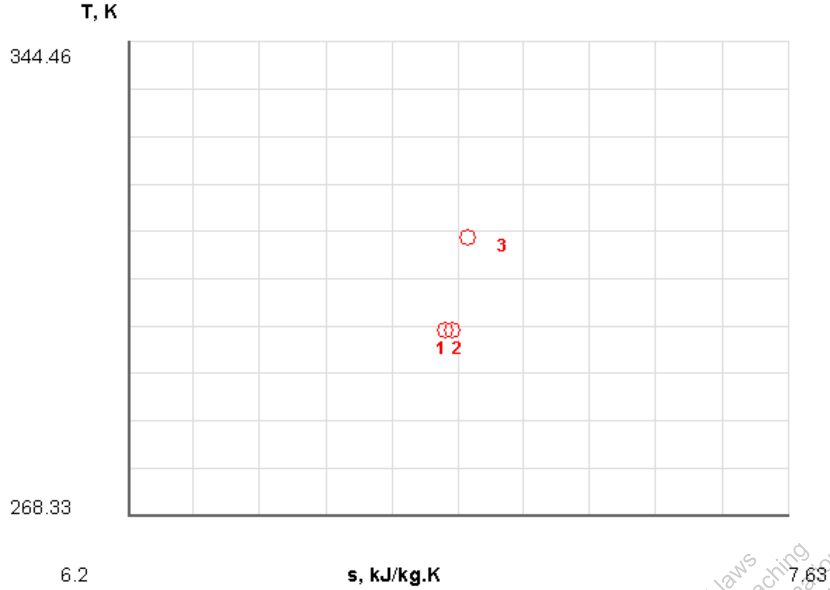
3-4-1 [MB] Determine (a) the mass of air at 100 kPa, 25°C in a room with dimensions 5 m x 5 m x 5 m. (b) How much air must leave the room if the pressure drops to 95 kPa at constant temperature? (c) How much air must leave the room if the temperature increased to 40°C at constant pressure?

SOLUTION



Using Table-C and the PG model for air

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

(a) $$m = \frac{p\mathcal{V}}{RT}; \quad \Rightarrow m = \frac{100(5\cdot5\cdot5)}{0.287(273+25)}; \Rightarrow m = 146.2 \text{ kg}$$

(b) $$\Delta m = m_2 - m_1; \quad \Rightarrow \Delta m = m - \frac{\mathcal{V}}{RT}(p_2 - p_1); \quad \Rightarrow \Delta m = \frac{(5\cdot5\cdot5)}{0.287(273+25)}(95-100);$$

$$\Rightarrow \Delta m = -7.3 \text{ kg}; \quad \Rightarrow \Delta m = 7.3 \text{ kg}$$

(c) $$\Delta m = m_1 - m_2; \quad \Rightarrow \Delta m = m - \frac{p\mathcal{V}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right);$$

$$\Rightarrow \Delta m = \frac{100(5\cdot5\cdot5)}{0.287}\left(\frac{1}{273+40} - \frac{1}{273+25}\right); \quad \Rightarrow \Delta m = -7 \text{ kg}; \quad \Rightarrow \Delta m = 7 \text{ kg}$$

TEST Solution:

Launch the PG 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).

3-4-2 [BEJ] Determine the specific enthalpy (h) of a gas (PG model: k = 1.4, R= 4.12 kJ/kg-K) given u = 6001 kJ/kg and T = 1000 K.

SOLUTION

Using the following equations:

$h = u + pv$ and $pv = RT$,

$$\Rightarrow h = u + RT; \quad \Rightarrow h = (6001) + (4.12)(1000);$$

$$\Rightarrow h = 10121 \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the PG 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).

3-4-3 [BEW] A tank of volume 1 m^3 contains 5 kg of an ideal gas with a molar mass of 44 kg/kmol. If the difference between the specific enthalpy (h) and the specific internal energy (u) of the gas is 200 kJ/kg, determine its temperature (T).

SOLUTION

(a) $h = u + pv; \quad \Rightarrow pv = h - u; \quad \Rightarrow pv = 200\dfrac{\text{kJ}}{\text{kg}};$

$$R = \frac{\bar{R}}{\bar{M}}; \quad \Rightarrow R = \frac{8.314}{44}; \quad \Rightarrow R = 0.18895\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$pv = RT; \quad \Rightarrow (0.18895)T = 200; \quad \Rightarrow T = 1058\,\text{K}$$

(b) $pv = RT$

$$v = \frac{\cancel{V}}{m}; \quad \Rightarrow v = \frac{1}{5}; \quad \Rightarrow v = 0.2$$

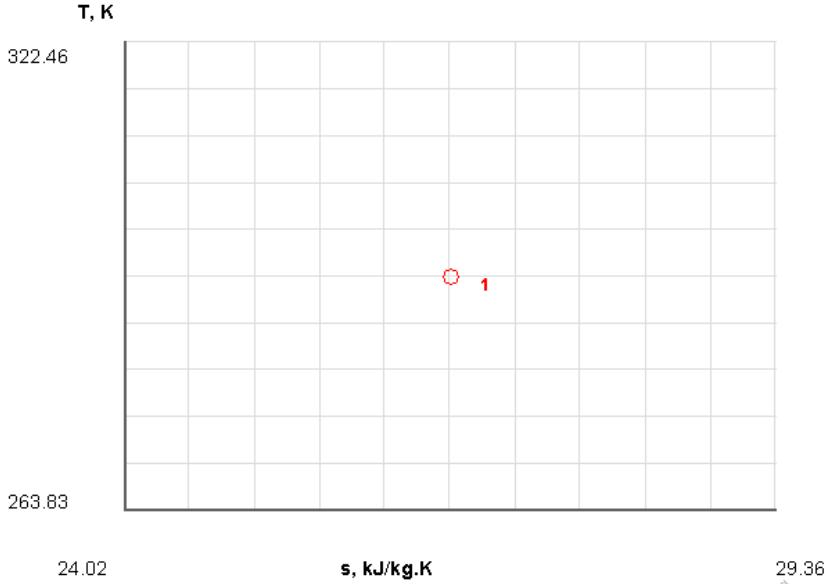
$$p(0.2) = (0.18895)(1058); \quad \Rightarrow p = 1000\,\text{kPa}$$

TEST Solution:

Launch the IG 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).

3-4-4 [MS] A tank contains helium (molar Mass = 4 kg/kmol) at 1 MPa and 20°C. If the volume of the tank is 1 m^3, determine (a) the mass and (b) the mole of helium in the tank. Use the PG or IG model.

SOLUTION



Using Table-C and the PG model for air

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

$$R = \frac{\bar{R}}{\bar{M}}; \qquad \Rightarrow \bar{R} = R\bar{M}; \qquad \Rightarrow \bar{R} = (2.0769)(4); \qquad \Rightarrow \bar{R} = 8.3076 \ \frac{\text{kJ}}{\text{kmol}\cdot\text{K}};$$

$$\text{(a)} \quad p = \rho \text{R} T; \qquad \Rightarrow p = \frac{RT}{v}; \qquad \Rightarrow p = \frac{m}{\mathcal{V}} RT; \qquad \Rightarrow p = \frac{m}{\mathcal{V}} \frac{\bar{R}}{\bar{M}} T;$$

$$\Rightarrow m = p \frac{\bar{M}}{\bar{R}} \frac{\mathcal{V}}{T}; \qquad \Rightarrow m = (1{,}000) \frac{(4)}{(8.3076)} \frac{(1)}{(20 + 273.15)}; \qquad \Rightarrow m = 1.64 \text{ kg}$$

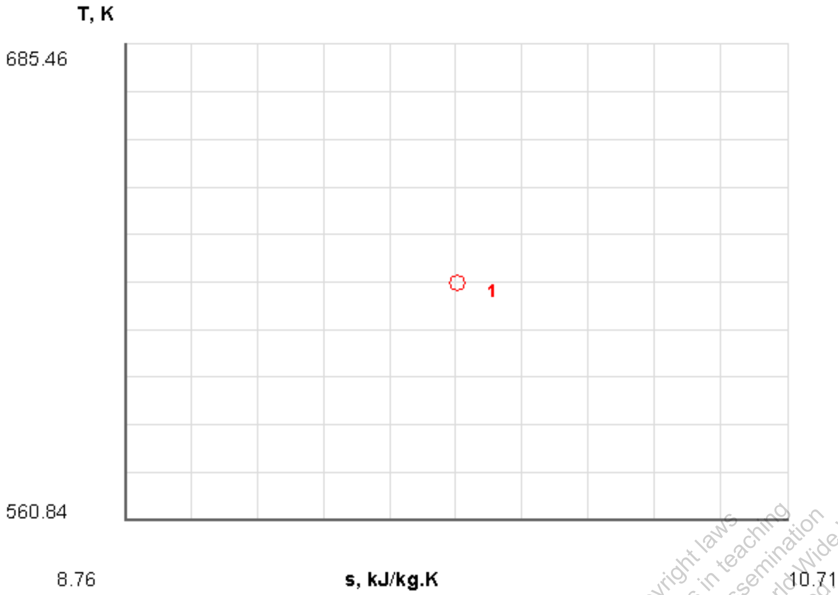
$$\text{(b)} \quad \text{mole} = \frac{m}{\bar{M}}; \qquad \Rightarrow \text{mole} = \frac{1.64}{4}; \qquad \Rightarrow \text{mole} = 0.41 \text{ kmol}$$

TEST Solution:

Launch the PG 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).

3-4-5 [MA] Determine c_p of steam at 10 MPa, 350°C using (a) PG model if the specific heat ratio is 1.327, (b) the PC model (use the PC state daemon to find a neighboring state, hotter by, say, 1°C at constant pressure and numerically evaluate c_p from its definition). (c) What-if Scenario: What would be the answer in part b if the temperature separation between the states is reduced to 0.5°C?

SOLUTION



(a) At 10 MPa, 350°C

$$v = 0.02242\ \frac{\text{m}^3}{\text{kg}}; \quad \Rightarrow \rho = \frac{1}{v}; \quad \Rightarrow \rho = \frac{1}{0.02875}; \quad \Rightarrow \rho = 34.783\ \frac{\text{kg}}{\text{m}^3};$$

$$p = \rho RT; \quad \Rightarrow R = \frac{p}{\rho T}; \quad \Rightarrow R = \frac{10{,}000}{(34.783)(350+273.15)}; \quad \Rightarrow R = 0.46136\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_p = \frac{kR}{k-1}; \quad \Rightarrow c_p = \frac{(1.327)(0.46136)}{1.327-1}; \quad \Rightarrow c_p = 1.872\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

(b) At 10 MPa, 350°C

$$h_1 = 2923.3386\ \frac{\text{kJ}}{\text{kg}};$$

At 10 MPa, 351°C

$$h_2 = 2926.8167\ \frac{\text{kJ}}{\text{kg}};$$

$$c_p = \frac{h_2 - h_1}{\Delta T}; \quad c_p = \frac{2926.8167 - 2923.3386}{1}; \quad c_p = 3.4781\ \frac{\text{kJ}}{\text{kg}}$$

(c) At 10 MPa, 350.5°C

$$h_3 = 2925.086\ \frac{\text{kJ}}{\text{kg}};$$

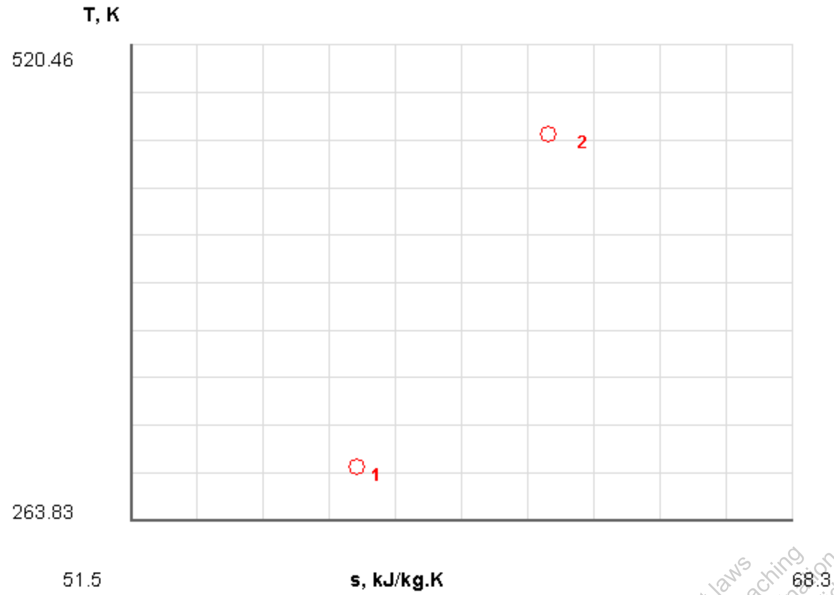
$$c_p = \frac{h_3 - h_1}{\Delta T}; \quad c_p = \frac{2926.8167 - 2925.086}{0.5}; \quad c_p = 3.4614\ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the PG 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).

3-4-6 [MH] A cylinder of volume 2 m^3 contains 1 kg of hydrogen at 20^{o}C. Determine the change in (a) pressure (Δp), (b) stored energy (ΔE) and (c) entropy (ΔS) of the gas as the chamber is heated to 200^{o}C. Use the PG model for hydrogen. (d) What-if Scenario: What would the (d) pressure, (e) stored energy, (f) entropy be if the chamber contained carbon-dioxide instead?

SOLUTION



Using Table-C and the PG model for hydrogen and carbon dioxide:

$$R_{H_2} = 4.124 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad c_{v,H_2} = 10.183 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$R_{CO_2} = 0.1889 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}; \quad c_{v,CO_2} = 0.657 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) Using the ideal gas equation of state

$$\Delta p = \frac{mR_{H_2}(T_2 - T_1)}{\mathcal{V}}; \quad \Rightarrow \Delta p = \frac{(1)(4.124)(200-20)}{2}; \quad \Rightarrow \Delta p = 371.2 \text{ kPa}$$

(b) The change in stored energy of the hydrogen can be found as

$$\Delta E = mc_v(T_2 - T_1); \quad \Rightarrow \Delta E = (1)(10.183)(200-20); \quad \Rightarrow \Delta E = 1833 \text{ kJ}$$

(c) The change in entropy of the hydrogen can be

$$\Delta S = m\left[c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{v_2}{v_1}\right)\right]; \quad \Rightarrow \Delta S = 1\left[10.183\ln\left(\frac{273+200}{273+20}\right) - 0\right];$$

$$\Rightarrow \Delta S = 4.88 \ \frac{\text{kJ}}{\text{K}}$$

(d) If the chamber contained carbon dioxide instead:

$$\Delta p = \frac{mR_{H_2}(T_2 - T_1)}{\mathcal{V}}; \quad \Rightarrow \Delta p = \frac{1(0.1889)(200-20)}{2}; \quad \Rightarrow \Delta p = 17 \text{ kPa}$$

(e) $\Delta E = mc_v(T_2 - T_1); \quad \Rightarrow \Delta E = 1(0.657)(200-20); \quad \Rightarrow \Delta E = 118.3 \text{ kJ}$

(f) $\Delta S = m\left[c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{v_2}{v_1}\right)\right]; \qquad \Rightarrow \Delta S = 1\left[0.657\ln\left(\frac{273+200}{273+20}\right) - 0\right];$

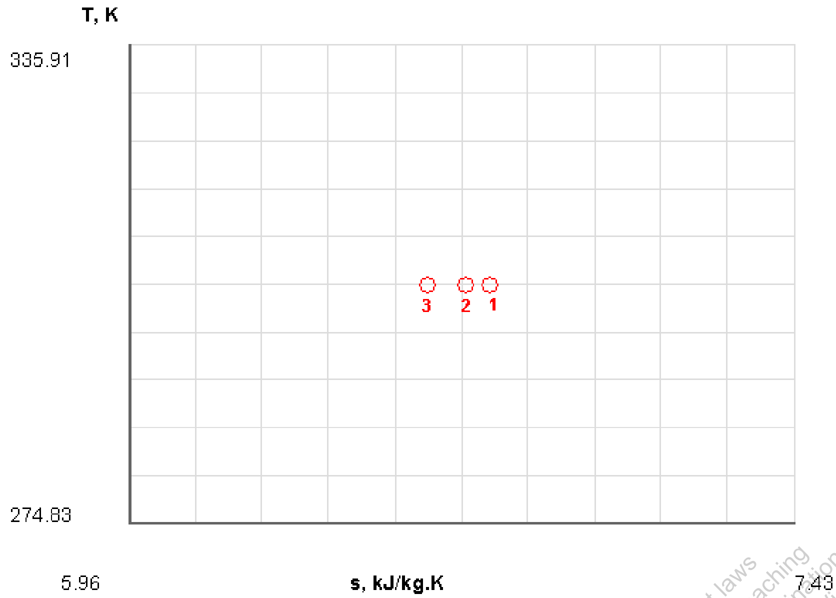
$$\Rightarrow \Delta S = 0.315 \ \frac{\text{kJ}}{\text{K}}$$

TEST Solution:

Launch the PG 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).

3-4-7 [MN] Air in an automobile tire with a volume of 18 ft^3 is at 90^{o}F and 25 psia. Determine (a) the amount of air to be added to bring the pressure up to 30 psig. Assume the atmospheric pressure to be 14.7 psia and the temperature and volume to remain constant. (b) What-if Scenario: What would the answer in (a) be if the pressure went up to 40 psig?

SOLUTION



Using Table-C.1E and the PG model for air:

$$R_{\text{air}} = 0.06855\ \frac{\text{BTU}}{\text{lbm}\cdot\text{R}}; \qquad \Rightarrow R_{\text{air}} = \left(0.06855\frac{\text{BTU}}{\text{hr}}\right)\left(9337.11\frac{\text{in}\cdot\text{lbf}}{\text{BTU}}\right);$$

$$\Rightarrow R_{\text{air}} = 640\ \frac{\text{in}\cdot\text{lbf}}{\text{lbm}\cdot\text{R}};$$

(a) Using the ideal gas equation of state

$$\Delta m = m_2 - m_1; \qquad \Rightarrow \Delta m = \frac{p_2\mathcal{V}}{RT} - \frac{p_1\mathcal{V}}{RT}; \qquad \Rightarrow \Delta m = \frac{\mathcal{V}}{RT}(p_2 - p_1);$$

$$\Rightarrow \Delta m = \frac{18(12)^2}{640(459.67-90)}(30-25); \qquad \Rightarrow \Delta m = 0.441 \text{ lbm}$$

(b) When $p_2 = 40$ psig

$$\Delta m = m_2 - m_1; \qquad \Rightarrow \Delta m = \frac{p_2\mathcal{V}}{RT} - \frac{p_1\mathcal{V}}{RT}; \qquad \Rightarrow \Delta m = \frac{\mathcal{V}}{RT}(p_2 - p_1);$$

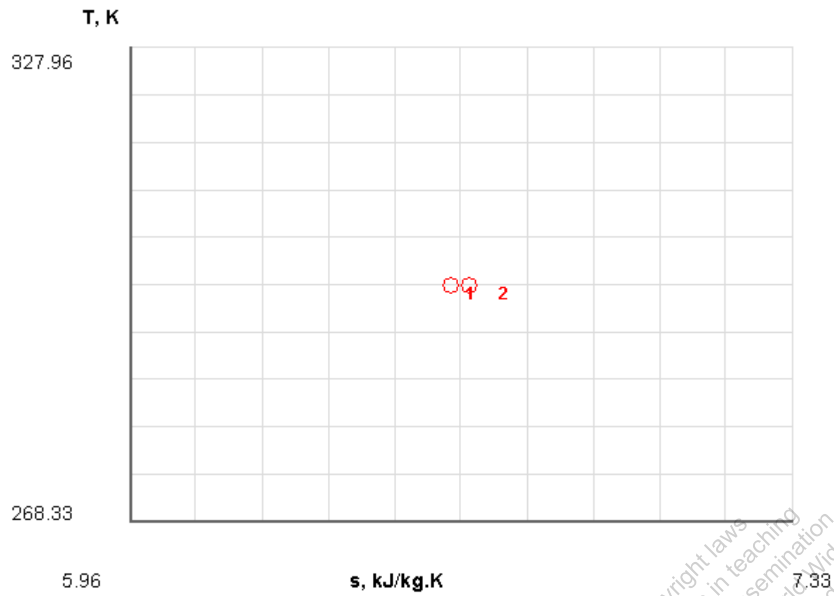
$$\Rightarrow \Delta m = \frac{18(12)^2}{640(459.67-90)}(40-25); \qquad \Rightarrow \Delta m = 1.324 \text{ lbm}$$

TEST Solution:

Launch the PG 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).

3-4-8 [ME] The gauge pressure in an automobile tire is measured as 250 kPa when the outside pressure is 100 kPa and temperature is 25°C. If the volume of the tire is 0.025 m^3, (a) determine the amount of air that must be bled in order to reduce the pressure to the recommended value of 220 kPa gauge. Use the PG model for air. (b) What-if Scenario: What would the answer be if the IG model were used instead?

SOLUTION



Using the PG model for air and Table-C:

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

(a) Using the perfect gas equation of state and assuming constant temperature

$$\Delta m = m_2 - m_1; \quad \Rightarrow \Delta m = \frac{p_2 \cancel{V}}{RT} - \frac{p_1 \cancel{V}}{RT}; \quad \Rightarrow \Delta m = \frac{\cancel{V}}{RT}(p_2 - p_1);$$

$$\Rightarrow \Delta m = \frac{0.025}{0.287(273+25)}(220-250); \quad \Rightarrow \Delta m = -0.00877 \text{ kg};$$

Therefore, 8.77 g must be bled from the tire.

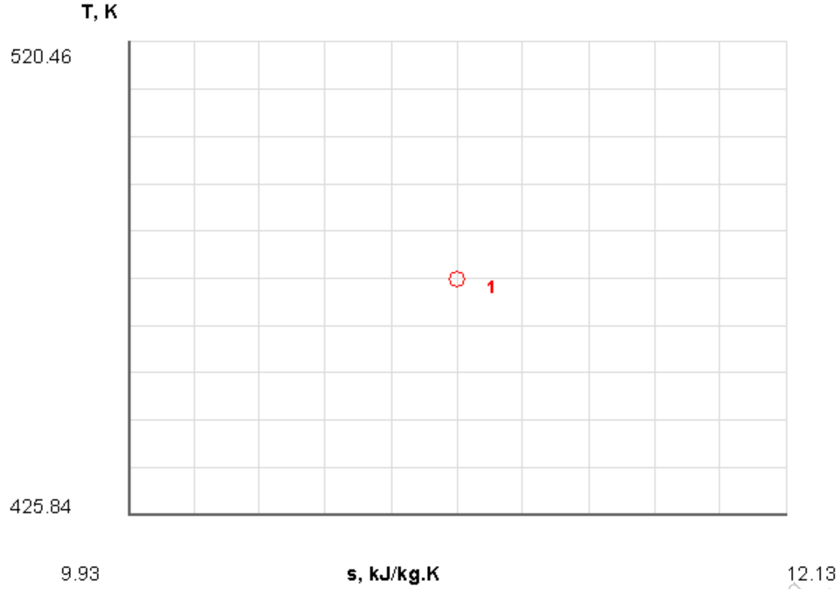
(b) There would be no change, all relationships between m, v, T and p are the same for both the IG and PG model. Therefore, the answer would be 8.77 g.

TEST Solution:

Launch the PG 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).

3-4-9 [MI] A rigid tank of volume 10 m^3 contains steam at 200 kPa and 200^{o}C. Determine the mass of steam inside the tank using (a) the PC model for steam, (b) PG model for steam and (c) IG model for steam. (d) Which answer is the most accurate?

SOLUTION



(a) Using the PC model for steam and Table-B.3:
At 200 kPa, 200 °C

$$v_{\text{steam}} = 1.0803 \frac{\text{m}^3}{\text{kg}};$$

$$m_{\text{steam}} = \frac{\mathcal{V}}{v_{\text{steam}}}; \quad \Rightarrow m_{\text{steam}} = \frac{10}{1.0803}; \quad \Rightarrow m_{\text{steam}} = 9.257 \text{ kg}$$

(b) Using the PG model for steam and Table-C:

$$R_{\text{steam}} = 0.4615 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m = \frac{p\mathcal{V}}{RT}; \quad \Rightarrow m = \frac{(200)(10)}{(0.4615)(273+200)}; \quad \Rightarrow m = 9.162 \text{ kg}$$

(c) Using the IG model for steam and Table-C:

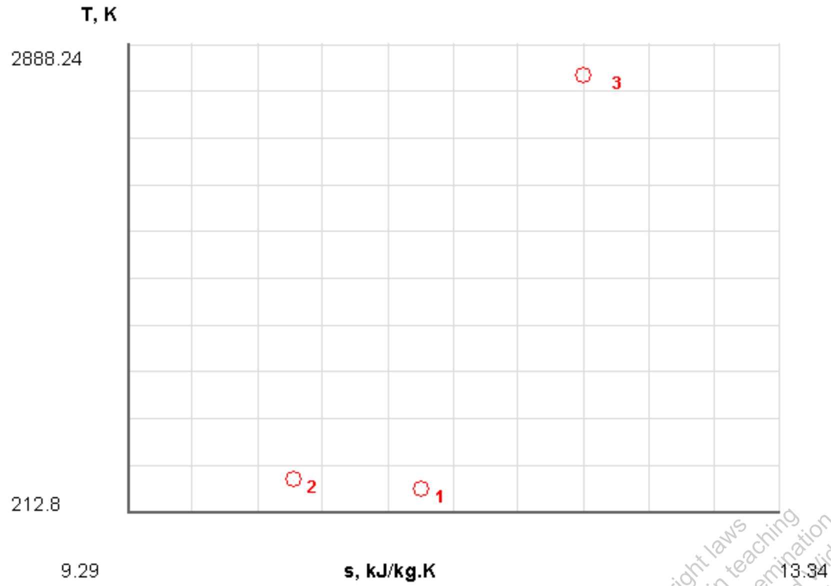
$$R_{\text{steam}} = 0.4615 \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m = \frac{p\mathcal{V}}{RT}; \quad \Rightarrow m = \frac{(200)(10)}{(0.4615)(273+200)}; \quad \Rightarrow m = 9.162 \text{ kg}$$

TEST Solution:
Launch the PC, PG, or IG 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).

3-4-10 [ML] In order to test the applicability of the ideal gas equation of state to calculate the density of saturated steam, compare the specific volume of saturated steam obtained from the steam table with the prediction from the IG model for the following conditions: (a) 50 kPa, (b) 500 kPa and (c) critical point. Express the comparisons as percentage errors, using the steam table results as benchmarks.

SOLUTION



Using Table-B.1

State-1: 50 kPa, saturated steam:

$$v = 3.24\ \frac{\mathrm{m^3}}{\mathrm{kg}}; \quad \Rightarrow \rho_{\mathrm{PC}} = \frac{1}{v}; \quad \Rightarrow \rho_{\mathrm{PC}} = \frac{1}{3.24}; \quad \Rightarrow \rho_{\mathrm{PC}} = 0.309\ \frac{\mathrm{kg}}{\mathrm{m^3}};$$

State-2: 500 kPa, saturated steam

$$v = 0.3749\ \frac{\mathrm{m^3}}{\mathrm{kg}}; \quad \Rightarrow \rho_{\mathrm{PC}} = \frac{1}{v}; \quad \Rightarrow \rho_{\mathrm{PC}} = \frac{1}{0.3749}; \quad \Rightarrow \rho_{\mathrm{PC}} = 2.67\ \frac{\mathrm{kg}}{\mathrm{m^3}};$$

$$T_{\mathrm{sat@500kPa}} = 151.86\ ^\circ\mathrm{C};$$

Using Table-E.1

State-3: At the critical point

$$\left.\begin{aligned} p_{\mathrm{cr}} &= 22090\ \mathrm{kPa} \\ v_{\mathrm{cr}} &= 0.0568\ \frac{\mathrm{m^3}}{\mathrm{kmol}} \\ \bar{M} &= 18.015\ \frac{\mathrm{kg}}{\mathrm{kmol}} \end{aligned}\right\} \quad v_{\mathrm{crit}} = \frac{v_{\mathrm{cr}}}{\bar{M}} = \frac{0.0568}{18.015} = 0.0032\ \frac{\mathrm{m^3}}{\mathrm{kg}},\ \rho_{\mathrm{PC}} = \frac{1}{v_{\mathrm{crit}}} = \frac{1}{0.0032} = 312.5\ \frac{\mathrm{kg}}{\mathrm{m^3}}$$

Using the IG model for steam and Table-C:

$$R_{\mathrm{steam}} = 0.4615\ \frac{\mathrm{kJ}}{\mathrm{kg\cdot K}}$$

(a) At 50 kPa

$$\rho_{IG} = \frac{p}{RT}; \quad \Rightarrow \rho_{IG} = \frac{50}{(0.4615)(273+81.33)}; \quad \Rightarrow \rho_{IG} = 0.306\ \frac{kg}{m^3};$$

$$\%\text{Diff} = (100)\left|1-\frac{\rho_{IG}}{\rho_{PC}}\right|; \quad \Rightarrow \%\text{Diff} = (100)\left|1-\frac{0.306}{0.309}\right|; \quad \Rightarrow \%\text{Diff} = 0.97\%$$

(b) At 500kPa

$$\rho_{IG} = \frac{p}{RT}; \quad \Rightarrow \rho_{IG} = \frac{500}{(0.4615)(273+151.86)}; \quad \Rightarrow \rho_{IG} = 2.55\ \frac{kg}{m^3};$$

$$\%\text{DIFF} = (100)\left|1-\frac{\rho_{IG}}{\rho_{PC}}\right|; \quad \Rightarrow \%\text{Diff} = (100)\left|1-\frac{2.55}{2.67}\right|; \quad \Rightarrow \%\text{Diff} = 4.5\%$$

(c) At the critical point

$$\rho_{IG} = \frac{p}{RT}; \quad \Rightarrow \rho_{IG} = \frac{22090}{(0.4615)(273+647.3)}; \quad \Rightarrow \rho_{IG} = 73.95\ \frac{kg}{m^3};$$

$$\%\text{DIFF} = (100)\left|1-\frac{\rho_{IG}}{\rho_{PC}}\right|; \quad \Rightarrow \%\text{Diff} = (100)\left|1-\frac{73.95}{312.5}\right|; \quad \Rightarrow \%\text{Diff} = 76.3\%$$

TEST Solution:

Launch the IG 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).

3-4-11 [BEY] A weightless piston separates an insulated horizontal cylindrical vessel into two closed chambers. The piston is in equilibrium with air on one side and H_2O on the other side, each occupying a volume of 1 m^3. If the temperature of both the chambers is 200^{o}C, and the mass of H_2O is 15 kg, determine the mass of air. Treat air as a perfect gas and H_2O as a PC fluid.

SOLUTION

For H_2O: 200°C, 15 kg, 1 m^3

$$\rho = \frac{m}{V}; \quad \Rightarrow \rho = \frac{15}{1}; \quad \Rightarrow \rho = 15\ \frac{\text{kg}}{\text{m}^3};$$

$$v = \frac{1}{\rho}; \quad \Rightarrow v = 0.0667\ \frac{\text{m}^3}{\text{kg}};$$

$$p = p(v,T); \quad \Rightarrow p = p\left(0.0667\frac{m^3}{kg},\ 200°\text{C}\right); \quad \Rightarrow p = 1553.999\ \text{kPa};$$

For air: 200°C, ? kPa

$$v = 0.08738\ \frac{\text{m}^3}{\text{kg}};$$

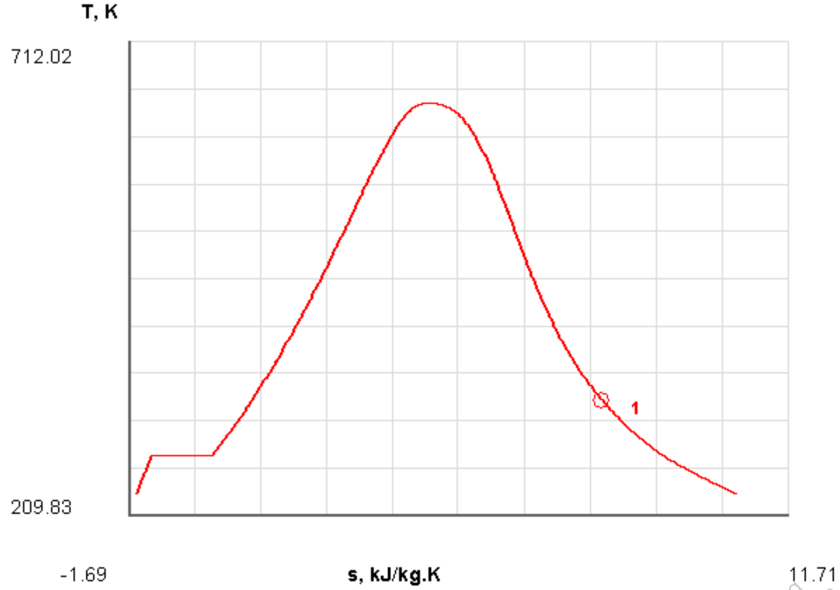
$$m = \frac{V}{v}; \quad \Rightarrow m = \frac{1}{0.08738}; \quad \Rightarrow m = 11.44\ \text{kg}$$

TEST Solution:

Launch the PC/IG 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).

3-4-12 [MP] Determine the mass of saturated steam stored in a rigid tank of volume 2 m^3 at 20 kPa using (a) the PC model and (b) the IG model. (c) What-if Scenario: What would the answers using (c) PC model and (d) IG model be if the steam had a quality of 95% instead?

SOLUTION



(a) Using the PC model for steam and Table-B.1:
At 20 kPa

$$T_{\text{sat}} = 60.06\ ^\circ\text{C};$$

$$v_g = 7.649\ \frac{\text{m}^3}{\text{kg}};$$

$$m = \frac{\mathcal{V}}{v_g}; \qquad \Rightarrow m = \frac{2}{7.649}; \qquad \Rightarrow m = 0.261\ \text{kg}$$

(b) Using the IG model for steam and Table-C:

$$R = 0.4615\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$m = \frac{p\mathcal{V}}{RT}; \qquad \Rightarrow m = \frac{(20)(2)}{(0.4615)(273+60.06)}; \qquad \Rightarrow m = 0.260\ \text{kg}$$

(c) At x = 0.95, using PC model:

$$v = v_f + \left(v_g - v_f\right)x; \qquad \Rightarrow v = 0.001017 + \left(7.649 - 0.001017\right)0.95;$$

$$\Rightarrow v = 7.27\ \text{kg};$$

$$m = \frac{\mathcal{V}}{v_g}; \qquad \Rightarrow m = \frac{2}{7.27}; \qquad \Rightarrow m = 0.275\ \text{kg}$$

(d) At x = 0.95, using IG model:

$$m = \frac{p\mathcal{V}}{RT}; \qquad \Rightarrow m = \frac{(20)(2)}{(0.4615)(273+60.06)}; \qquad \Rightarrow m = 0.260\ \text{kg}$$

TEST Solution:

Launch the IG 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).

3-4-13 [MG] Calculate the change in specific internal energy (Δu) as air is heated from 300 K to 1000 K using (a) the PG model and (b) the IG model (for the IG model, use the IG system state daemon).

SOLUTION

(a) Using the PG model for air and Table-C:

$$c_v = 0.718 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$\Delta u = c_v \Delta T; \quad \Rightarrow \Delta u = c_v\left(T_2 - T_1\right); \quad \Rightarrow \Delta u = 0.718\left(1000-300\right); \quad \Rightarrow \Delta u = 502.6 \ \frac{\text{kJ}}{\text{kg}}$$

(b) Using the IG model for air and Table-D1:

State-1: At 300 K

$$u_1 = 217.16 \ \frac{\text{kJ}}{\text{kg}};$$

State-2: At 1000 K

$$u_2 = 758.94 \ \frac{\text{kJ}}{\text{kg}};$$

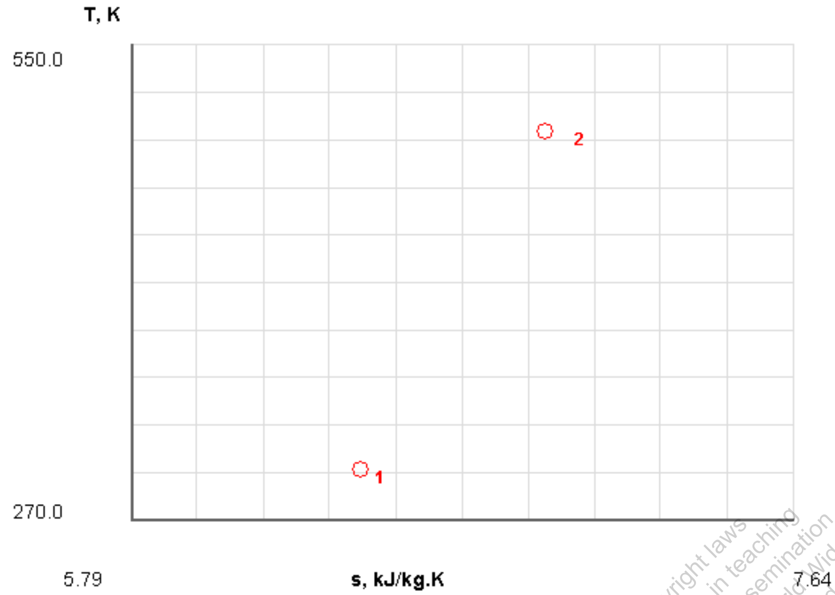
$$\Delta u = u_2 - u_1; \quad \Rightarrow \Delta u = 758.94 - 217.16; \quad \Rightarrow \Delta u = 541.3 \ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the PG 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).

3-4-14 [MZ] A 1 L piston-cylinder device contains air at 500 kPa and 300 K. An electrical resistance heater is used to raise the temperature of the gas to 500 K at constant pressure. Determine (a) the boundary work transfer, the change in (b) stored energy (ΔE) and (c) entropy (ΔS) of the gas. (d) What-if Scenario: Which part of the answers would not change if the IG modelwere used?

SOLUTION



Using the PG model for air and Table-C:

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

$$c_v = 0.718\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Using the IG equation of state:

$$\frac{p\mathcal{V}_1}{T_1} = \frac{p\mathcal{V}_2}{T_2}; \quad \Rightarrow \mathcal{V}_2 = \mathcal{V}_1 \frac{T_2}{T_1}; \quad \Rightarrow \mathcal{V}_2 = (0.001)\frac{500}{300}; \quad \Rightarrow \mathcal{V}_2 = 0.001667\ \text{m}^3;$$

(a) $W_B = p\Delta\mathcal{V}; \quad \Rightarrow W_B = p(\mathcal{V}_2 - \mathcal{V}_1); \quad \Rightarrow W_B = 500(0.001667 - 0.001); \quad \Rightarrow W_B = 0.333\ \text{kJ}$

(b) $m = \dfrac{p_1\mathcal{V}_1}{RT_1}; \quad \Rightarrow m = \dfrac{(500)(0.001)}{(0.287)(300)}; \quad \Rightarrow m = 0.00581\text{kg}$

$$\Delta E = mc_v\Delta T; \quad \Rightarrow \Delta E = mc_v(T_2 - T_1);$$

$$\Rightarrow \Delta E = 0.00581(0.718)(500-300); \quad \Rightarrow \Delta E = 0.834\ \text{kJ}$$

(c) $S = m\Delta s; \quad \Rightarrow S = m\left[c_p \ln\left(\dfrac{T_2}{T_1}\right) - R\ln\left(\dfrac{p_2}{p_1}\right)\right]; \quad \Rightarrow S = m(c_v + R)\ln\left(\dfrac{T_2}{T_1}\right) - 0;$

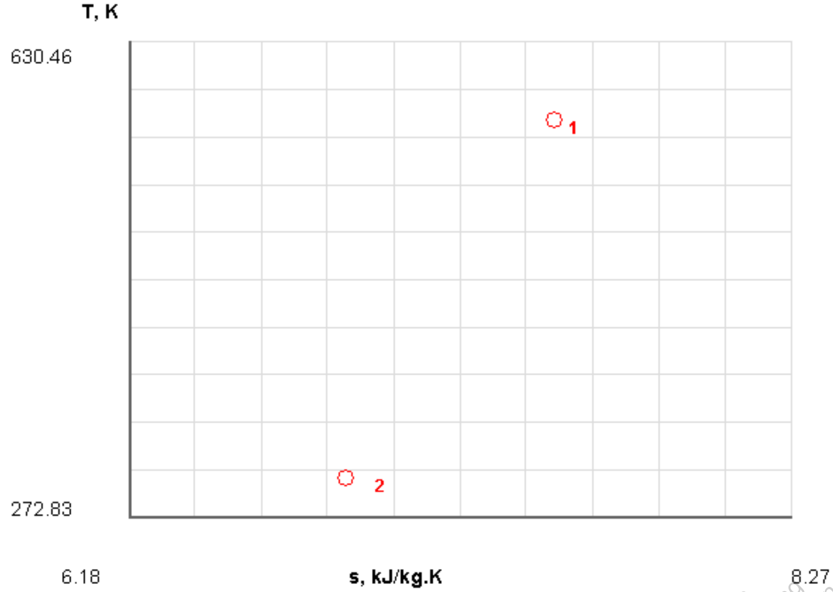
$$\Rightarrow S = 0.00581(0.718+0.287)\ln\left(\frac{500}{300}\right) - 0; \quad \Rightarrow S = 0.00298\ \frac{\text{kJ}}{\text{K}}$$

(d) Part (a) is not dependent on the gas model used.

TEST Solution:
Launch the PG 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).

3-4-15 [MU] A piston-cylinder device contains 0.01 kg of nitrogen at 100 kPa and 300°C. Using (a) the PG model and (b) IG model, determine the boundary work transfer as nitrogen cools down to 30°C. Show the process on a *T-s* and a *p-v* diagram.

SOLUTION



Using the PG model for nitrogen and Table-C:

$$R = 0.2968 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Assuming constant pressure

$$\mathcal{V}_1 = \frac{mRT_1}{p_1}; \quad \Rightarrow \mathcal{V}_1 = \frac{0.01(0.2968)(273+300)}{100}; \quad \Rightarrow \mathcal{V}_1 = 0.017 \text{ m}^3;$$

$$\mathcal{V}_2 = \frac{mRT_2}{p_2}; \quad \Rightarrow \mathcal{V}_2 = \frac{0.01(0.2968)(273+30)}{100}; \quad \Rightarrow \mathcal{V}_2 = 0.00899 \text{ m}^3;$$

(a) $W_B = p\Delta\mathcal{V}; \quad \Rightarrow W_B = p(\mathcal{V}_2 - \mathcal{V}_1); \quad \Rightarrow W_B = 100(0.00899 - 0.017);$

$$\Rightarrow W_B = -0.8 \text{ kJ}$$

(b) Using the IG model assumptions will yield the same result where

$$W_B = p\Delta\mathcal{V}; \quad \Rightarrow W_B = p(\mathcal{V}_2 - \mathcal{V}_1); \quad \Rightarrow W_B = 100(0.00899 - 0.017);$$

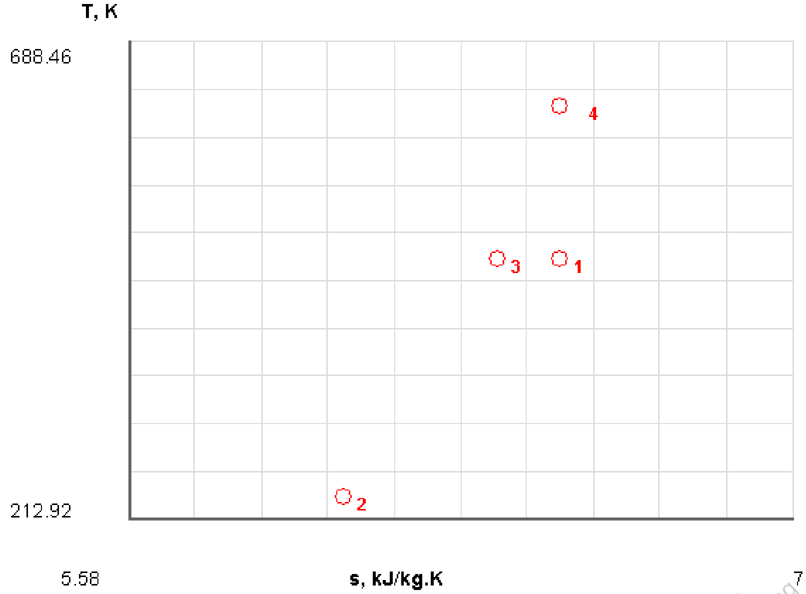
$$\Rightarrow W_B = -0.8 \text{ kJ}$$

TEST Solution:

Launch the PG 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).

3-4-16 [MK] Oxygen at 100 kPa and 200°C is compressed to half its initial volume. Determine the final state in terms of pressure (p_2) and temperature (T_2) if the compression is carried out in an (a) isobaric, (b) isothermal and (c) isentropic manner. Use the PG model for oxygen.

SOLUTION



Using the PG model for oxygen and Table-C:

$$R = 0.2598 \ \frac{\text{kJ}}{\text{kg} \cdot \text{K}};$$

$$k = 1.395;$$

Using the ideal gas equation of state

$$\frac{p_1 \cancel{V}_1}{T_1} = \frac{p_2 \cancel{V}_2}{T_2};$$

(a.1) The compression is isobaric, therefore the pressure remains constant and $p = 100 \text{ kPa}$

(a.2) $T_2 = T_1 \dfrac{p_2 \cancel{V}_2}{p_1 \cancel{V}_1}; \quad \Rightarrow T_2 = \dfrac{T_1}{2}; \quad \Rightarrow T_2 = \dfrac{273+200}{2}; \quad \Rightarrow T_2 = 236.5 \text{K};$

$\Rightarrow T_2 = -36.5 \ ^\circ\text{C}$

(b.1) $p_2 = p_1 \dfrac{T_2}{T_1} \dfrac{v_2}{v_1}; \quad \Rightarrow p_2 = 2 p_1; \quad \Rightarrow p_2 = 2(100); \quad \Rightarrow p_2 = 200 \text{ kPa}$

(b.2) The compression is isothermal, therefore the temperature remains constant and $T = 200°\text{C}$

(c.1) Isentropic compression $(\Delta s = 0)$

$$p_2 = p_1 \left(\frac{v_1}{v_2} \right)^k; \quad \Rightarrow p_2 = (100)(2)^{1.395}; \quad \Rightarrow p_2 = 263 \text{ kPa}$$

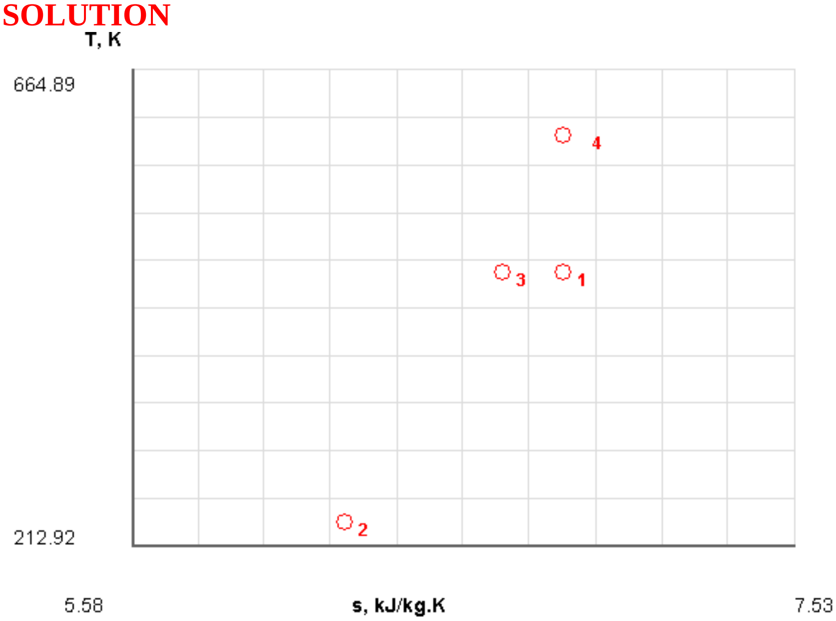
(c.2) $T_2 = T_1 \left(\dfrac{v_1}{v_2} \right)^{k-1}; \quad \Rightarrow T_2 = (273+200)(2)^{1.395-1}; \quad \Rightarrow T_2 = 622 \text{K}; \quad \Rightarrow T_2 = 348 \ ^\circ\text{C}$

TEST Solution:

Launch the PG 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).

3-4-17 [MQ] Repeat the problem 3-4-16 [MK] using the IG model for oxygen.

SOLUTION



Using the PG model for oxygen:

$$R = 0.2598 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$p = \frac{m}{V}RT;$$

(a.1) The compression is isobaric, therefore the pressure remains constant and $p = 100 \text{ kPa}$

(a.2) $p_1 = p_2; \quad \Rightarrow \frac{m}{V_1}RT_1 = \frac{m}{V_2}RT_2; \quad \Rightarrow \frac{m}{V_1}RT_1 = \frac{m}{0.5V_1}RT_2; \quad \Rightarrow T_1 = \frac{1}{0.5}T_2;$

$$\Rightarrow (200 + 273.15) = \frac{1}{0.5}T_2; \quad \Rightarrow T_2 = 236.575 \text{ K}; \quad \Rightarrow T_2 = -36.575°\text{C}$$

(b.1) $p_1 = \frac{m}{V_1}RT_1; \quad \Rightarrow T_1 = p_1\frac{V_1}{mR};$

$$T_1 = T_2; \quad \Rightarrow p_1\frac{V_1}{mR} = p_2\frac{V_2}{mR}; \quad \Rightarrow p_1\frac{V_1}{mR} = p_2\frac{0.5V_1}{mR}; \quad \Rightarrow p_1 = 0.5p_2; \quad \Rightarrow p_2 = 2p_1;$$

$$\Rightarrow p_2 = 2(100); \quad \Rightarrow p_2 = 200 \text{ kPa}$$

(b.2) The compression is isothermal, therefore the temperature remains constant and $T = 200°\text{C}$

(c.1) Isentropic compression $(\Delta s = 0)$

$p_2 = 255.5 \text{ kPa}$

(c.2) $T_2 = 331.3 \ ^\circ\text{C}$

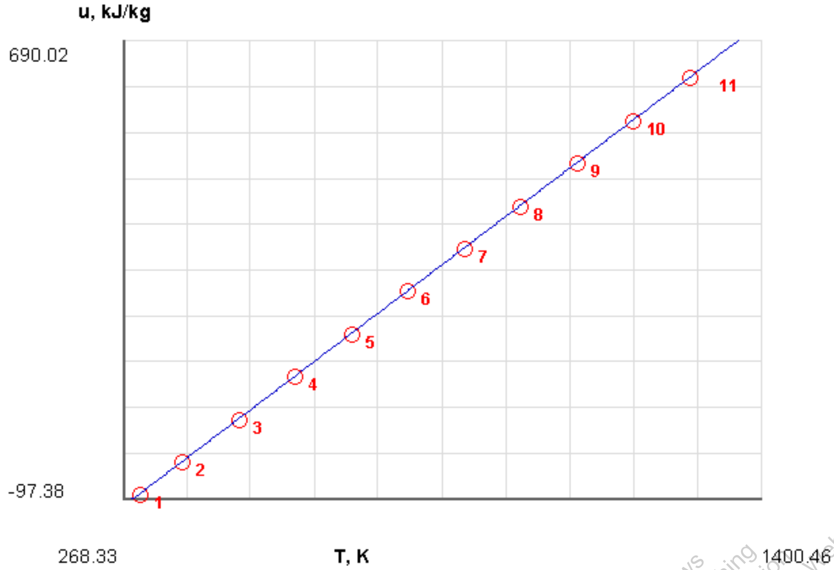
TEST Solution:

Launch the IG 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).

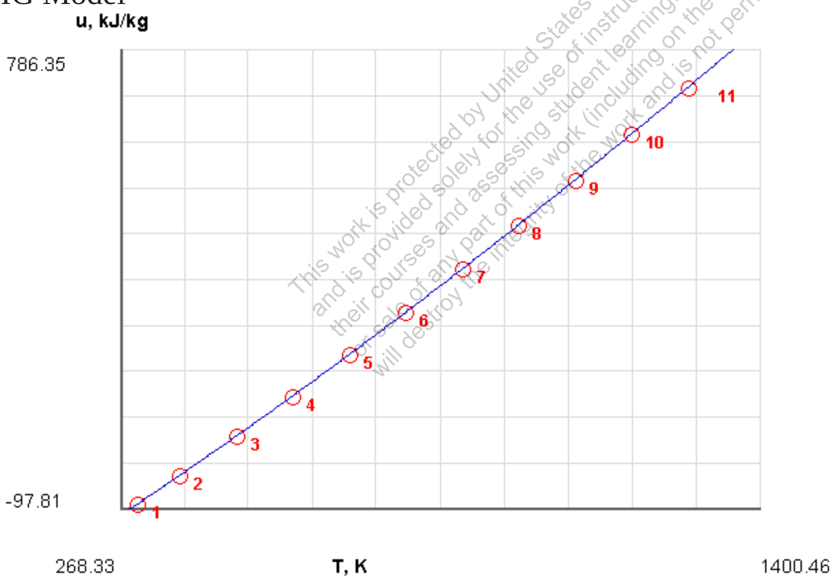
3-4-18 [MX] For nitrogen, plot how the internal energy (*U*) varies with *T* within the range 25^{o}C - 1000^{o}C while the pressure is held constant at 100 kPa. Use (a) the PG model and (b) the IG model. (c) What-if Scenario: Would any of the plots change if the pressure were 1 MPa instead?

SOLUTION

(a) PG Model



(b) IG Model



(c) No, they would not change.

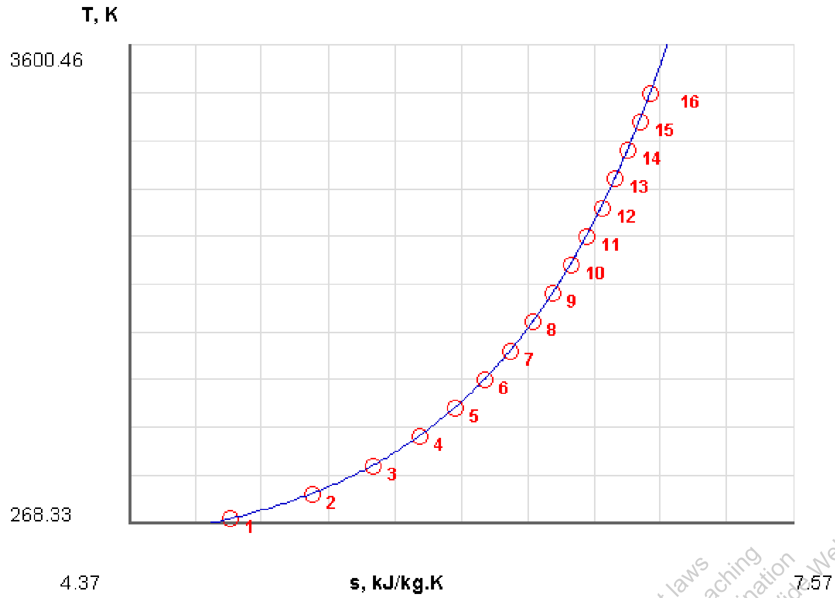
TEST Solution:

Launch the PG 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).

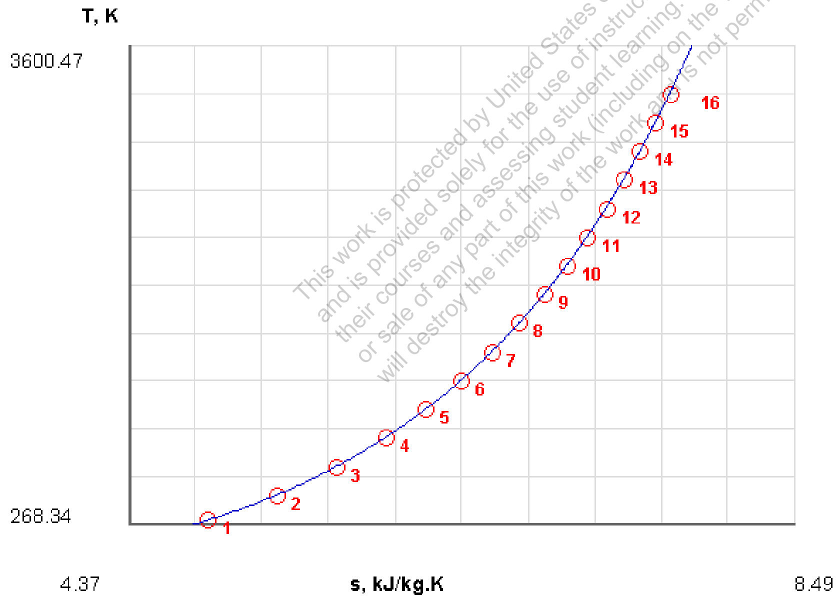
3-4-19 [MC] For carbon dioxide, plot how the specific entropy (*s*) varies with *T* within the range 25^{o}C - 3000^{o}C while the pressure is held constant at 100 kPa. Use (a) the PG model and (b) the IG model.

SOLUTION

(a) PG Model



(b) IG Model

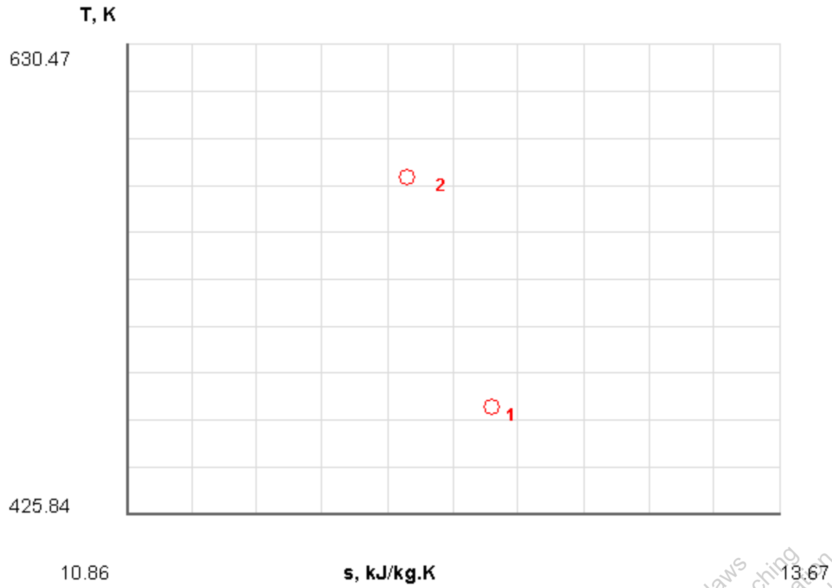


TEST Solution:

Launch the PG 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).

3-4-20 [MV] Superheated steam at a pressure of 10 kPa and temperature 200°C undergoes a process to a final pressure of 50 kPa and temperature of 300°C. Determine, magnitude only, (a) Δu, (b) Δh and (c) Δs. Assume superheated steam to behave as an ideal gas. What-if Scenario: What would (d) Δu, (e)Δh, (f) Δs be if the phase-change and the perfect gas models were used?

SOLUTION



Using the IG model for steam and Table-D7:

State-1: 200 °C

$$u_1 = 115.4 \ \frac{\text{kJ}}{\text{kg}};$$

$$h_1 = 333.7 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = 12.43 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: 300 °C

$$u_2 = 266.9 \ \frac{\text{kJ}}{\text{kg}};$$

$$h_2 = 531.4 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = 12.8 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) $\Delta u = u_2 - u_1; \quad \Rightarrow \Delta u = 266.9 - 115.4; \quad \Rightarrow \Delta u = 151.9 \ \frac{\text{kJ}}{\text{kg}}$

(b) $\Delta h = h_2 - h_1; \quad \Rightarrow \Delta h = 531.4 - 333.7; \quad \Rightarrow \Delta h = 197.7 \ \frac{\text{kJ}}{\text{kg}}$

(c) $\Delta s = s_2 - s_1; \quad \Rightarrow \Delta s = 12.43 - 12.8; \quad \Rightarrow |\Delta s| = 0.37 \ \frac{\text{kJ}}{\text{kg}}$

Using the PG model for steam and Table-C:

$$R = 0.4615 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_p = 1.8723 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$c_v = 1.4108 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(d) $\Delta u = c_v\left(T_2 - T_1\right); \quad \Rightarrow \Delta u = 1.4108(300-200); \quad \Rightarrow \Delta u = 141.1 \ \frac{\text{kJ}}{\text{kg}}$

(e) $\Delta h = c_p\left(T_2 - T_1\right); \quad \Rightarrow \Delta h = 1.8723(300-200); \quad \Rightarrow \Delta h = 187.23 \ \frac{\text{kJ}}{\text{kg}}$

(f) $\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right); \quad \Rightarrow \Delta s = (1.8723)\ln\left(\frac{300+273}{200+273}\right) - (0.4615)\ln\left(\frac{50}{10}\right);$

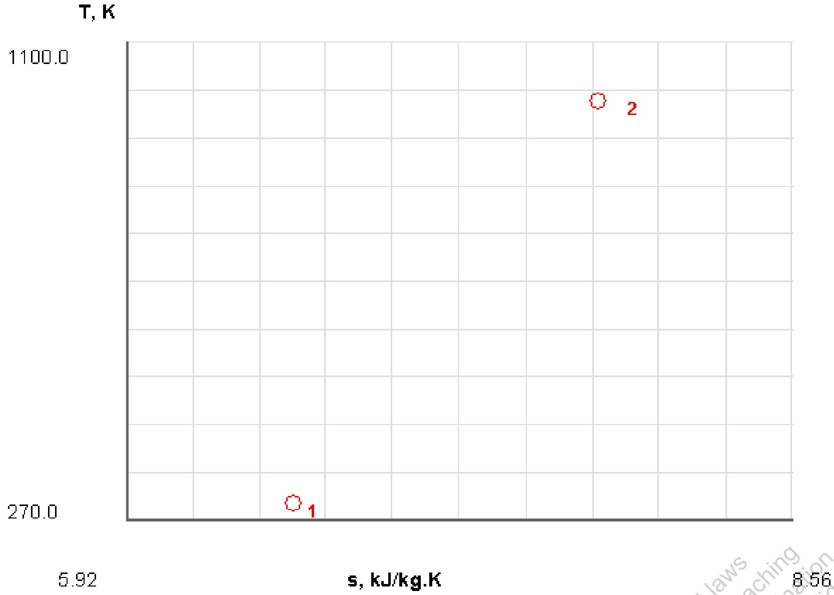
$$\Rightarrow |\Delta s| = 0.38 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

TEST Solution:

Launch the PC uniform closed process 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).

3-4-21 [MT] Air at 300 K and 300 kPa is heated at constant pressure to 1000 K. Determine the change in specific internal energy (Δu) using (a) perfect gas model with c_p evaluated at 298 K, (b) perfect gas model with c_p evaluated at the average temperature, (c) data from the ideal gas air table and (d) polynomial correlation between c_p and T.

SOLUTION



Using the PG model for air and Table-C:

$$c_p = 0.718 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

(a) $\Delta u = c_p\left(T_2 - T_1\right); \quad \Rightarrow \Delta u = 0.718\left(1000 - 300\right); \quad \Rightarrow \Delta u = 502.6 \ \frac{\text{kJ}}{\text{kg}}$

(b) At $\overline{T} = 760$ K, $c_v = 0.800 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

$$\Delta u = c_v\left(T_2 - T_1\right); \quad \Rightarrow \Delta u = 0.800\left(1000 - 300\right); \quad \Rightarrow \Delta u = 560 \ \frac{\text{kJ}}{\text{kg}}$$

(c) Using the IG model for air and Table-D1:

State-1: 300 K

$$u_1 = 214.07 \ \frac{\text{kJ}}{\text{kg}};$$

State-2: 1000 K

$$u_2 = 758.94 \ \frac{\text{kJ}}{\text{kg}};$$

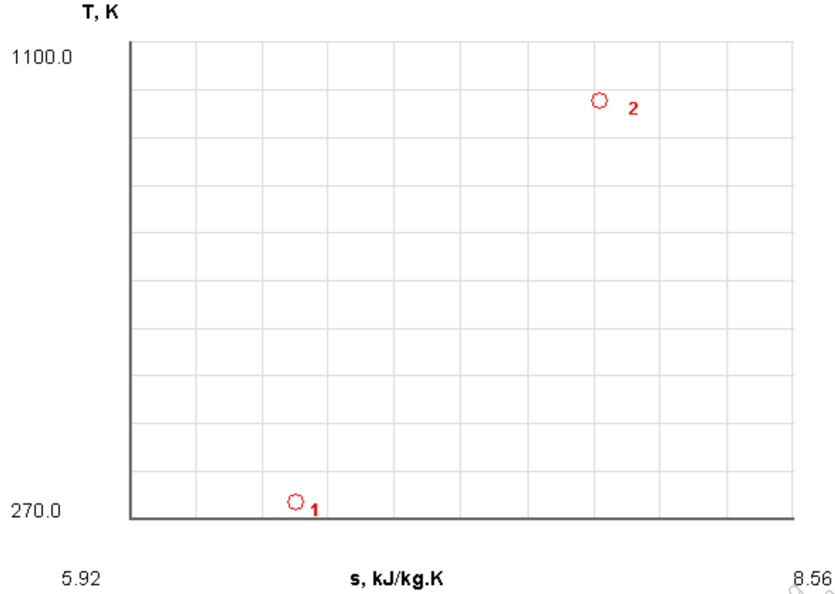
$$\Delta u = u_2 - u_1; \quad \Rightarrow \Delta u = 758.94 - 214.07; \quad \Rightarrow \Delta u = 544.87 \ \frac{\text{kJ}}{\text{kg}}$$

TEST Solution:

Launch the PG 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).

3-4-22 [MY] Air at 300 K and 300 kPa is heated at constant pressure to 1000 K. Determine the change in specific entropy, Δs, using (a) perfect gas model with c_p evaluated at 298 K, (b) perfect gas model with c_p evaluated at the average temperature and (c) data from the ideal gas air table.

SOLUTION



Using the PG model for air and Table-C:

$$c_p = 1.005 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

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

(a) $$\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right); \quad \Rightarrow \Delta s = (1.005)\ln\left(\frac{1000}{300}\right) - 0;$$

$$\Rightarrow \Delta s = 1.2 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

(b) At 750 K, $c_p = 1.087 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

$$\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right); \quad \Rightarrow \Delta s = (1.087)\ln\left(\frac{1000}{300}\right) - 0;$$

$$\Rightarrow \Delta s = 1.31 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

(c) Using the IG model for air and Table-D1:

State-1: 300 K

$$s_1 = 1.70203 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: 1000 K

$$s_2 = 2.9677 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

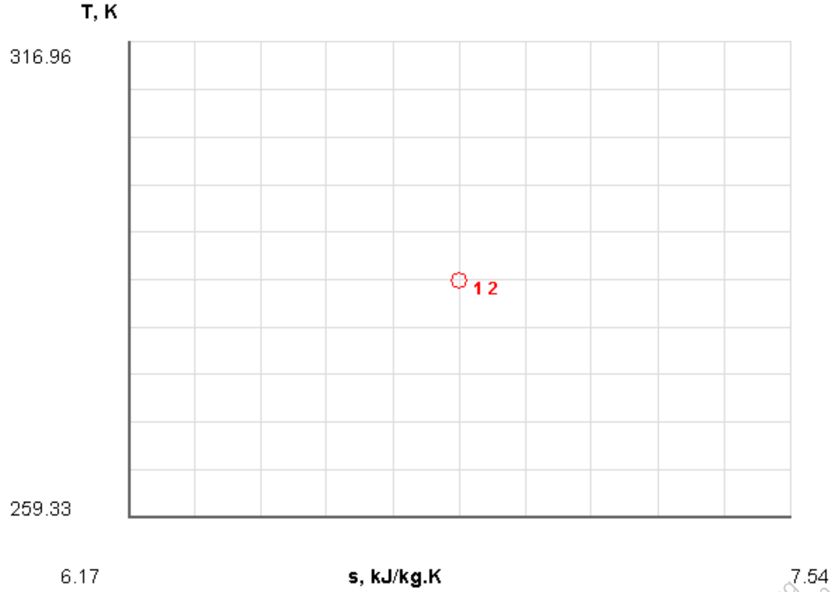
$$\Delta s = s_2 - s_1; \qquad \Rightarrow \Delta s = 2.9677 - 1.70203; \qquad \Rightarrow \Delta s = 1.266 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

TEST Solution:

Launch the PG 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).

3-4-23 [MF] Air at 15°C and 100 kPa enters the diffuser of a jet engine steadily with a velocity of 100 m/s. The inlet area is 0.2 m^2. Determine (a) the mass flow rate of the air ($\dot{m}$). (b) What-if Scenario: What would the mass flow rate be if the entrance velocity were 150 m/s?

SOLUTION



Using the PG model for air and Table-C:

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

$$v = \frac{RT}{p}; \qquad \Rightarrow v = \frac{(0.287)(273+15)}{100}; \quad \Rightarrow v = 0.826 \ \frac{\text{m}^3}{\text{kg}};$$

$$\text{(a)} \ \ \dot{m} = \rho \text{Av}; \qquad \Rightarrow \dot{m} = \frac{\text{Av}}{v}; \ \Rightarrow \dot{m} = \frac{(0.2)(100)}{0.826}; \qquad \Rightarrow \dot{m} = 24.2 \ \frac{\text{kg}}{\text{s}}$$

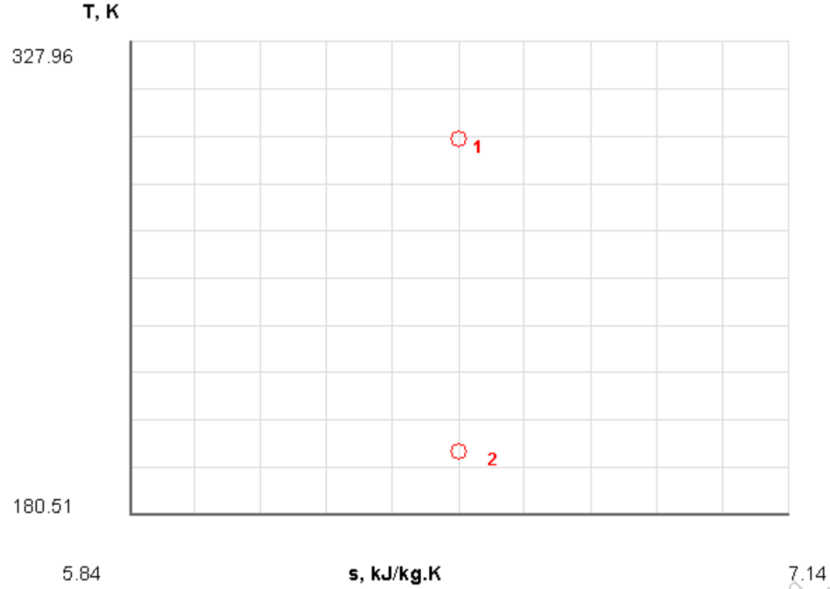
$$\text{(b)} \ \ \dot{m} = \frac{\text{Av}}{v}; \qquad \Rightarrow \dot{m} = \frac{(0.2)(150)}{0.826}; \qquad \Rightarrow \dot{m} = 36.3 \ \frac{\text{kg}}{\text{s}}$$

TEST Solution:

Launch the PG 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).

3-4-24 [MD] Air flows through a nozzle in an isentropic manner from p = 400 kPa, T = 25°C at the inlet to p = 100 KPa at the exit. Determine the temperature at the exit (T_2), modeling air as a perfect gas.

SOLUTION



Using Table-C:
$k = 1.4;$

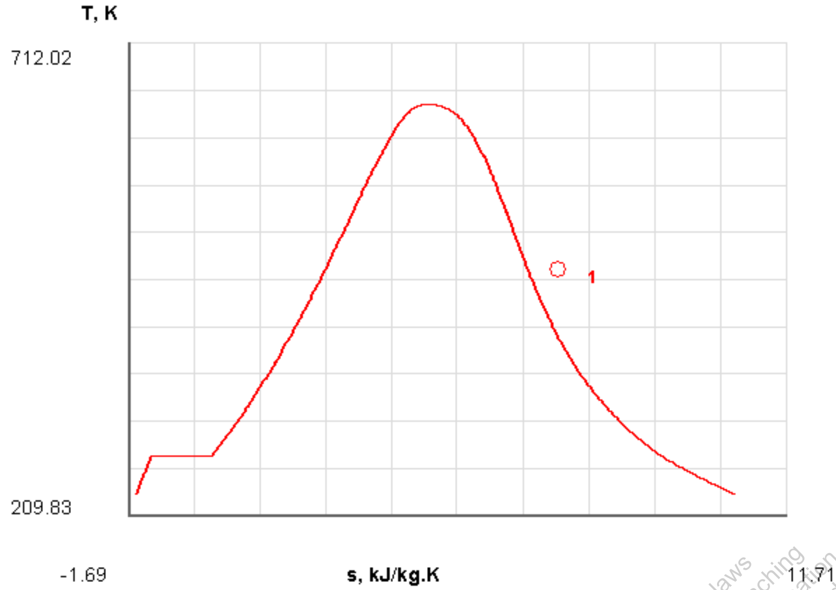
Using the PG model for air and the isentropic equation:

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}; \quad \Rightarrow T_2 = (273+25)\left(\frac{100}{400}\right)^{\frac{1.4-1}{1.4}}; \quad \Rightarrow T_2 = 200.5\,\text{K}; \quad \Rightarrow T_2 = -72.5\ ^\circ\text{C}$$

TEST Solution:
Launch the PG open steady 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).

3-4-25 [MM] H_2O at 500 kPa, 200°C enters a long insulated pipe with a flow rate of 5 kg/s. If the pipe diameter is 30 cm, determine the flow velocity in m/s (a) using the PC model for H_2O, (b) using the PG model for H_2O (Molar Mass of H_2O = 18 kg/kmol). (c) What-if Scenario: What would be the answer if the IG model were used instead?

SOLUTION



$$\dot{m} = \rho A V; \qquad \Rightarrow V = \frac{\dot{m}}{\rho A};$$

$$A = \pi r^2; \qquad \Rightarrow A = \pi \left(\frac{0.3}{2}\right)^2; \qquad \Rightarrow A = 0.0706858 \text{ m}^2;$$

(a) **State-1:** 500 kPa, 200°C

Using Table B-3:

$$v = 0.4249 \ \frac{\text{m}^3}{\text{kg}}; \qquad \Rightarrow v = \frac{1}{\rho}; \qquad \Rightarrow \rho = \frac{1}{v}; \qquad \Rightarrow \rho = \frac{1}{0.4249}; \qquad \Rightarrow \rho = 2.3535 \ \frac{\text{kg}}{\text{m}^3};$$

$$V = \frac{\dot{m}}{\rho A}; \qquad \Rightarrow V = \frac{5}{(0.0706858)(2.3535)}; \qquad \Rightarrow V = 30.06 \ \frac{\text{m}}{\text{s}}$$

(b) PG Model

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

$$p = \rho R T; \qquad \Rightarrow \rho = \frac{p}{RT}; \qquad \Rightarrow \rho = \frac{500}{(0.4614)(200+273.15)}; \qquad \Rightarrow \rho = 2.2903 \ \frac{\text{kg}}{\text{m}^3};$$

$$V = \frac{\dot{m}}{\rho A}; \qquad \Rightarrow V = \frac{5}{(0.0706858)(2.2903)}; \qquad \Rightarrow V = 30.88 \ \frac{\text{m}}{\text{s}}$$

(c) IG Model

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

$$p = \rho R T; \qquad \Rightarrow \rho = \frac{p}{RT}; \qquad \Rightarrow \rho = \frac{500}{(0.4614)(200+273.15)}; \qquad \Rightarrow \rho = 2.2903 \ \frac{\text{kg}}{\text{m}^3};$$

$$V = \frac{\dot{m}}{\rho A}; \qquad \Rightarrow V = \frac{5}{(0.0706858)(2.2903)}; \qquad \Rightarrow V = 30.88 \ \frac{\text{m}}{\text{s}}$$

TEST Solution:

Launch the PG 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).