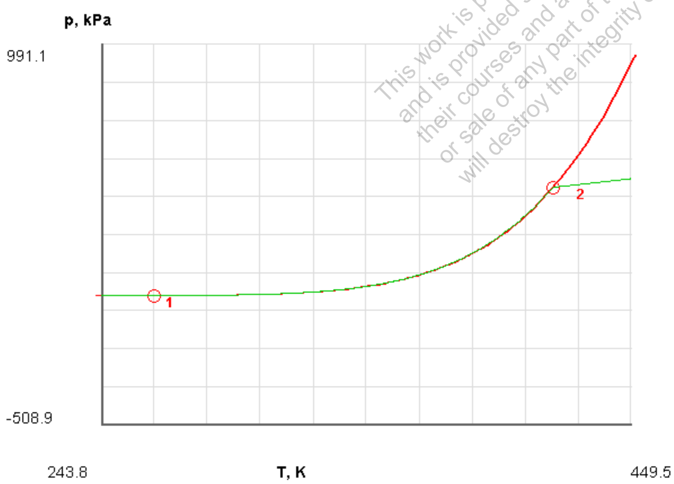
3-3-45 [DO] A 1 m^3 rigid tank contains 2.3 kg of a vapor-liquid mixture of water. The tank is heated to raise the quality of steam. Plot how the pressure and temperature in the tank vary as the quality of steam gradually increases to 100%.

SOLUTION



$$v = \frac{V}{m}; \quad \Rightarrow v = \frac{1}{2.3}; \quad \Rightarrow v = 0.43478 \frac{m^3}{kg};$$

v remains constant going from a vapor-liquid mixture to a saturated vapor

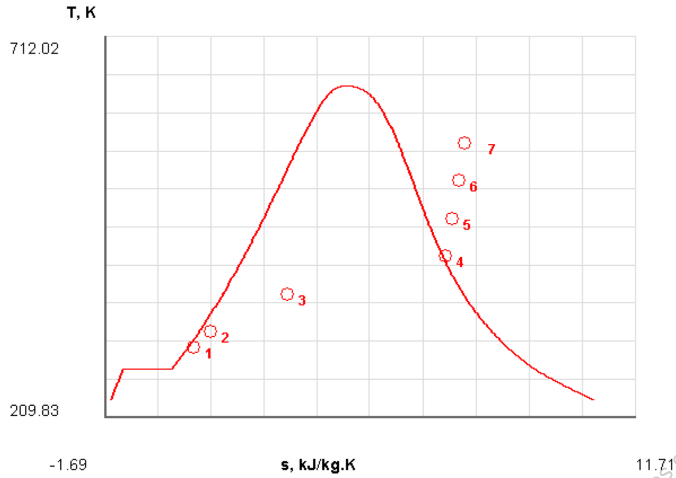


TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

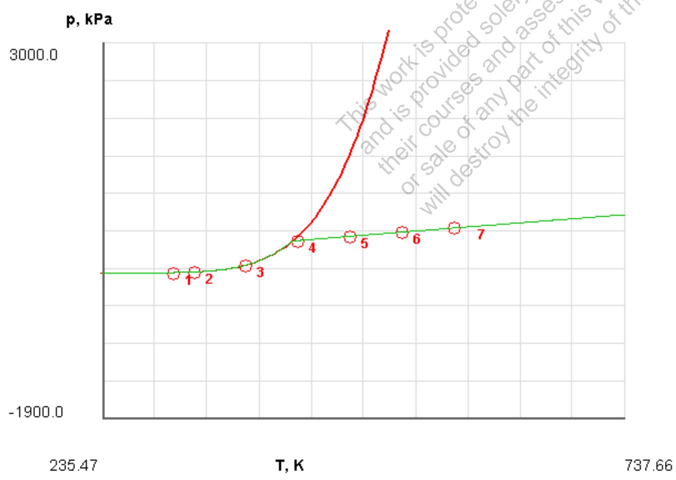
3-3-46 [DB] Plot how (a) the pressure (p), (b) the stored energy (E), and (c) the entropy (S) of 4.5 kg of water contained in a 2 m^3 rigid vessel as the temperature is increased from 30^oC to 300^oC.

SOLUTION



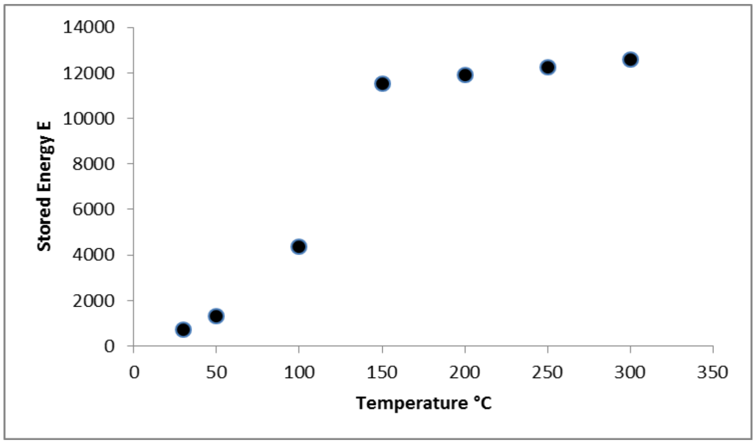
$$v = \frac{V}{m}; \qquad \Rightarrow v = \frac{2}{4.5}; \qquad \Rightarrow v = 0.4444 \frac{m^3}{kg};$$

(a)



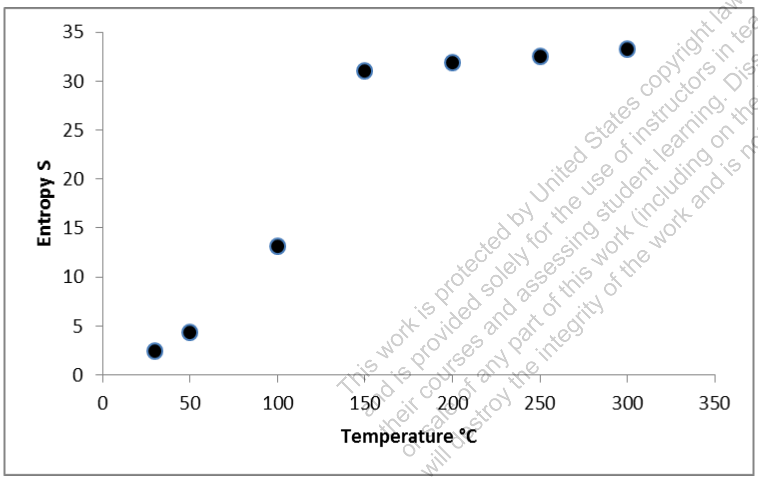
(b)

T	E



30	705.0299
50	1312.554
100	4376.442
150	11532.3
200	11896.79
250	12251.77
300	12604.74

(c)



T	S
30	2.45241
50	4.39011
100	13.09869
150	31.04838
200	31.86459
250	32.57793
300	33.22247

TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-47 [DS] A piston-cylinder device contains 3 kg of saturated mixture of water with a quality of 0.8 at 180°C. Heat is added until all the liquid vaporizes. Determine (a) the pressure (p), (b) the initial volume, (c) the final volume and (d) the work (W) performed by the vapor during the expansion process. (e) Show the process on a p-v diagram.

SOLUTION

State-1: $T_1 = 180^\circ\text{C},\ x_1 = 0.8$

Using Table-B.2

$$\left.\begin{aligned} v_{\text{f @ }180^\circ\text{C}} &= 0.001127\ \frac{\text{m}^3}{\text{kg}} \\ v_{\text{g @ }180^\circ\text{C}} &= 0.19405\ \frac{\text{m}^3}{\text{kg}} \end{aligned}\right\rangle\ v_1 = v_\text{f} + x_1\left(v_\text{g} - v_\text{f}\right) = 0.001127 + 0.8\left(0.19405 - 0.001127\right) = 0.1555\ \frac{\text{m}^3}{\text{kg}};$$

(a) Initial pressure

$$p_1 = p_{\text{sat @ }180^\circ\text{C}};\qquad \Rightarrow p_1 = 1.0021\ \text{MPa}$$

(b) Initial volume

$$\cancel{V}_1 = m v_1;\qquad \Rightarrow \cancel{V}_1 = 3\left(0.1555\right);\qquad \Rightarrow \cancel{V}_1 = 0.4664\ \text{m}^3$$

State-2: $p_2 = p_1 = 1.0021\ \text{MPa},\ x_2 = 1$

Using Table-B.2

$$v_2 = v_{\text{g @ }1.0021\text{ MPa}};\qquad \Rightarrow\ v_2 \cong 0.19405\ \frac{\text{m}^3}{\text{kg}};$$

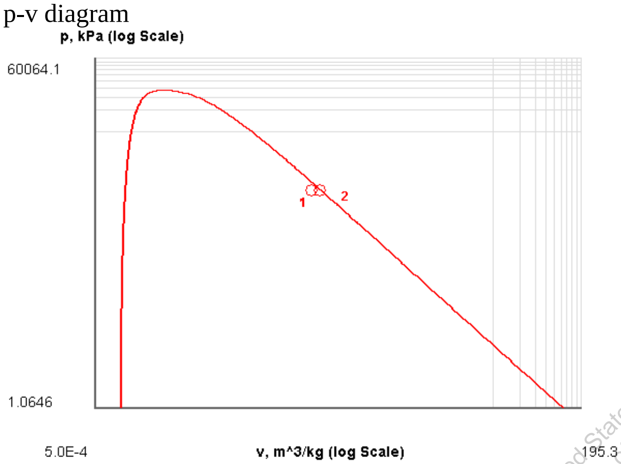
(c) Final volume

$$\forall_2 = mv_2; \quad \Rightarrow \forall_2 = 3(0.19405); \quad \Rightarrow \forall_2 = 0.582 \text{ m}^3$$

(d) Boundary work

$$W_B = p\Delta\forall; \quad \Rightarrow W_B = p(\forall_2 - \forall_1); \quad \Rightarrow W_B = 1002.1(0.582 - 0.4664);$$
$$\Rightarrow W_B = 116 \text{ kJ}$$

(e) p-v diagram

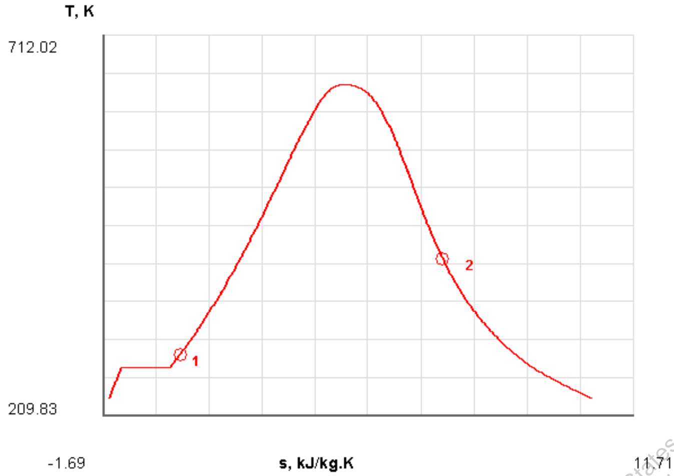


TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-48 [DA] A piston-cylinder device initially contains 3 ft^3 of liquid water at 60 psia and 63^{o}F. Heat is now transferred to the water at constant pressure until the entire liquid is vaporized. Determine (a) the mass of the water, (b) final temperature (T_2) and (c) total enthalpy change (ΔH). The *T-s* diagram is to be drawn.

SOLUTION



$V = 3\text{ ft}^3 = 0.0849505\text{ m}^3;$

$p = 60\text{ psia} = 413.685\text{ kPa};$

$T = 63°\text{F} = 17.22°\text{C};$

(a) $v = v(p,T); \quad \Rightarrow v = v(413.685\text{ kPa}, 17.22°\text{C}); \quad \Rightarrow v = 0.001\ \frac{\text{m}^3}{\text{kg}};$

$m = \frac{V}{v}; \quad \Rightarrow m = \frac{0.0849505}{0.001}; \quad \Rightarrow m = 84.95\text{ kg} = 187.04\text{ lbm}$

(b) Pressure remains constant, therefore

$T_{final} = T_{sat@413.685kPa} = 144.805°\text{C} = 292.65°\text{F}$

(c) $h_1 = h_1(413.685\text{ kPa}, 17.22°\text{C}); \quad \Rightarrow h_1 = 72.7171\ \frac{\text{kJ}}{\text{kg}}$

$h_2 = h_{g@413.685kPa}; \quad \Rightarrow h_2 = 2739.9834\ \frac{\text{kJ}}{\text{kg}}$

$\Delta H = m(h_2 - h_1); \quad \Rightarrow \Delta H = (84.95)(2739.9834 - 72.7171); \quad \Rightarrow \Delta H = 226584.27\text{ kJ} = 214760\text{ Btu}$

TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-49 [DH] A piston-cylinder device contains 0.6 kg of steam at 350°C and 1.5 MPa. Steam is now cooled at constant pressure until half of the mass condenses. Determine (a) the final temperature (T_2) and (b) the boundary work transfer. (c) Show the process on a *T-s* diagram.

SOLUTION

State-1: $p_1 = 1.5 \text{ MPa}, \; T_1 = 350^\circ\text{C}$

Using Table-B.3

$$v_1 = v_1(p,T); \quad \Rightarrow v_1 = v_1(150\text{kPa}, 450^\circ\text{C}); \quad \Rightarrow v_1 = 0.18655 \; \frac{\text{m}^3}{\text{kg}};$$

(a) **State-2:** $p_2 = p_1 = 1.5 \text{ MPa}, \; x_2 = 0.5$

Using Table-B.1

$$T_2 = T_{\text{sat @ 1.5 MPa}} = 198.32^\circ\text{C}$$

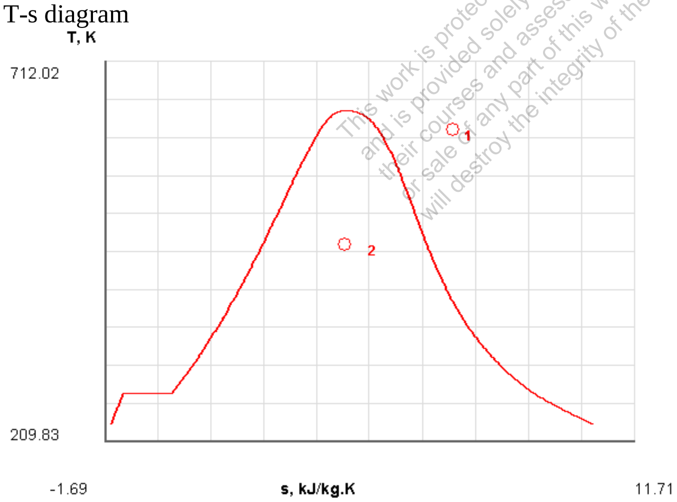
(b) Boundary work

$$\left. \begin{aligned} v_{\text{f @ 1.5 MPa}} &= 0.001154 \; \frac{\text{m}^3}{\text{kg}} \\ v_{\text{g @ 1.5 MPa}} &= 0.13177 \; \frac{\text{m}^3}{\text{kg}} \end{aligned} \right\rangle \; v_2 = v_\text{f} + x_2(v_\text{g} - v_\text{f}); \quad \Rightarrow v_2 = 0.0665 \; \frac{\text{m}^3}{\text{kg}};$$

$$W_\text{B} = p\Delta\mathcal{V}; \quad \Rightarrow W_\text{B} = pm\Delta v; \quad \Rightarrow W_\text{B} = pm(v_2 - v_1);$$

$$\Rightarrow W_\text{B} = 1500(0.6)(0.0665 - 0.18655); \quad \Rightarrow W_\text{B} = -108 \text{ kJ}$$

(c) T-s diagram

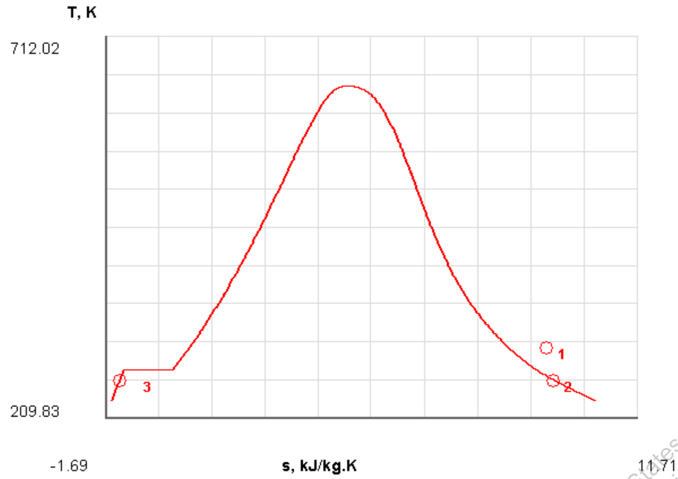


TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-50 [DN] Water vapor (1 kg) at 0.2 kPa and 30°C is cooled in a constant pressure process until condensation begins. Determine (a) the boundary work transfer and (b) change of enthalpy (*ΔH*) treating water as the system. What-if Scenario: What would the (c) boundary work transfer and (d) change of enthalpy be if all the vapor condensed?

SOLUTION



State-1: $p_1 = 0.2 \text{ kPa},\ T_1 = 30^\circ\text{C}$

Using Table-B.3

$$v_1 = v_1(p,T); \quad \Rightarrow v_1 = v_1\left(0.2 \text{ kPa, } 30^\circ\text{C}\right); \quad \Rightarrow v_1 = 699.46 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h_1(p,T); \quad \Rightarrow h_1 = h_1\left(0.2 \text{ kPa, } 30^\circ\text{C}\right); \quad \Rightarrow h_1 = 2555.97 \ \frac{\text{kJ}}{\text{kg}};$$

State-2: $p_2 = 0.2 \text{ kPa},\ x_2 = 1$

Using Table-B.1

$$v_2 = v_{g\,@\,0.2\text{ kPa}}; \quad \Rightarrow v_2 = 604.97 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_2 = h_{g\,@\,0.2\text{ kPa}}; \quad \Rightarrow h_2 = 2477.4 \ \frac{\text{kJ}}{\text{kg}};$$

(a) Boundary work

$$W_B = p\Delta\cancel{V}; \quad \Rightarrow W_B = pm\Delta v; \quad \Rightarrow W_B = pm(v_2 - v_1);$$

$$\Rightarrow W_B = 0.2(1)(604.97 - 699.46); \quad \Rightarrow W_B = -18.9 \text{ kJ}$$

(b) Change in enthalpy

$$\Delta H = H_2 - H_1; \quad \Rightarrow \Delta H = m(h_2 - h_1); \quad \Rightarrow \Delta H = 1(2447.4 - 2555.97);$$

$$\Rightarrow \Delta H = -78.57 \text{ kJ}$$

What-if-Scenario:

State-2: $p_2 = 0.2 \text{ kPa}, x_2 = 0$

Using Table-B.1

$$v_2 = v_{\text{f @ 0.2 kPa}}; \qquad \Rightarrow v_2 = 0.00109 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_2 = h_{\text{f @ 0.2 kPa}}; \qquad \Rightarrow h_2 = -360.09 \ \frac{\text{kJ}}{\text{kg}};$$

(c) $W_\text{B} = p\Delta \cancel{V}; \qquad \Rightarrow W_\text{B} = pm\Delta v; \qquad \Rightarrow W_\text{B} = pm(v_2 - v_1);$

$$\Rightarrow W_\text{B} = 0.2(1)(0.00109 - 699.46); \qquad \Rightarrow W_\text{B} = -139.9 \text{ kJ}$$

(d) $\Delta H = H_2 - H_1; \qquad \Rightarrow \Delta H = m(h_2 - h_1); \qquad \Rightarrow \Delta H = 1(360.09 - 2555.97);$

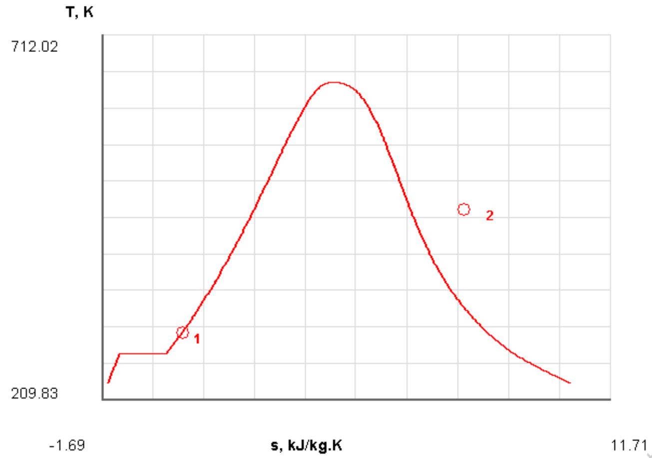
$$\Rightarrow \Delta H = -2916.1 \text{ kJ}$$

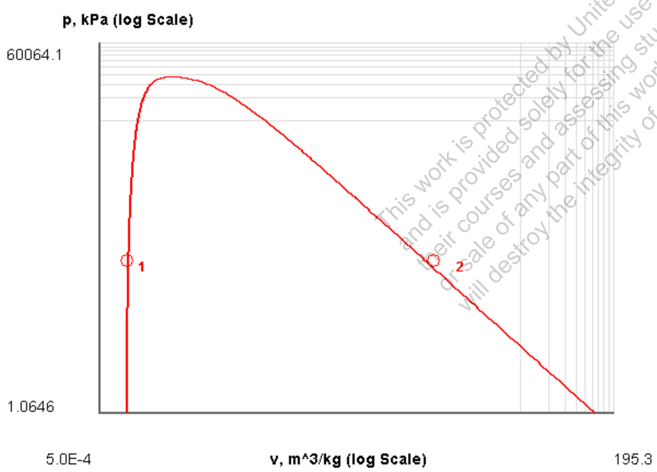
TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-51 [DE] A piston cylinder device contains 10 L of liquid water at 100 kPa and 30^{o}C. Heat is transferred at constant pressure until the temperature increases to 200^{o}C. Determine the change in (a) the total volume and (b) total internal energy (ΔU) of steam. Show the process on a *T*-*s* and *p*-*v* diagram.

SOLUTION





Using Table-A

$$\rho_{\text{water}} = 996\ \frac{\text{m}^3}{\text{kg}};$$

$$m = \mathcal{V}\rho; \qquad \Rightarrow \text{m} = \frac{10}{1000}(996); \qquad \Rightarrow \text{m} = 9.96\ \text{kg};$$

State-1: $p_1 = 100 \text{ kPa}, T_1 = 30^\circ\text{C}$

Using the CL sub-model assumptions and Table-B.2

$$v_1 \cong v_{\text{g @ }30^\circ\text{C}} = 0.00104 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_1 \cong u_{\text{g @ }30^\circ\text{C}} = 125.78 \ \frac{\text{kJ}}{\text{kg}};$$

State-2: $p_2 = 100 \text{ kPa}, T_2 = 200^\circ\text{C}$

Using Table-B.3

$$v_2 = v_2(p,T) = v_2(100 \text{ kPa}, 200^\circ\text{C}) = 2.172 \ \frac{\text{m}^3}{\text{kg}};$$

$$u_2 = u_2(p,T) = u_2(100 \text{ kPa}, 200^\circ\text{C}) = 2658.1 \ \frac{\text{kJ}}{\text{kg}};$$

(a) Change in volume

$$\Delta V = m(v_2 - v_1); \quad \Rightarrow \Delta V = 9.96(2.172 - 0.00104); \quad \Rightarrow \Delta V = 21.6 \text{ m}^3$$

(b) Change in internal energy

$$\Delta U = m\Delta u; \quad \Rightarrow \Delta U = m(u_2 - u_1); \quad \Rightarrow \Delta U = 9.96(2658.1 - 125.78);$$

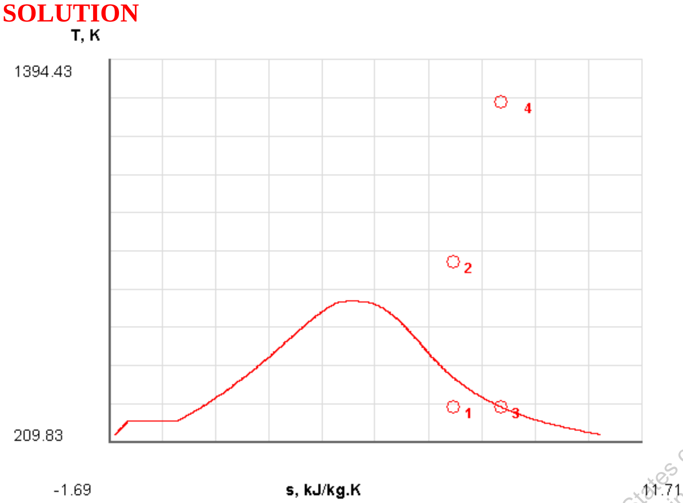
$$\Rightarrow \Delta U = 25,222 \text{ kJ}$$

TEST Solution:

Launch the PC open steady state single-flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-52 [DI] A piston-cylinder device contains a saturated mixture of water with a quality of 84.3% at 10 kPa. If the pressure is raised in an isentropic (constant entropy) manner to 5000 kPa, (a) determine the final temperature (T_2). (b) What-if Scenario: What would the final temperature be if water were at saturated vapor state to start with?

SOLUTION



(a) **State-1:** $p_1 = 10\text{ kPa},\ x_1 = 0.843$

Using Table-B.1

$$\left.\begin{array}{l} s_{f\,@\,10\text{ kPa}} = 0.6493\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}} \\ s_{g\,@\,10\text{ kPa}} = 8.1502\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}} \end{array}\right\rangle s_1 = s_f + x_1\left(s_g - s_f\right); \quad \Rightarrow s_1 = 6.793\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p_2 = 5000\text{ kPa},\ s_2 = s_1 = 6.973\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.3

$$T_2 = T_2(P, s); \qquad \Rightarrow T_2 = T_2\left(5000\text{ kPa},\ 6.973\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \qquad \Rightarrow T_2 \cong 499^\circ\text{C}$$

(b) What-if-Scenario:

State-1: $p_1 = 10\text{ kPa},\ x_1 = 1$

$$s_1 = s_{g\,@\,10\text{ kPa}} = 8.1502\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p_2 = 5000\text{ kPa},\ s_2 = s_1 = 8.1502\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.3

$$T_2 = T_2(P, s); \qquad \Rightarrow T_2 = T_2\left(5000 \text{ kPa, } 8.1502 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}}\right); \qquad \Rightarrow T_2 \cong 994^\circ \text{C}$$

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-53 [DL] A piston-cylinder device contains a saturated mixture of R-134a with a quality of 90% at 50 kPa. The quality of the mixture is raised to 100% by (i) compressing the mixture in an isentropic manner or, alternatively, (ii) by adding heat in a constant temperature process. (a) Draw the two processes on a *T-s* diagram. Determine the change in specific internal energy (*Δu*) (b) in (i) and (c) adding heat at constant temperature.

SOLUTION

State-1: 50 kPa, x = 0.9

$$s_1 = 0.8672 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$u_1 = 184.968 \ \frac{\text{kJ}}{\text{kg}};$$

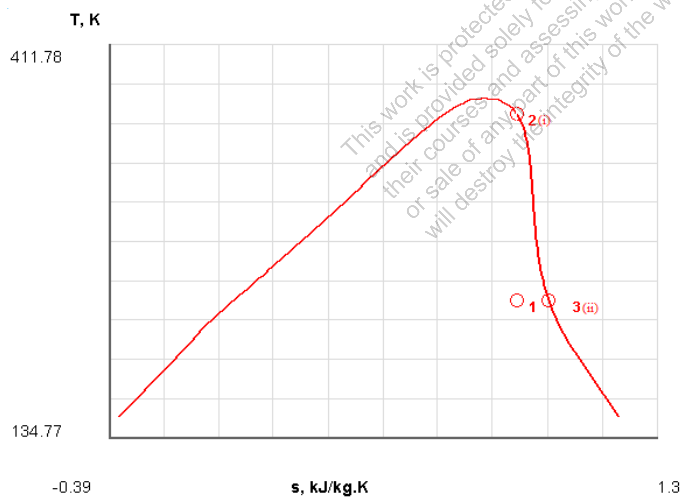
State-2 (i): $s = s_1 = 0.8672 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}}, \ x = 1$

$$u_2 = 261.62 \ \frac{\text{kJ}}{\text{kg}};$$

State-3 (ii): $T = T_1 = T_{sat@50kPa}, \ x = 1$

$$u_3 = 205.61 \ \frac{\text{kJ}}{\text{kg}};$$

(a)



(b) $\Delta u = u_2 - u_1; \qquad \Rightarrow \Delta u = 261.62 - 184.968; \qquad \Rightarrow \Delta u = 76.652 \ \frac{\text{kJ}}{\text{kg}}$

(c) $\Delta u = u_3 - u_1;\quad \Rightarrow \Delta u = 205.61 - 184.968;\quad \Rightarrow \Delta u = 20.642\ \frac{\text{kJ}}{\text{kg}}$

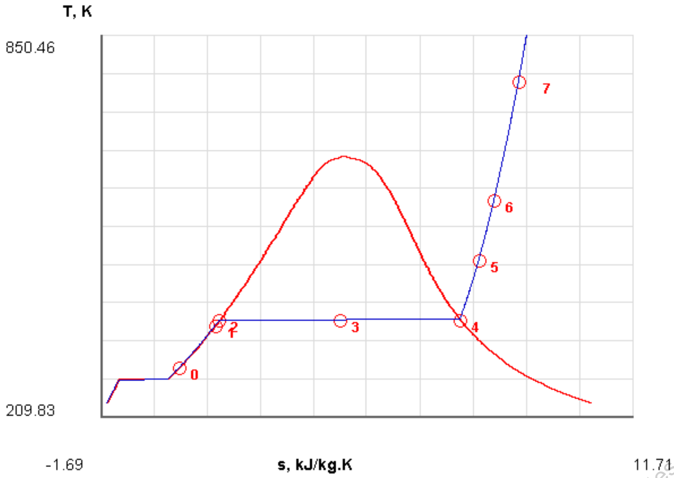
TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

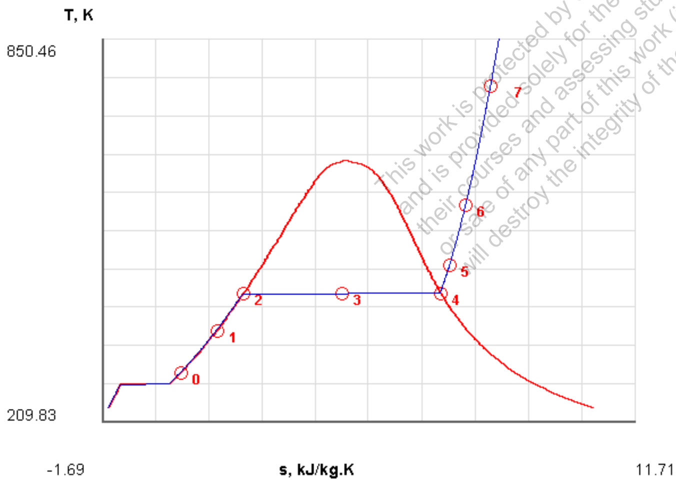
3-3-54 [DG] Draw the constant pressure line on a *T-s* diagram for H_2O at p = 100 kPa as liquid water is heated to superheated vapor. Redo the plot for a pressure of 500 kPa.

SOLUTION

$p = 100$ kPa



$p = 500$ kPa



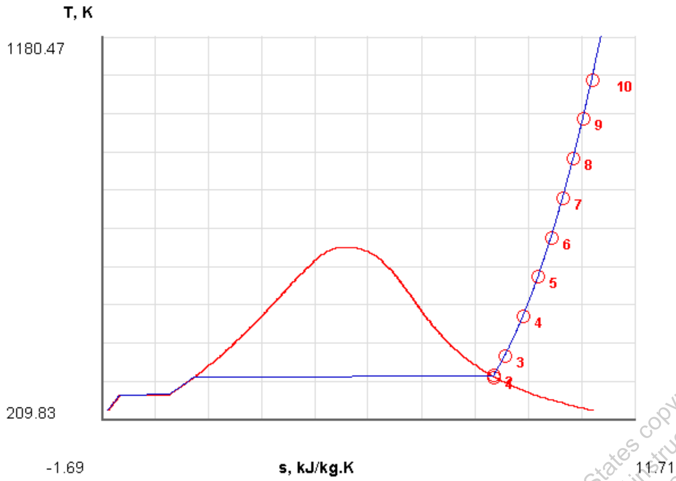
TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

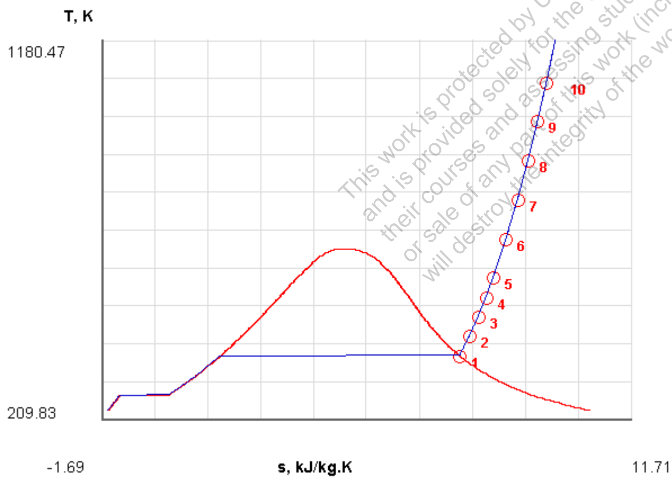
3-3-55 [DZ] For H_2O, plot how the entropy (S) changes with T in the superheated vapor region for a pressure of (a) 10 kPa, (b) 100 kPa and (c) 10 MPa. Take at least 10 points from the saturation temperature to 800°C.

SOLUTION

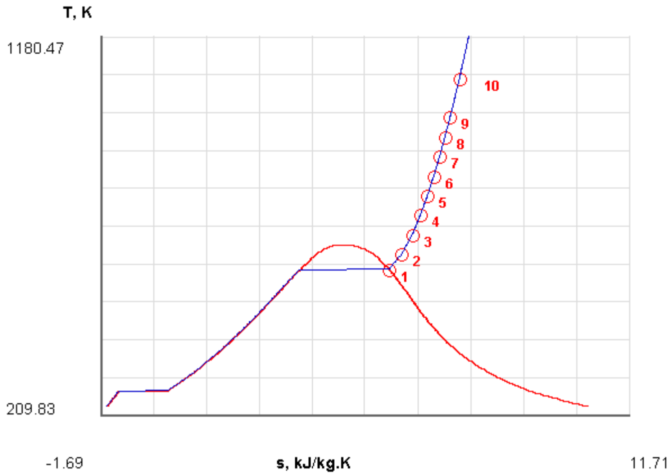
(a) 10 kPa



(b) 100 kPa



(c) 10 MPa



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-56 [DK] Water at a pressure of 50 MPa is heated in a constant pressure electrical heater from 50°C to 1000°C. Spot the states on a *T-s* diagram and determine (a) the change of specific enthalpy (Δh) and (b) specific entropy (Δs). Use compressed liquid model for liquid water.

SOLUTION

State-1: $p = 50 \text{ MPa},\ T = 50°\text{C}$

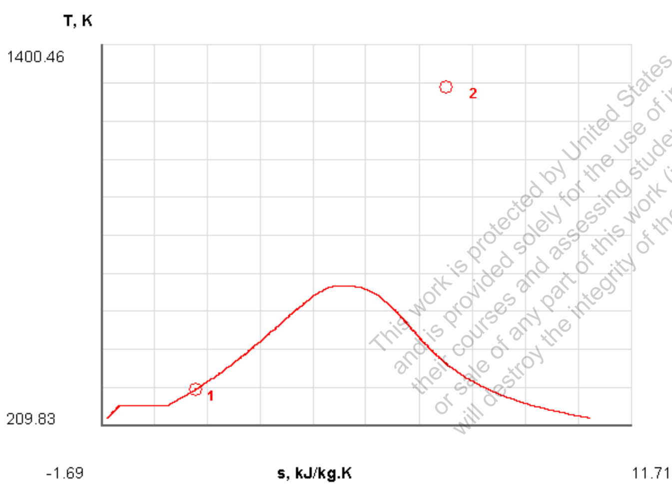
$h_1 = 259.9157 \ \frac{\text{kJ}}{\text{kg}};$

$s_1 = 0.7038 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$

State-2: $p = 50 \text{ MPa},\ T = 1000°\text{C}$

$h_1 = 4501.062 \ \frac{\text{kJ}}{\text{kg}};$

$s_1 = 7.01458 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$



(a) $\Delta h = h_2 - h_1; \quad \Rightarrow \Delta h = 4501.062 - 259.9157; \quad \Rightarrow \Delta h = 4241.1463 \ \frac{\text{kJ}}{\text{kg}}$

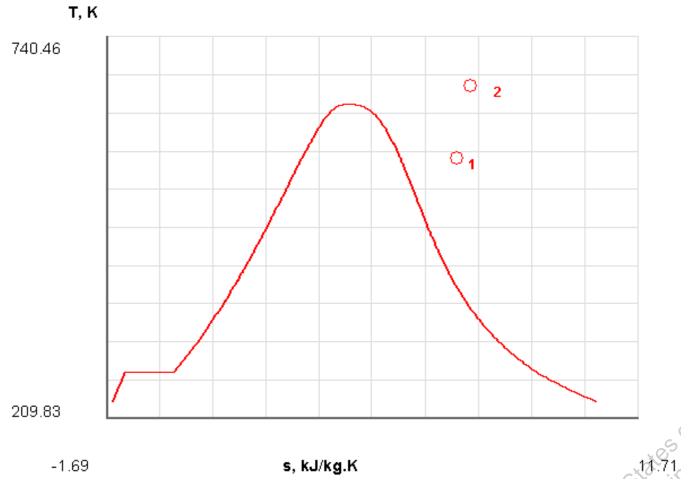
(b) $\Delta s = s_2 - s_1; \quad \Rightarrow \Delta s = 7.01458 - 0.7038; \quad \Rightarrow \Delta s = 6.31078 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

TEST Solution:

Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-57 [DP] Determine (a) the mass flow rate and (b) the volume flow rate of steam flowing through a pipe of diameter 0.1 m at 1000 kPa, 300°C and 50 m/s. (c) Also determine the rate of transport of energy by the steam. (d) What-if Scenario: What would the answer in (c) be if the temperature were 400°C?

SOLUTION



Specific properties where: $p = 1000 \text{ kPa}, T = 300^\circ\text{C}$

Using Table.3

$$v = v(1000 \text{ kPa}, 300^\circ\text{C}) = 0.2579 \ \frac{\text{m}^3}{\text{kg}};$$

$$h = h(1000 \text{ kPa}, 300^\circ\text{C}) = 3051.2 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $\dot{V} = \text{Av}; \quad \Rightarrow \dot{V} = \pi\frac{0.1^2}{4}(50); \quad \Rightarrow \dot{V} = 0.3927 \ \frac{\text{m}^3}{\text{s}};$

$$\dot{m} = \frac{\dot{V}}{v}; \quad \Rightarrow \dot{m} = \frac{0.3927}{0.2579}; \quad \Rightarrow \dot{m} = 1.5227 \ \frac{\text{kg}}{\text{s}}$$

(b) Volume flow rate

$$\dot{V} = \text{Av}; \quad \Rightarrow \dot{V} = \pi\frac{0.1^2}{4}(50); \quad \Rightarrow \dot{V} = 0.3927 \ \frac{\text{m}^3}{\text{s}}$$

(c) Energy transport rate

$$\dot{J} = \dot{m}\left(h + ke + \cancel{pe}^{\text{neg}}\right); \quad \Rightarrow \dot{J} = \dot{m}\left(h + \frac{\text{v}^2}{2000}\right);$$

$$\Rightarrow \dot{J} = 1.5227\left(3051.2 + \frac{50^2}{2000}\right); \qquad \Rightarrow \dot{J} = 4648 \text{ kW}$$

(d) What-if-Scenario

Specific properties where $p = 1000$ kPa, $T = 400^\circ$C,

Using Table.3

$$v = v\left(1000 \text{ kPa, } 400^\circ\text{C}\right) = 0.3066 \ \frac{\text{m}^3}{\text{kg}};$$

$$h = h\left(1000 \text{ kPa, } 400^\circ\text{C}\right) = 3263.9 \ \frac{\text{kJ}}{\text{kg}};$$

$$\dot{m} = \frac{\dot{V}}{v}; \qquad \Rightarrow \dot{m} = \frac{0.3927}{0.3066}; \qquad \Rightarrow \dot{m} = 1.28 \ \frac{\text{kg}}{\text{s}};$$

$$\dot{J} = \dot{m}\left(h + ke + \cancel{pe}^{\text{neg}}\right); \qquad \Rightarrow \dot{J} = \dot{m}\left(h + \frac{\text{v}^2}{2000}\right);$$

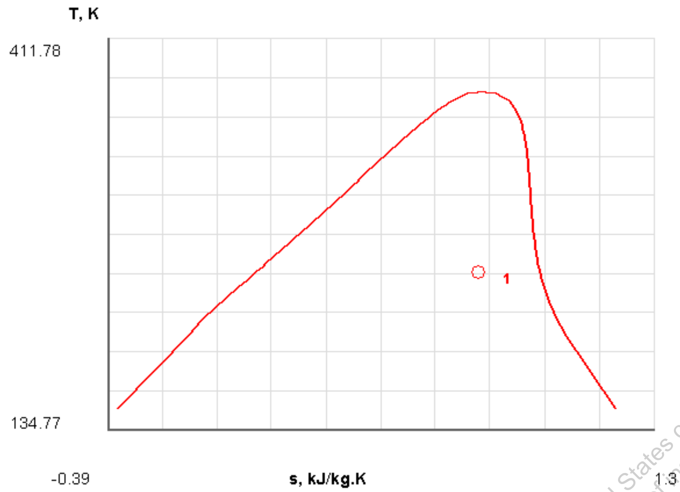
$$\Rightarrow \dot{J} = 1.28\left(3263.9 + \frac{50^2}{2000}\right); \qquad \Rightarrow \dot{J} = 4179.4 \text{ kW}$$

TEST Solution:

Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-58 [DX] Refrigerant-134a flows through a pipe of diameter 5 cm with a mass flow rate of 0.13 kg/s at 100 kPa and 10 m/s. Determine (a) the temperature (T) and (b) quality of the refrigerant in the pipe. Also determine the rate of transport of (c) energy (J) and (d) entropy (S) by the flow.

SOLUTION



$$\dot{V} = \mathrm{Av}; \quad \Rightarrow \dot{V} = \pi \frac{0.01^2}{4}(10); \quad \Rightarrow \dot{V} = 0.19635 \frac{\mathrm{m}^3}{\mathrm{s}};$$

$$v = \frac{\dot{V}}{\dot{m}}; \quad \Rightarrow v = \frac{0.019635}{0.13}; \quad \Rightarrow v = 0.151 \frac{\mathrm{m}^3}{\mathrm{kg}};$$

Using Table-B.5

$$v_{\mathrm{f\,@\,100\,kPa}} = 0.00073 \frac{\mathrm{m}^3}{\mathrm{kg}}; \quad v_{\mathrm{g\,@\,100\,kPa}} = 0.19269 \frac{\mathrm{m}^3}{\mathrm{kg}};$$

Since $v_\mathrm{f} < v < v_\mathrm{g}$, this fluid is a saturated mixture.

(a) $T = T_{\mathrm{sat\,@\,100\,kPa}} \cong -26.59^\circ\mathrm{C}$

(b) Mass fraction

$$x = \frac{v - v_\mathrm{f}}{v_\mathrm{g} - v_\mathrm{f}}; \quad \Rightarrow x = \frac{0.150 - 0.00073}{0.19269 - 0.00073}; \quad \Rightarrow x = 0.7828; \quad \Rightarrow x = 78.28\%$$

(c) Energy transport rate

$$\left.\begin{array}{l} h_{\text{f @ 100 kPa}} = 16.458\ \dfrac{\text{kJ}}{\text{kg}}; \\ h_{\text{g @ 100 kPa}} = 233\ \dfrac{\text{kJ}}{\text{kg}}; \end{array}\right\rangle\ h = h_f + x\left(h_g - h_f\right); \quad \Rightarrow h = 185.97\ \frac{\text{kJ}}{\text{kg}};$$

$$\dot{J} = \dot{m}\left(h + ke + \cancel{pe}^{\,\text{neg}}\right); \quad \Rightarrow \dot{J} = \dot{m}\left(h + \frac{\text{v}^2}{2000}\right); \quad \Rightarrow \dot{J} = 0.13\left(185.97 + \frac{10^2}{2000}\right);$$

$$\Rightarrow \dot{J} = 24.18\ \text{kW}$$

(d) Entropy transport rate

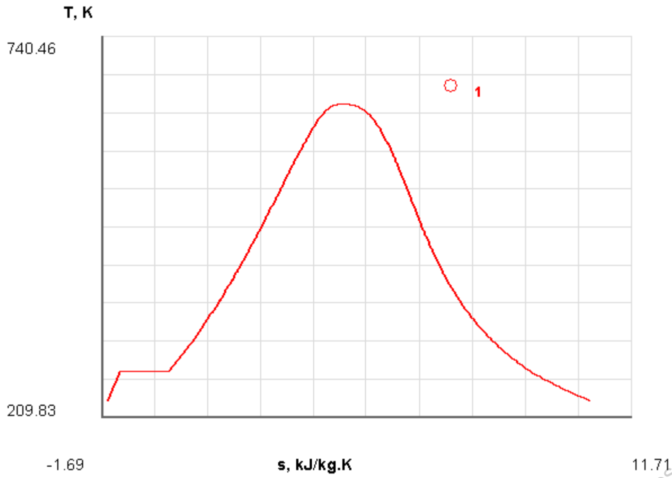
$$\left.\begin{array}{l} s_{\text{f @ 100 kPa}} = 0.0684\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}; \\ s_{\text{g @ 100 kPa}} = 0.9465\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}; \end{array}\right\rangle\ s = s_f + x\left(s_g - s_f\right); \quad \Rightarrow s = 0.7558\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\dot{S} = \dot{m}s; \quad \Rightarrow \dot{S} = 0.13(0.7558); \quad \Rightarrow \dot{S} = 0.0983\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-59 [DU] Steam at a pressure of 2 MPa and 400°C flows through a pipe of diameter 10 cm with a velocity of 50 m/s. Determine the flow rates of (a) mass (*m*), (b) energy (*J*) and (c) entropy (*S*).

SOLUTION



Specific properties
Using Table-B.3

$$v = v(p,T); \quad \Rightarrow v = v(2\text{ MPa}, 400^\circ\text{C}); \quad \Rightarrow v = 0.1512\ \frac{\text{m}^3}{\text{kg}};$$

$$h = h(p,T); \quad \Rightarrow h = h(2\text{ MPa}, 400^\circ\text{C}); \quad \Rightarrow h = 3247.6\ \frac{\text{kJ}}{\text{kg}};$$

$$s = s(p,T); \quad \Rightarrow s = s(2\text{ MPa}, 400^\circ\text{C}); \quad \Rightarrow s = 7.1271\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $$\dot{V} = \text{Av}; \quad \Rightarrow \dot{V} = \pi\frac{0.1^2}{4}(50); \quad \Rightarrow \dot{V} = 0.3927\ \frac{\text{m}^3}{\text{s}};$$

$$\dot{m} = \frac{\dot{V}}{v}; \quad \Rightarrow \dot{m} = \frac{0.3927}{0.1512}; \quad \Rightarrow \dot{m} = 2.6\ \frac{\text{kg}}{\text{s}}$$

(b) $$\dot{J} = \dot{m}\left(h + ke + \cancel{pe}^{\text{neg}}\right); \quad \Rightarrow \dot{J} = \dot{m}\left(h + \frac{\text{v}^2}{2000}\right); \quad \Rightarrow \dot{J} = 2.6\left(3247.6 + \frac{50^2}{2000}\right);$$

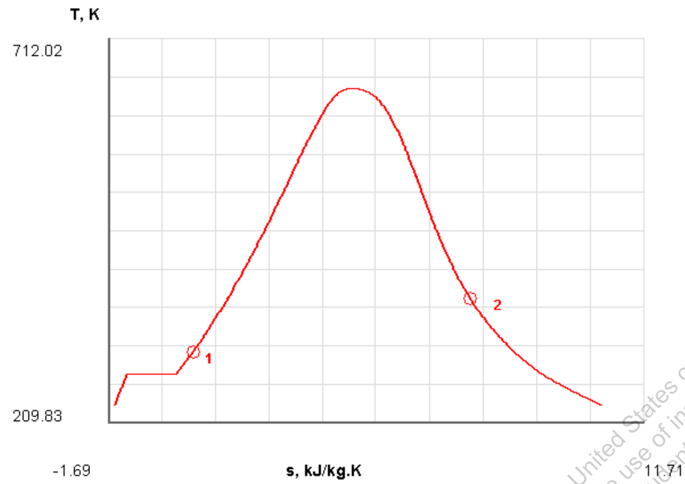
$$\Rightarrow \dot{J} = 8447\text{ kW}$$

(c) $$\dot{S} = \dot{m}s; \quad \Rightarrow \dot{S} = 2.6(7.1271); \quad \Rightarrow \dot{S} = 18.53\ \frac{\text{kW}}{\text{K}}$$

TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-60 [DV] Liquid water at 100 kPa, 30°C enters a boiler through a 2 cm-diameter pipe with a mass flow rate of 1 kg/s. It leaves the boiler as saturated vapor through a 20 cm-diameter pipe without any significant pressure loss. Determine (a) the exit velocity (V_2), the rate of transport of energy at (b) the inlet and (c) exit. Neglect potential energy, but not kinetic energy. (d) What-if Scenario: What would the rate of transport of energy at (d) inlet and (e) exit be if kinetic energy were neglected?

SOLUTION



State-1: $p_1 = 100 \text{ kPa}, T_1 = 30^\circ\text{C}$

Using the CL sub-model assumptions and Table-B.2

$$v_1 \cong v_{f @ 30^\circ C} = 0.001004 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 \cong h_{f @ 30^\circ C} = 125.79 \ \frac{\text{kJ}}{\text{kg}};$$

State-2: $p_2 = 100 \text{ kPa}, x_2 = 1$

Using Table-B.1

$$v_2 = v_{g @ 100 \text{ kPa}} = 1.694 \ \frac{\text{m}^3}{\text{kg}};$$

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

(a) $$\text{V}_1 = \frac{\dot{m}v_1}{\text{A}_1}; \qquad \Rightarrow \text{V}_1 = \frac{1(0.001004)}{\pi \frac{0.02^2}{4}}; \qquad \Rightarrow \text{V}_1 = 3.2 \ \frac{\text{m}}{\text{s}};$$

$$\mathrm{v}_2 = \frac{\dot{m}v_2}{\mathrm{A}_2}; \qquad \Rightarrow \mathrm{v}_2 = \frac{1(1.694)}{\pi \frac{0.2^2}{4}}; \qquad \Rightarrow \mathrm{v}_2 = 53.92 \ \frac{\mathrm{m}}{\mathrm{s}}$$

(b) $\dot{J}_1 = \dot{m}\left(h_1 + ke_1 + \cancel{pe_1}^{\text{neg}}\right); \qquad \Rightarrow \dot{J}_1 = \dot{m}\left(h_1 + \frac{\mathrm{v}_1^{\,2}}{2000}\right); \qquad \Rightarrow \dot{J}_1 = 1\left(125.79 + \frac{3.2^2}{2000}\right);$

$\Rightarrow \dot{J}_1 = 125.8 \text{ kW}$

(c) $\dot{J}_2 = \dot{m}\left(h_2 + ke_2 + \cancel{pe_2}^{\text{neg}}\right); \qquad \Rightarrow \dot{J}_2 = \dot{m}\left(h_2 + \frac{\mathrm{v}_2^{\,2}}{2000}\right); \qquad \Rightarrow \dot{J}_2 = 1\left(2675.5 + \frac{53.92^2}{2000}\right);$

$\Rightarrow \dot{J}_2 = 2676.5 \text{ kW}$

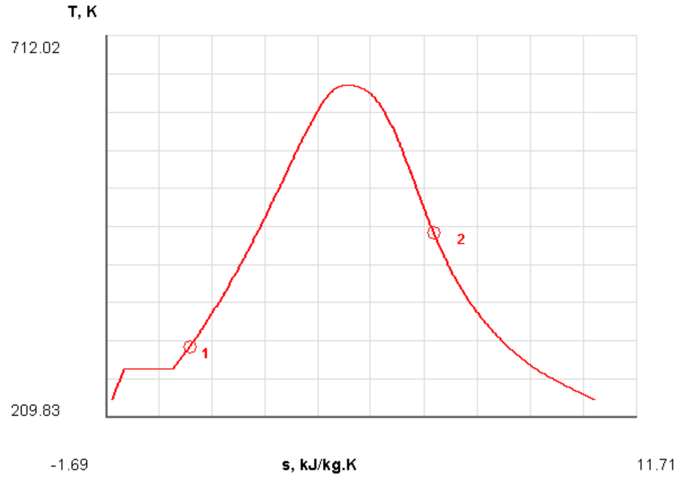
(d) $\dot{J}_1 = \dot{m}\left(h_1 + \cancel{ke_1}^{\text{neg}} + \cancel{pe_1}^{\text{neg}}\right); \qquad \Rightarrow \dot{J}_1 = \dot{m}\left(h_1\right); \qquad \Rightarrow \dot{J}_1 = 1(125.79); \qquad \Rightarrow \dot{J}_1 = 125.79 \text{ kW}$

(e) $\dot{J}_2 = \dot{m}\left(h_2 + \cancel{ke_1}^{\text{neg}} + \cancel{pe_2}^{\text{neg}}\right); \qquad \Rightarrow \dot{J}_2 = \dot{m}\left(h_2\right); \qquad \Rightarrow \dot{J}_2 = 1(2675.5); \qquad \Rightarrow \dot{J}_2 = 2675.5 \text{ kW}$

TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-61 [DC] Repeat the above problem (3-3-60 [DV]) for a boiler pressure of 1 MPa.

SOLUTION



State-1: $p_1 = 1\text{ MPa}, T_1 = 30^\circ\text{C}$

Using the CL sub-model assumptions and Table-B.2

$$v_1 \cong v_{f\,@\,30^\circ\text{C}} = 0.001004\ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 \cong h_{f\,@\,30^\circ\text{C}} = 125.79\ \frac{\text{kJ}}{\text{kg}};$$

State-2: $p_2 = 1\text{ MPa}, x_2 = 1$

Using Table-B.1

$$v_2 = v_{g\,@\,1\text{ MPa}} = 0.19444\ \frac{\text{m}^3}{\text{kg}};$$

$$h_2 = h_{g\,@\,1\text{ MPa}} = 2778.1\ \frac{\text{kJ}}{\text{kg}};$$

(a) $$\text{V}_1 = \frac{\dot{m}v_1}{\text{A}_1}; \quad \Rightarrow \text{V}_1 = \frac{1(0.001004)}{\pi\frac{0.02^2}{4}}; \quad \Rightarrow \text{V}_1 = 3.2\ \frac{\text{m}}{\text{s}};$$

$$\text{V}_2 = \frac{\dot{m}v_2}{\text{A}_2}; \quad \Rightarrow \text{V}_2 = \frac{1(0.19444)}{\pi\frac{0.2^2}{4}}; \quad \Rightarrow \text{V}_2 = 6.2\ \frac{\text{m}}{\text{s}}$$

(b) $\dot{J}_1 = \dot{m}\left(h_1 + ke_1 + \cancelto{\text{neg}}{pe_1}\right);\quad \Rightarrow \dot{J}_1 = \dot{m}\left(h_1 + \frac{\mathrm{v}_1^{\,2}}{2000}\right);\quad \Rightarrow \dot{J}_1 = 1\left(125.79 + \frac{3.2^2}{2000}\right);$

$\Rightarrow \dot{J}_1 = 125.8\ \text{kW}$

(c) $\dot{J}_2 = \dot{m}\left(h_2 + ke_2 + \cancelto{\text{neg}}{pe_2}\right);\quad \Rightarrow \dot{J}_2 = \dot{m}\left(h_2 + \frac{\mathrm{v}_2^{\,2}}{2000}\right);\quad \Rightarrow \dot{J}_2 = 1\left(2778.1 + \frac{6.2^2}{2000}\right);$

$\Rightarrow \dot{J}_2 = 2778.12\ \text{kW}$

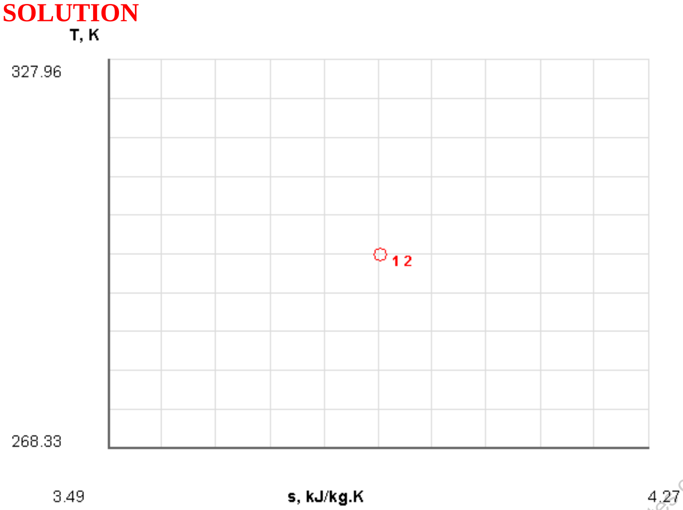
(d) $\dot{J}_1 = \dot{m}\left(h_1 + \cancelto{\text{neg}}{ke_1} + \cancelto{\text{neg}}{pe_1}\right);\quad \Rightarrow \dot{J}_1 = \dot{m}\left(h_1\right);\quad \Rightarrow \dot{J}_1 = 1(125.79);\quad \Rightarrow \dot{J}_1 = 125.79\ \text{kW}$

(e) $\dot{J}_2 = \dot{m}\left(h_2 + \cancelto{\text{neg}}{ke_1} + \cancelto{\text{neg}}{pe_2}\right);\quad \Rightarrow \dot{J}_2 = \dot{m}\left(h_2\right);\quad \Rightarrow \dot{J}_2 = 1(2778.1);\quad \Rightarrow \dot{J}_2 = 2778.1\ \text{kW}$

TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-62 [DY] Water is pumped in an isentropic (constant entropy) manner from 100 kPa, 25°C to 40 MPa. Determine the change in specific enthalpy (Δh) using (a) the compressed liquid table, (b) compressed liquid model and (c) solid/liquid model.

SOLUTION



State-1: $p_1 = 100 \text{ kPa}, T_1 = 25^{\circ}\text{C}$

Using the CL sub-model assumptions and Table-B.2

$$h_1 \cong h_{f\,@\,25^{\circ}\text{C}} = 104.89\ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 \cong s_{f\,@\,25^{\circ}\text{C}} = 0.3674\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p = 40 \text{ MPa}, s_2 = s_1 = 0.3674\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.4

$$h_2 = h_2(p, s); \quad \Rightarrow h_2 = h_2\left(40 \text{ MPa}, 0.3674\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \quad \Rightarrow h_2 = 161.725\ \frac{\text{kJ}}{\text{kg}};$$

(a) $\Delta h = h_2 - h_1; \quad \Rightarrow \Delta h = 161.725 - 125.79; \quad \Rightarrow \Delta h = 35.9\ \frac{\text{kJ}}{\text{kg}}$

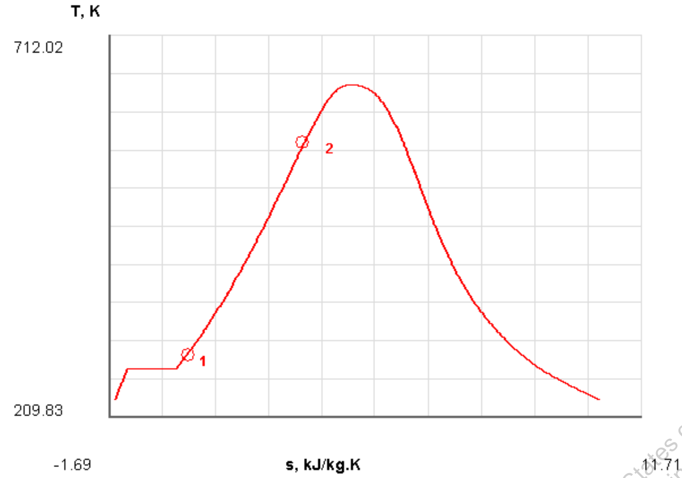
For parts b and c, use TEST and its appropriate daemon to solve for the change in specific enthalpy.

TEST Solution:

Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-63 [DQ] Water at 30 MPa and 20^{o}C is heated at constant pressure until the temperature reaches 300^{o}C. Determine (a) the change in specific volume (Δv) and (b) specific enthalpy (Δh). Use compressed liquid table for water. (c) What-if Scenario: What would the specific enthalpy be if water were only heated to 200^{o}C?

SOLUTION



State-1: $p_1 = 30\text{ MPa},\ T_1 = 20^\circ\text{C}$

Using Table-B.4

$$v_1 = v(p,T); \quad \Rightarrow v_1 = v\left(30\text{ MPa, }20^\circ\text{C}\right); \quad \Rightarrow v_1 = 0.0001886\ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h(p,T); \quad \Rightarrow h_1 = h\left(30\text{ MPa, }20^\circ\text{C}\right); \quad \Rightarrow h_1 = 111.8\ \frac{\text{kJ}}{\text{kg}};$$

State-2: $p_2 = 30\text{ MPa},\ T_2 = 300^\circ\text{C}$

Using Table-B.4

$$v_2 = v(p,T); \quad \Rightarrow v_2 = v\left(30\text{ MPa, }300^\circ\text{C}\right); \quad \Rightarrow v_2 = 0.0013307\ \frac{\text{m}^3}{\text{kg}};$$

$$h_2 = h(p,T); \quad \Rightarrow h_2 = h\left(30\text{ MPa, }300^\circ\text{C}\right); \quad \Rightarrow h_2 = 1327.8\ \frac{\text{kJ}}{\text{kg}};$$

(a) $\Delta v = v_2 - v_1; \quad \Rightarrow \Delta v = 0.0013307 - 0.0009886; \quad \Rightarrow \Delta v = 0.000342\ \frac{\text{m}^3}{\text{kg}}$

(b) $\Delta h = h_2 - h_1; \quad \Rightarrow \Delta h = 1327.8 - 118.8; \quad \Rightarrow \Delta h = 1216\ \frac{\text{kJ}}{\text{kg}}$

(c) What-if-Scenario

State-2: $p_2 = 30 \text{ MPa}, T_2 = 200^\circ\text{C}$

Using Table-B.4

$$h_2 = h(p,T); \qquad \Rightarrow h_2 = h(30 \text{ MPa}, 200^\circ\text{C}); \qquad \Rightarrow h_2 = 865.2 \ \frac{\text{kJ}}{\text{kg}};$$

$$\Delta h = h_2 - h_1; \qquad \Rightarrow \Delta h = 865.2 - 118.8; \qquad \Rightarrow \Delta h = 753.4 \ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

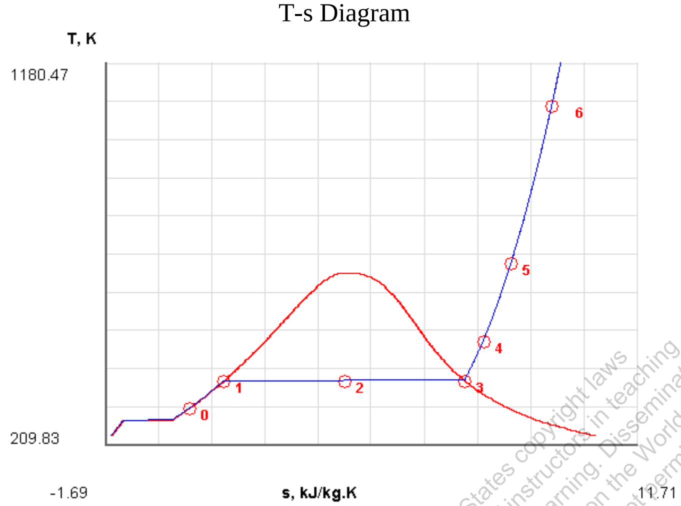
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-64 [DT] Draw a constant pressure line (p = 100 kPa) on a T-v and a T-s diagram for H_2O. Repeat the problem with p = 1000 kPa.

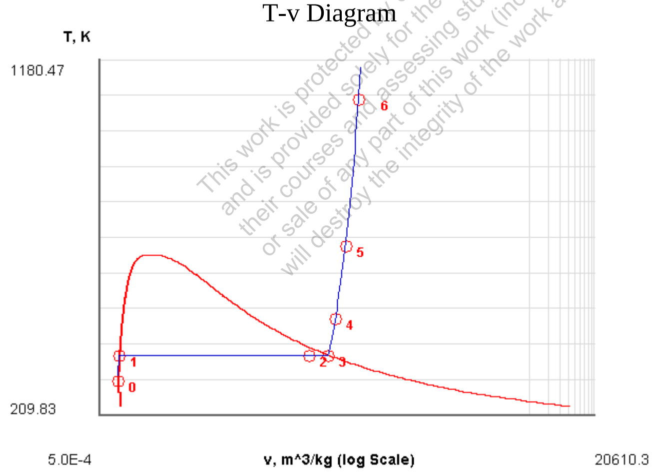
SOLUTION

***p* = 100 kPa:**

T-s Diagram

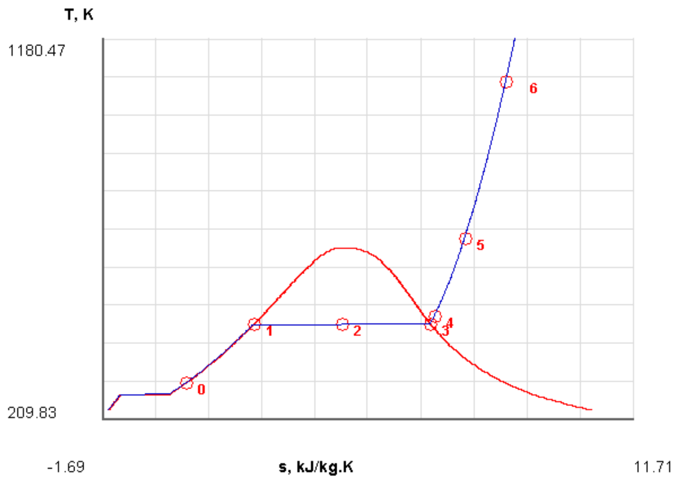


T-v Diagram

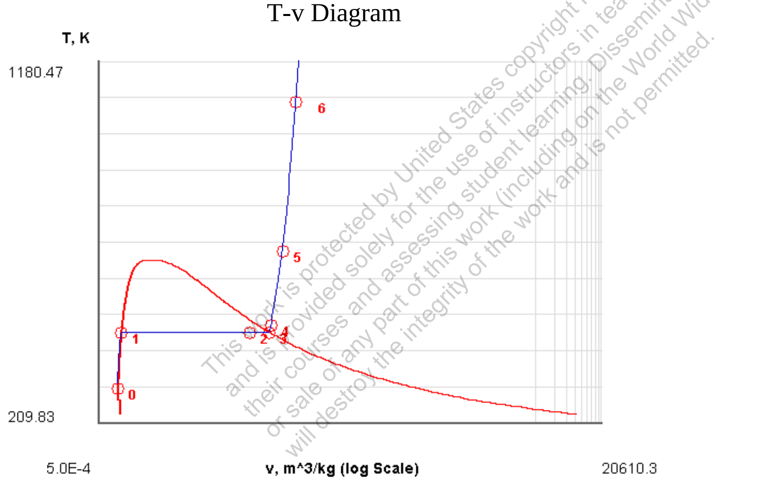


***p* = 1000 kPa:**

T-s Diagram



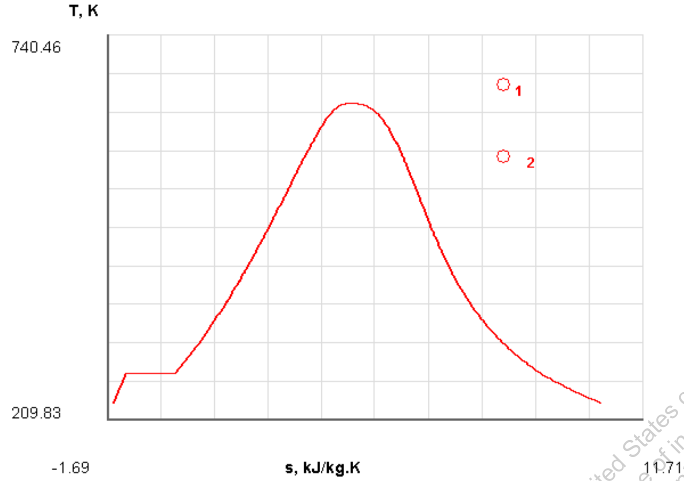
T-v Diagram



TEST Solution:
Launch the PC system-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-65 [DF] In an isentropic nozzle the specific flow energy (j) and entropy (s) remain constant along the flow. Superheated steam flows steadily through an isentropic nozzle for which the following properties are known at the inlet and exit ports. Inlet: p = 200 kPa, T = 400°C, A = 100 cm^2, V = 5 m/s; Exit: p = 100 kPa. Determine (a) the exit velocity (V_2), (b) the exit temperature (T_2) and (c) the exit area.

SOLUTION



State-1: $p_1 = 200$ kPa, $T_1 = 400^\circ$C
Using Table-B.3

$$v_1 = v_1(p,T); \quad \Rightarrow v_1 = v_1(200 \text{ kPa, } 400^\circ\text{C}); \quad \Rightarrow v_1 = 1.5493 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h_1(p,T); \quad \Rightarrow h_1 = h_1(200 \text{ kPa, } 400^\circ\text{C}); \quad \Rightarrow h_1 = 3276.6 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_1(p,T); \quad \Rightarrow s_1 = s_1(200 \text{ kPa, } 400^\circ\text{C}); \quad \Rightarrow s_1 = 8.2218 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p_2 = 100$ kPa, $s_2 = s_1 = 8.2218 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$
Using Table-B.3

$$v_2 = v_2(p,s); \quad \Rightarrow v_2 = v_2\left(100 \text{ kPa, } 8.2218 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \quad \Rightarrow v_2 = 2.647 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_2 = h_2(p,s); \quad \Rightarrow h_2 = h_2\left(100 \text{ kPa, } 8.2218 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \quad \Rightarrow h_2 = 3078 \ \frac{\text{kJ}}{\text{kg}};$$

(a) $\Delta j = 0; \quad \Rightarrow j_1 = j_2; \quad \Rightarrow h_1 + \frac{\text{V}_1^2}{2000} = h_2 + \frac{\text{V}_2^2}{2000};$

$$\Rightarrow \mathrm{v}_2 = \sqrt{2000(h_2 - h_1) + \mathrm{v}_1^{\,2}}; \qquad \Rightarrow \mathrm{v}_2 = \sqrt{2000(3276.6 - 3078) + 5^2};$$

$$\Rightarrow \mathrm{v}_2 = 630.3\ \frac{\mathrm{m}}{\mathrm{s}}$$

(b) $T_2 = T_2(p, s); \qquad \Rightarrow T_2 = T_2\left(100\text{ kPa, } 8.2218\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \qquad \Rightarrow T_2 = 302^\circ\text{C}$

(c) Knowing that this is a steady flow

$$\frac{dm}{dT} = 0;$$

$$\Rightarrow \dot{m}_1 = \dot{m}_2; \qquad \Rightarrow \frac{\mathrm{A}_1 \mathrm{v}_1}{v_1} = \frac{\mathrm{A}_2 \mathrm{v}_2}{v_2};$$

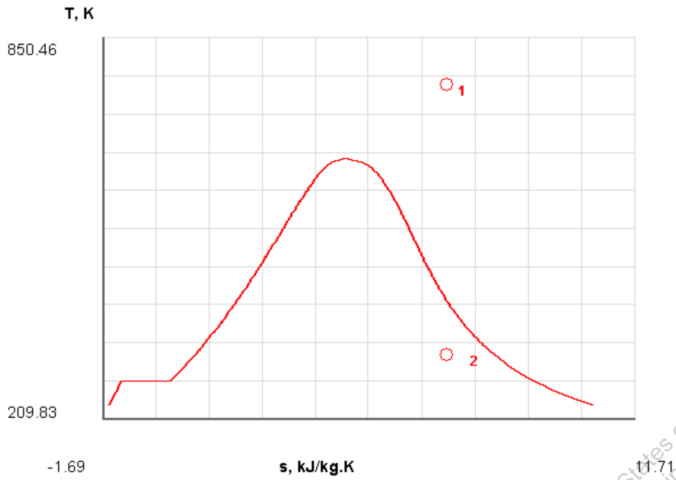
$$\mathrm{A}_2 = \mathrm{A}_1 \frac{\mathrm{v}_1}{\mathrm{v}_2} \frac{v_1}{v_2}; \qquad \Rightarrow \mathrm{A}_2 = \left(\frac{100}{100^2}\right)\left(\frac{5}{630.3}\right)\left(\frac{2.647}{1.5493}\right);$$

$$\Rightarrow \mathrm{A}_2 = 0.000136\ \mathrm{m}^2; \qquad \Rightarrow \mathrm{A}_2 = 1.36\ \mathrm{cm}^2$$

TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-66 [DD] Steam enters a turbine, operating at steady state, at 5000 kPa and 500°C with a mass flow rate of 5 kg/s. It expands in an isentropic manner to an exit pressure of 10 kPa. Determine (a) the exit temperature (T_2), (b) exit quality and the volumetric flow rate at (c) the inlet and (d) exit .

SOLUTION



State-1: $p_1 = 5\text{ MPa},\ T_1 = 500^\circ\text{C}$

Using Table-B.3

$$v_1 = v_1(p,T) = v_1(5\text{ MPa}, 500^\circ\text{C}) = 0.06857\ \frac{\text{m}^3}{\text{kg}};$$

$$s_1 = s_1(p,T) = s_1(5\text{ MPa}, 500^\circ\text{C}) = 6.9759\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p_2 = 10\text{ kPa},\ s_2 = s_1 = 6.9759\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.2

$$s_{\text{f @ 10 kPa}} = 0.6493\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$s_{\text{g @ 10 kPa}} = 8.1502\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

(a) $s_\text{f} < s_2 < s_\text{g};$

$$\Rightarrow T_2 = T_{\text{sat @ 10 kPa}} = 45.81^\circ\text{C}$$

(b) $x_2 = \dfrac{s_2 - s_\text{f}}{s_\text{g} - s_\text{f}};\quad \Rightarrow x_2 = \dfrac{6.9759 - 0.6493}{8.1502 - 0.6493};\quad \Rightarrow x_2 = 0.843;\quad \Rightarrow x_2 = 84.3\%$

(c) Inlet

$$\dot{V}_1 = \dot{m}v_1; \qquad \Rightarrow \dot{V}_1 = 5(0.06857); \qquad \Rightarrow \dot{V}_1 = 0.343\ \frac{\text{m}^3}{\text{s}}$$

(d) Exit

$$\left.\begin{array}{l} v_{\text{f @ 10 kPa}} = 0.00101\ \dfrac{\text{m}^3}{\text{kg}}; \\ v_{\text{g @ 10 kPa}} = 14.67\ \dfrac{\text{m}^3}{\text{kg}}; \end{array}\right\rangle\ v_2 = v_\text{f} + x_2\left(v_\text{g} - v_\text{f}\right); \qquad \Rightarrow v_2 = 12.37\ \frac{\text{m}^3}{\text{kg}};$$

$$\dot{V}_2 = \dot{m}v_2; \qquad \Rightarrow \dot{V}_2 = 5(12.37); \qquad \Rightarrow \dot{V}_2 = 61.83\ \frac{\text{m}^3}{\text{s}}$$

TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-67 [DM] Refrigerant-134a enters a throttle valve as saturated liquid at 40°C and exits at 294 kPa. If enthalpy remains constant during the flow, determine (a) the drop in pressure (Δp) and (b) the drop in temperature (ΔT) in the valve.

SOLUTION

State-1: $T_1 = 40^\circ\text{C}, x_1 = 0$

Using Table-B.6

$p_1 = p_{\text{sat @ }40^\circ\text{C}} = 1016.4 \text{ kPa};$

$h_1 = h_{\text{f @ }40^\circ\text{C}} = 106.19 \ \frac{\text{kJ}}{\text{kg}};$

State-2: $p_2 = 294 \text{ kPa}, h_2 = h_1 = 106.19 \frac{\text{kJ}}{\text{kg}}$

Using Table-B.6

$p_2 \cong p_{\text{sat @}0^\circ\text{C}}; \quad \Rightarrow T_2 = 0^\circ\text{C};$

(a) $\Delta p = p_1 - p_2; \quad \Rightarrow \Delta p = 1016.4 - 294; \quad \Rightarrow \Delta p = 722.4 \text{ kPa}$

(b) $\Delta T = T_1 - T_2; \quad \Rightarrow \Delta T = 40 - 0; \quad \Rightarrow \Delta T = 40^\circ\text{C}$

TEST Solution:

Launch the PC open steady state single-flow TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-68 [DJ] Saturated vapor of R-134a enters a compressor, operating at steady state at 160 kPa with a volume flow rate of 10 L/min. The specific entropy remains constant along the flow. Determine (a) the exit temperature (T_2) if the compressor raises the pressure of the flow by a factor of 10. Also, determine the rate of transport of energy at (b) the inlet and (c) the exit. Neglect kinetic and potential energies.

SOLUTION

$$\dot{m} = \frac{\dot{V}}{v}; \quad \Rightarrow \dot{m} = \frac{\left(\frac{10}{1000 \cdot 60}\right)}{0.1229}; \quad \Rightarrow \dot{m} = 0.001356 \ \frac{\text{kg}}{\text{s}};$$

State-1: $p_1 = 160 \text{ kPa}, x_1 = 1$

Using Table-B.5

$$v_1 = v_{g\,@\,160\text{ kPa}} = 0.1229 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h_{g\,@\,160\text{ kPa}} = 237.97 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_{g\,@\,160\text{ kPa}} = 0.9295 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p_2 = 10p_1 = 1.6 \text{ Mpa}, s_2 = s_1 = 0.9295 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.7

(a) $T_2 = T_2(p,s); \quad \Rightarrow T_2 = T_2\left(1.6 \text{ MPa}, 0.9295 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \quad \Rightarrow T_2 = 64.14^\circ\text{C}$

(b) $\dot{J}_1 = \dot{m}j_1; \quad \Rightarrow \dot{J}_1 = \dot{m}\left(h_1 + \cancel{pe_1}^{\text{neg}} + \cancel{ke_1}^{\text{neg}}\right); \quad \Rightarrow \dot{J}_1 = \dot{m}h_1;$

$\Rightarrow \dot{J}_1 = 0.001356(237.97); \quad \Rightarrow \dot{J}_1 = 0.323\ \text{kW}$

(c) $h_2 = h_2(p,s); \quad \Rightarrow h_2 = h_2\left(1.6\ \text{MPa},\ 0.9295\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \quad \Rightarrow h_2 = 285.5\frac{\text{kJ}}{\text{kg}};$

$\dot{J}_2 = \dot{m}j_2; \quad \Rightarrow \dot{J}_2 = \dot{m}\left(h_2 + \cancel{pe_2}^{\text{neg}} + \cancel{ke_2}^{\text{neg}}\right); \quad \Rightarrow \dot{J}_2 = \dot{m}h_2;$

$\Rightarrow \dot{J}_2 = 0.001356(285.5); \quad \Rightarrow \dot{J}_2 = 0.387\ \text{kW}$

TEST Solution:

Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-69 [DW] Repeat the above problem (3-3-68 [DJ]) with refrigerant-12 as the working fluid.

SOLUTION

$$\dot{m} = \frac{\dot{V}}{v}; \qquad \Rightarrow \dot{m} = \frac{\left(\frac{10}{1000 \cdot 60}\right)}{0.10324}; \qquad \Rightarrow \dot{m} = 0.001614\ \frac{\text{kg}}{\text{s}};$$

State-1: $p_1 = 160\text{ kPa},\ x_1 = 1$

Using Table-B.5

$$v_1 = v_{g\ @\ 160\text{ kPa}} = 0.10324\ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h_{g\ @\ 160\text{ kPa}} = 179.41\ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s_{g\ @\ 160\text{ kPa}} = 0.70763\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: $p_2 = 10p_1 = 1.6\text{ Mpa},\ s_2 = s_1 = 0.70763\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Using Table-B.7

(a) $T_2 = T_2(p, s); \qquad \Rightarrow T_2 = T_2\left(1.6\text{ MPa},\ 0.70763\ \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}\right); \qquad \Rightarrow T_2 = 75^\circ\text{C}$

(b) $\dot{J}_1 = \dot{m}j_1; \qquad \Rightarrow \dot{J}_1 = \dot{m}\left(h_1 + \cancel{pe_1}^{\text{neg}} + \cancel{ke_1}^{\text{neg}}\right); \qquad \Rightarrow \dot{J}_1 = \dot{m}h_1;$

$\Rightarrow \dot{J}_1 = 0.001614(179.41); \qquad \Rightarrow \dot{J}_1 = 0.2896\text{ kW}$

(c) $h_2 = h_2(p,s)$; $\Rightarrow h_2 = h_2\left(1.6 \text{ MPa}, 0.70763 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)$; $\Rightarrow h_2 = 220.86 \dfrac{\text{kJ}}{\text{kg}}$;

$\dot{J}_2 = \dot{m} j_2$; $\Rightarrow \dot{J}_2 = \dot{m}\left(h_2 + \cancel{pe_2}^{\text{neg}} + \cancel{ke_2}^{\text{neg}}\right)$; $\Rightarrow \dot{J}_2 = \dot{m} h_2$;

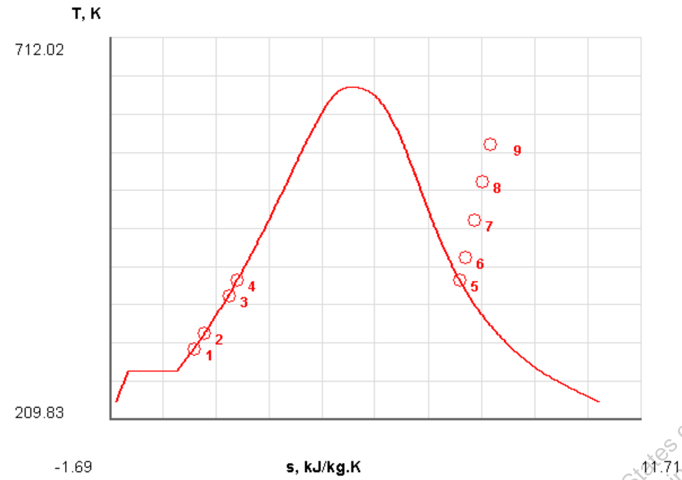
$\Rightarrow \dot{J}_2 = 0.001614(220.86)$; $\Rightarrow \dot{J}_2 = 0.3565 \text{ kW}$

TEST Solution:

Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

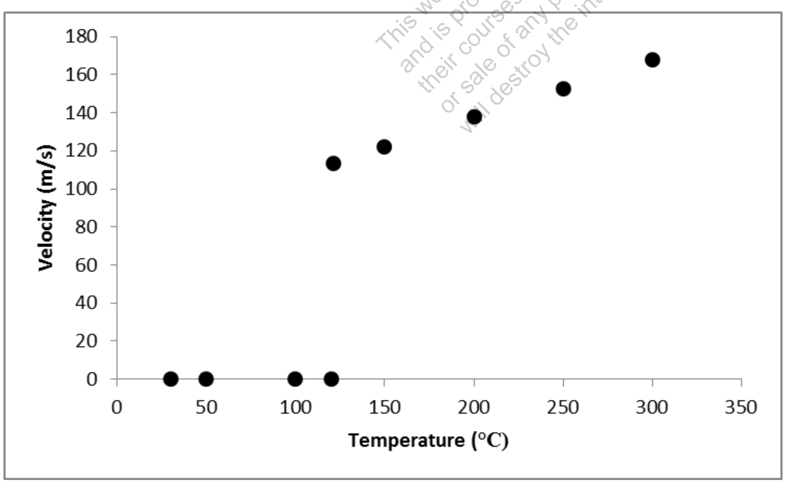
3-3-70 [MR] Water flows steadily through a 10 cm-diameter pipe with a mass flow rate of 1 kg/s. The flow enters the pipe at 200 kPa, 30°C and is gradually heated until it leaves the pipe at 300°C without any significant drop in pressure. Plot the flow velocity against the temperature of the flow.

SOLUTION



$$A = \pi\left(\frac{0.1}{2}\right)^2 = 0.031416 \text{ m}^2;$$

$$\dot{m} = \rho A v; \quad \Rightarrow v = \frac{\dot{m}}{\rho A}; \quad \Rightarrow v = \frac{1}{0.031416\rho};$$

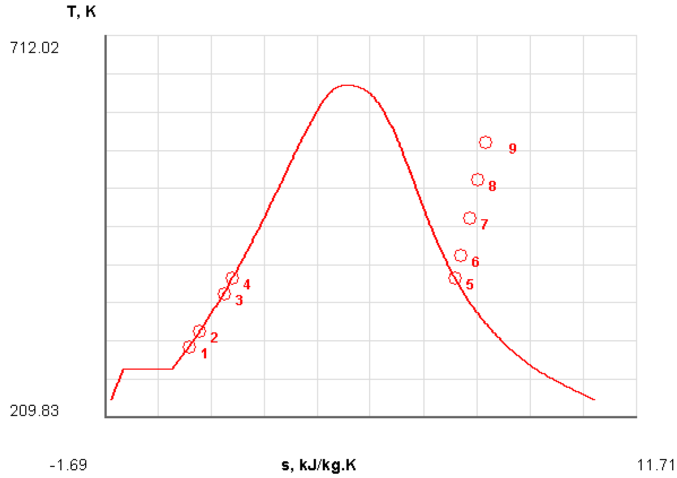


TEST Solution:

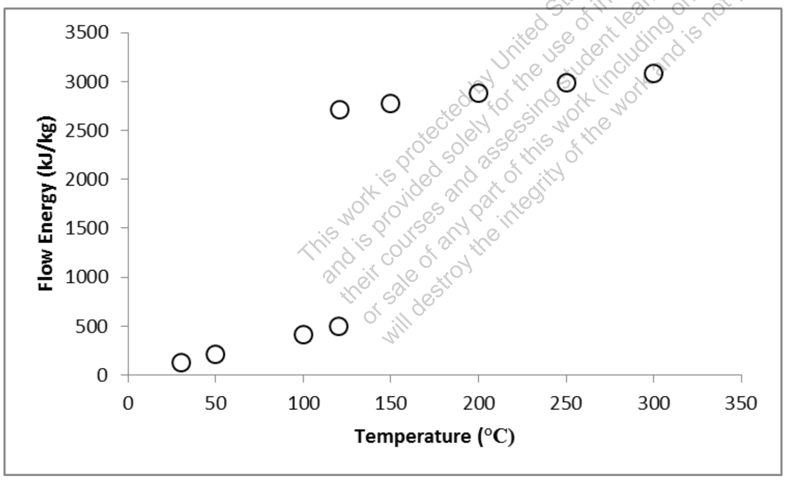
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).

3-3-71 [MO] In the above problem (3-3-70 [MR]), plot how the rate of transport of energy increases as the flow temperature increases by (a) including and (b) neglecting kinetic energy.

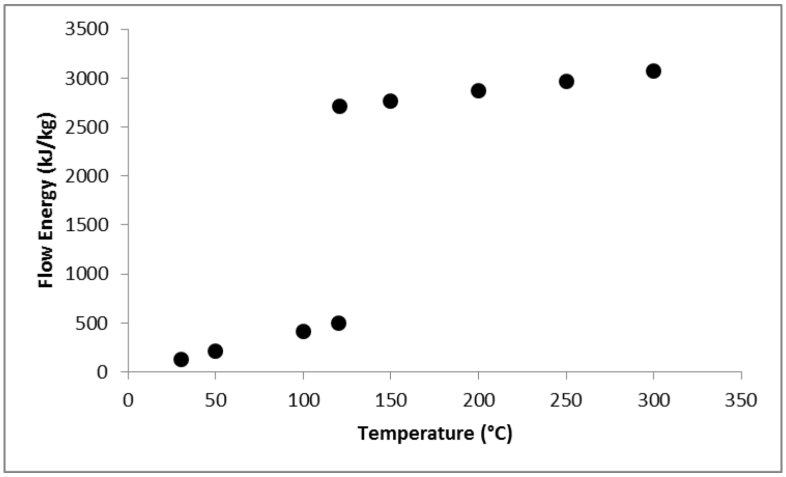
SOLUTION



(a)



(b) Neglecting ke



TEST Solution:
Launch the PC flow-state TESTcalc to verify the solution. Calculate the desired property changes in the I/O panel. The TEST-code for this problem can be found in the professional TEST site (www.thermofluids.net).