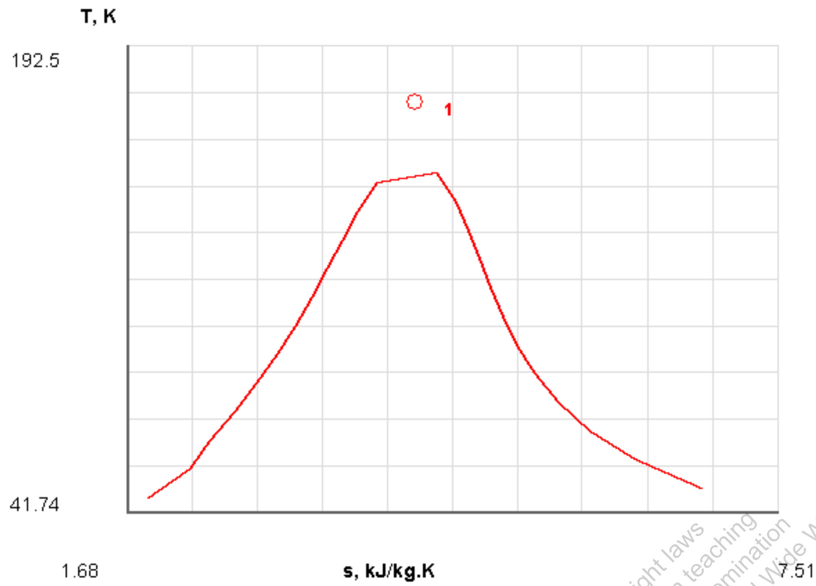
3-5-1 [MJ] Determine the specific volume (v) of oxygen at 10 MPa and 175K based on (a) Lee-Kesler and (b) Nelson-Obert generalized compressibility chart.

SOLUTION



Using the RG model for oxygen and Table-E1:

$$P_r = \frac{P}{P_{cr}}; \quad \Rightarrow P_r = \frac{10}{5.08}; \quad \Rightarrow P_r = 1.97;$$

$$T_r = \frac{T}{T_{cr}}; \quad \Rightarrow T_r = \frac{175}{154.8}; \quad \Rightarrow T_r = 1.13;$$

Using Figure-E.2 (L. K.):

$$z = z(T_r, P_r); \quad \Rightarrow z = 0.45;$$

Using Table-C:

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

(a) Using the RG equation of state

$$v = \frac{zRT}{p}; \quad \Rightarrow v = \frac{(0.45)(0.2598)(175)}{10000}; \quad \Rightarrow v = 0.00205 \ \frac{\text{m}^3}{\text{kg}}$$

(b) Using Figure-E.5 (N. O.):

$$z = z(T_r, P_r); \quad \Rightarrow z = 0.46;$$

Using the RG equation of state

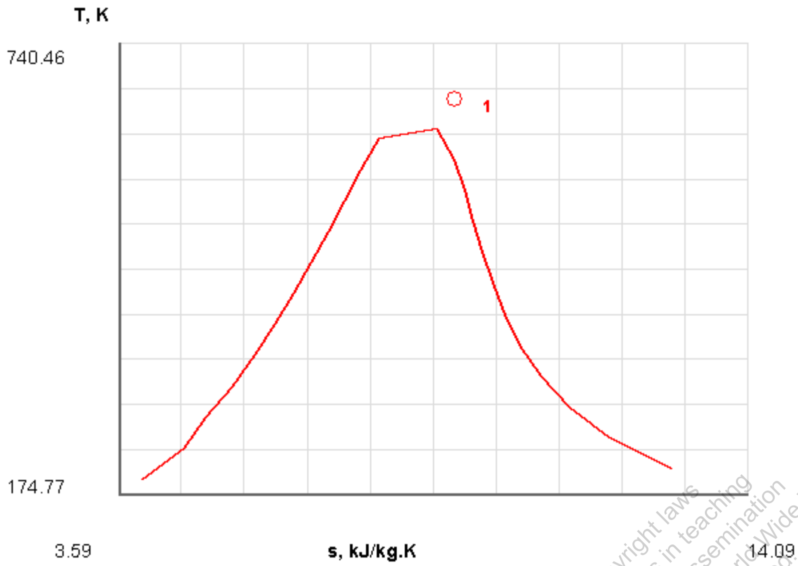
$$v = \frac{zRT}{p}; \qquad \Rightarrow v = \frac{(0.46)(0.2598)(175)}{10000}; \qquad \Rightarrow v = 0.0021 \ \frac{\text{m}^3}{\text{kg}}$$

TEST Solution:

Launch the RG 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).

3-5-2 [MW] Determine the compressibility factor of steam at 20 MPa, 400°C using (a) the LK chart, (b) the NO chart and (c) the PC model. (d) What-if Scenario: What would the answers be if the steam were saturated at 1 MPa?

SOLUTION



Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \qquad \Rightarrow P_r = \frac{20}{22.09}; \qquad \Rightarrow P_r = 0.905;$$

$$T_r = \frac{T}{T_{cr}}; \qquad \Rightarrow T_r = \frac{(400+273)}{647.3}; \qquad \Rightarrow T_r = 1.04;$$

(a) Using Figure-E.2 (L. K.)

$$z = z(T_r, P_r); \qquad \Rightarrow z = 0.62$$

(b) Using Figure-E.2 (N. O.)

$$z = z(T_r, P_r); \qquad \Rightarrow z = 0.62$$

(c) Using the PC model and Table-B.3

$$v = v(T, P); \qquad \Rightarrow v = 0.009942 \ \frac{\text{m}^3}{\text{kg}};$$

Using Table-C

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

$$z = \frac{v}{v_{IG}}; \qquad \Rightarrow z = \frac{Pv}{RT}; \qquad \Rightarrow z = \frac{(20000)(0.009942)}{(0.4615)(400+273)}; \qquad \Rightarrow z = 0.64$$

Repeating this process where P = 1 MPa, x = 1
Using Table-B.3

$$T = T_{sat@1\text{ MPa}}; \quad \Rightarrow T = 179.91\ ^\circ\text{C};$$

$$v = v_{sat@1\text{ MPa}}; \quad \Rightarrow v = 0.19444\ \frac{\text{m}^3}{\text{kg}};$$

Reduced Properties

$$P_r = \frac{P}{P_{cr}}; \quad \Rightarrow P_r = \frac{1}{22.09}; \quad \Rightarrow P_r = 0.045;$$

$$T_r = \frac{T}{T_{cr}}; \quad \Rightarrow T_r = \frac{(273+179.91)}{647.3}; \quad \Rightarrow T_r = 0.7;$$

(d) $z = z(T_r, P_r); \quad \Rightarrow z = 0.95$

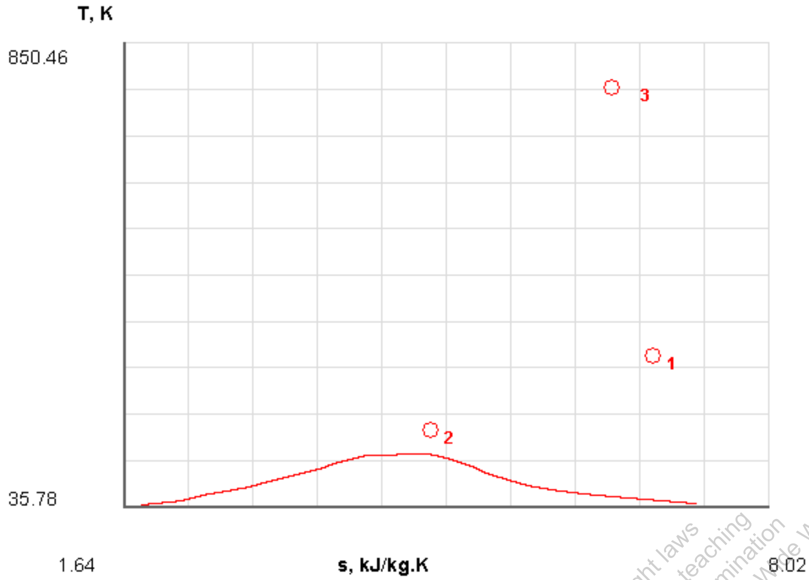
(e) $z = z(T_r, P_r); \quad \Rightarrow z = 0.93$

(f) $z = \frac{v}{v_{IG}}; \quad \Rightarrow z = \frac{Pv}{RT}; \quad \Rightarrow z = \frac{(1000)(0.19444)}{(0.4615)(179.91+273)}; \quad \Rightarrow z = 0.93$

TEST Solution:
Launch the RG 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).

3-5-3 [JB] Compare the IG model and RG model (Lee Kesler chart) in evaluating the density of air at (a) 100 kPa, 30°C (b) 10 MPa, -100°C (c) 10 MPa, 500°C.

SOLUTION



Using Table-C

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

Using Table-E1

$T_{cr} = 136.5\ \text{K};$

$P_{cr} = 3.77\ \text{MPa};$

As an Ideal Gas

$\rho_{IG} = \dfrac{P}{RT};$

As a Real Gas

$T_r = \dfrac{T}{T_{cr}};$

$P_r = \dfrac{P}{P_{cr}};$

Using Figure-E2 (L. K.)

$z = z\left(T_r, P_r\right);$

Real Gas equation of state

$$\rho_{RG} = \frac{P}{zRT};$$

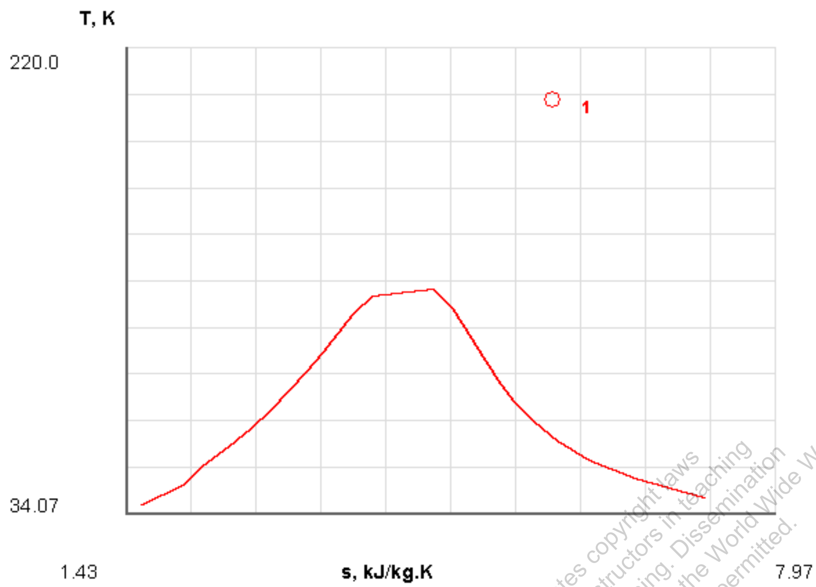
	P [MPa]	$T\left[{}^\circ\mathrm{C}\right]$	$\rho_{IG}\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]$	T_r	P_r	z	$\rho_{RG}\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]$
(a)	0.1	30	1.15	2.29	0.027	0.99	1.16
(b)	10	-100	201.4	1.3	2.65	0.65	309.9
(c)	10	500	45.1	5.83	2.65	1.03	43.8

TEST Solution:

Launch the RG 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).

3-5-4 [JR] A 1 m^3 closed rigid tank contains nitrogen at 1 MPa and 200 K. Determine the total mass of nitrogen using (a) the RG model (LK chart), (b) the IG model and (c) the PC model. Discuss the discrepancy among the results.

SOLUTION



Using Table-C

$$R = 0.2966\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \qquad \Rightarrow P_r = \frac{1}{3.39}; \qquad \Rightarrow P_r = 0.295;$$

$$T_r = \frac{T}{T_{cr}}; \qquad \Rightarrow T_r = \frac{200}{126.2}; \qquad \Rightarrow T_r = 1.58;$$

Using Figure-E.2 (L. K.)

$$z = z\left(T_r, P_r\right); \qquad \Rightarrow z = 0.98;$$

Real Gas equation of state

$$v = \frac{zRT}{\rho}; \qquad \Rightarrow v = \frac{(0.98)(0.2966)(200)}{1000}; \qquad \Rightarrow v = 0.0058\ \frac{\text{m}^3}{\text{kg}};$$

(a) $m = \frac{\forall}{v}; \quad \Rightarrow m = \frac{1}{0.058}; \quad \Rightarrow m = 17.24\ \text{kg}$

(b) Using the Ideal Gas model and equation of state

$$m = \frac{Pv}{RT}; \qquad \Rightarrow m = \frac{(1000)(1)}{(0.2966)(200)}; \qquad \Rightarrow m = 16.86 \text{ kg}$$

(c) Using the Phase Change model and Table-B.14

$$v = v(P,T); \qquad \Rightarrow v = 0.05809 \ \frac{\text{m}^3}{\text{kg}};$$

$$m = \frac{\text{V}}{\text{v}}; \qquad \Rightarrow m = \frac{1}{0.05809}; \qquad \Rightarrow m = 17.21 \text{ kg}$$

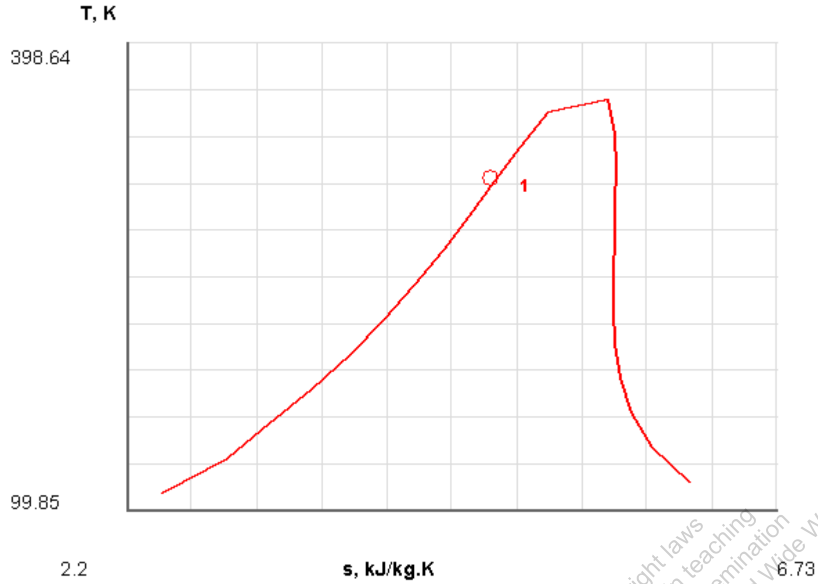
Discussion: At high pressure and low temperature, as in this problem, the nitrogen molecules are spaced closely together and their repulsion and attraction forces become significant. The RG model, which takes these forces into account, will provide a more accurate measure of the systems mass than the PC and IG models.

TEST Solution:

Launch the RG 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).

3-5-5 [JO] Calculate the specific volume (v) of propane at a pressure of 8 MPa and a temperature of 40°C using (a) the IG model, (b) the RG model and (c) the PC model.

SOLUTION



Using Table-C

$$R = 0.1855\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \quad \Rightarrow P_r = \frac{8}{4.26}; \quad \Rightarrow P_r = 1.878;$$

$$T_r = \frac{T}{T_{cr}}; \quad \Rightarrow T_r = \frac{273+40}{370}; \quad \Rightarrow T_r = 0.846;$$

Using Figure-E.2 (L. K.)

$$z = z(T_r, P_r); \quad \Rightarrow z = 0.3;$$

(a) Ideal Gas equation of state

$$v = \frac{RT}{\rho}; \quad \Rightarrow v = \frac{(0.1855)(273+40)}{8000}; \quad \Rightarrow v = 0.00726\ \frac{\text{m}^3}{\text{kg}}$$

(b) Real Gas equation of state

$$v = \frac{zRT}{\rho}; \quad \Rightarrow v = \frac{(0.3)(0.1855)(273+40)}{8000}; \quad \Rightarrow v = 0.00218\ \frac{\text{m}^3}{\text{kg}}$$

(c) Using the PC model and Tables

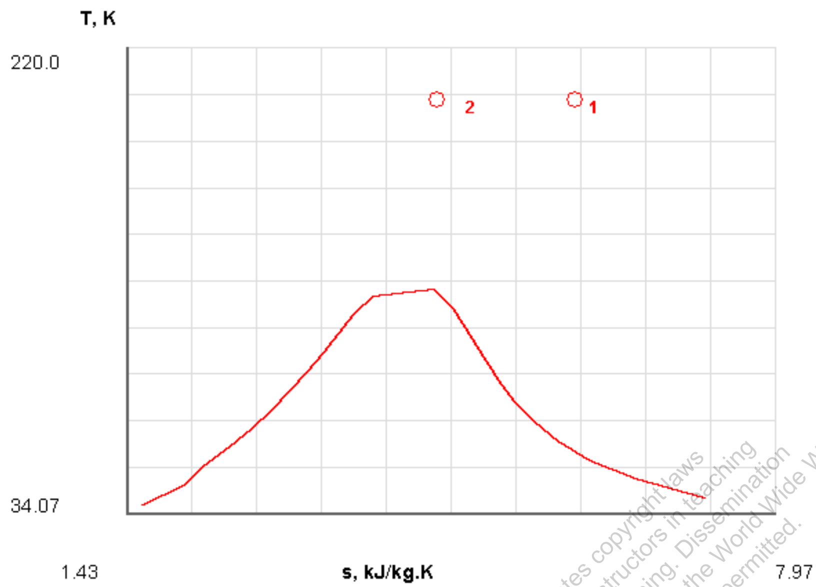
$$P = P(T, P); \qquad \Rightarrow P = 0.00101 \ \frac{\mathrm{m}^3}{\mathrm{kg}}$$

TEST Solution:

Launch the RG 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).

3-5-6 [JS] A tank of volume 10 m^3 contains nitrogen at a pressure of 0.5 MPa and a temperature of 200 K. Determine the mass of nitrogen in the tank using (a) the ideal gas and (b) real gas model. (c) What-if Scenario: What would the answer in part (a) be if the coditions in the tank were 3 MPa and 125 K?

SOLUTION



Using Table-C for nitrogen

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

(a) Ideal Gas equation of state

$$v = \frac{RT}{p}; \qquad \Rightarrow v = \frac{(0.2968)(200)}{500}; \qquad \Rightarrow v = 0.11872 \ \frac{\text{m}^3}{\text{kg}};$$

$$m_{IG} = \frac{\cancel{V}}{v_{IG}}; \qquad \Rightarrow m_{IG} = \frac{1}{0.11872}; \qquad \Rightarrow m_{IG} = 84.23 \text{ kg}$$

(b) Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \qquad \Rightarrow P_r = \frac{0.5}{3.39}; \qquad \Rightarrow P_r = 0.1475;$$

$$T_r = \frac{T}{T_{cr}}; \qquad \Rightarrow T_r = \frac{200}{126.2}; \qquad \Rightarrow T_r = 1.58;$$

Using Figure-E.2 (L. K.)

$$z = z(T_r, P_r); \qquad \Rightarrow z = 0.98;$$

$$v = \frac{zRT}{p}; \qquad \Rightarrow v = \frac{(0.98)(0.2968)(200)}{500}; \qquad \Rightarrow v = 0.1163 \ \frac{\text{m}^3}{\text{kg}};$$

$$m_{RG} = \frac{\cancel{V}}{v}; \quad \Rightarrow m_{RG} = \frac{1}{0.1163}; \quad \Rightarrow m_{RG} = 85.98 \text{ kg}$$

(c) What-if-Scenario:

$$v = \frac{RT}{p}; \quad \Rightarrow v = \frac{(0.2968)(125)}{3000}; \quad \Rightarrow v = 0.0124 \ \frac{\text{m}^3}{\text{kg}};$$

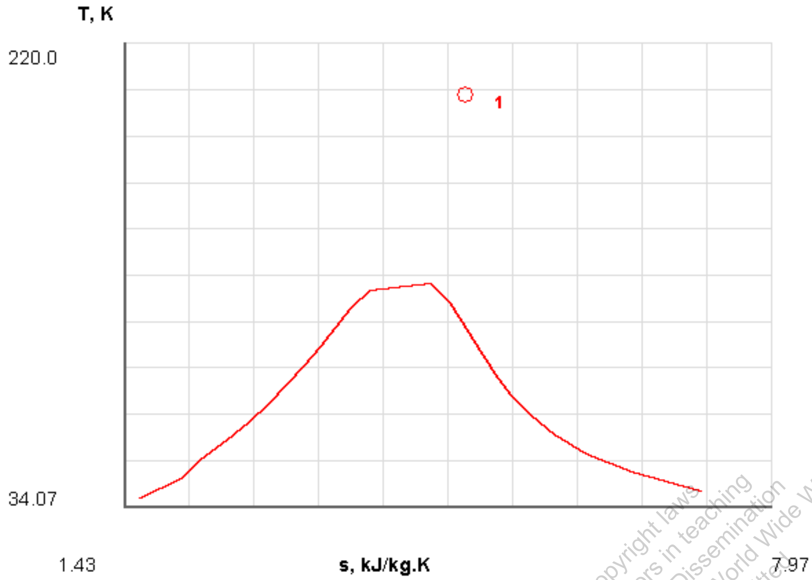
$$m_{IG} = \frac{\cancel{V}}{v_{IG}}; \quad \Rightarrow m_{IG} = \frac{1}{0.0124}; \quad \Rightarrow m_{IG} = 806.5 \text{ kg}$$

TEST Solution:

Launch the RG 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).

3-5-7 [JA] Calculate the error (in percent) in evaluating the mass of nitrogen at 10 MPa, 200 K in a 100 L rigid tank while using (a) the IG model and (b) the RG model (LK chart). Use the PC model as the benchmark.

SOLUTION



Using the PC model and Tables

$$v_{PC} = v(P,T); \qquad \Rightarrow v_{PC} = 0.005 \ \frac{\text{m}^3}{\text{kg}};$$

$$m_{PC} = \frac{\cancel{V}}{v_{PC}}; \qquad \Rightarrow m_{PC} = \frac{0.1}{0.005}; \qquad \Rightarrow m_{PC} = 20 \text{ kg};$$

Using Table-C for nitrogen

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

Ideal Gas equation of state

$$v_{IG} = \frac{RT}{p}; \qquad \Rightarrow v_{IG} = \frac{(0.2968)(200)}{10000}; \qquad \Rightarrow v_{IG} = 0.005936 \ \frac{\text{m}^3}{\text{kg}};$$

$$m_{IG} = \frac{\cancel{V}}{v_{IG}}; \qquad \Rightarrow m_{IG} = \frac{0.1}{0.005936}; \qquad \Rightarrow m_{IG} = 16.949 \text{ kg};$$

(a) $\% \text{ ERROR} = 100\left(1 - \frac{m_{IG}}{m_{PC}}\right); \qquad \Rightarrow \% \text{ ERROR} = 100\left(1 - \frac{16.949}{20}\right); \qquad \Rightarrow \% \text{ ERROR} = 15.26\%$

(b) Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \qquad \Rightarrow P_r = \frac{10}{3.39}; \qquad \Rightarrow P_r = 2.95;$$

$$T_r = \frac{T}{T_{cr}}; \qquad \Rightarrow T_r = \frac{200}{126.2}; \qquad \Rightarrow T_r = 1.58;$$

Using Figure-E.2 (L. K.)

$$z = z(T_r, P_r); \qquad \Rightarrow z = 0.835;$$

Real Gas equation of state

$$v_{RG} = \frac{zRT}{p}; \qquad \Rightarrow v_{RG} = \frac{(0.835)(0.2968)(200)}{10000}; \qquad \Rightarrow v_{RG} = 0.00495 \ \frac{\text{m}^3}{\text{kg}};$$

$$m_{RG} = \frac{\cancel{V}}{v_{RG}}; \qquad \Rightarrow m_{RG} = \frac{0.1}{0.00495}; \qquad \Rightarrow m_{RG} = 20.2 \text{ kg};$$

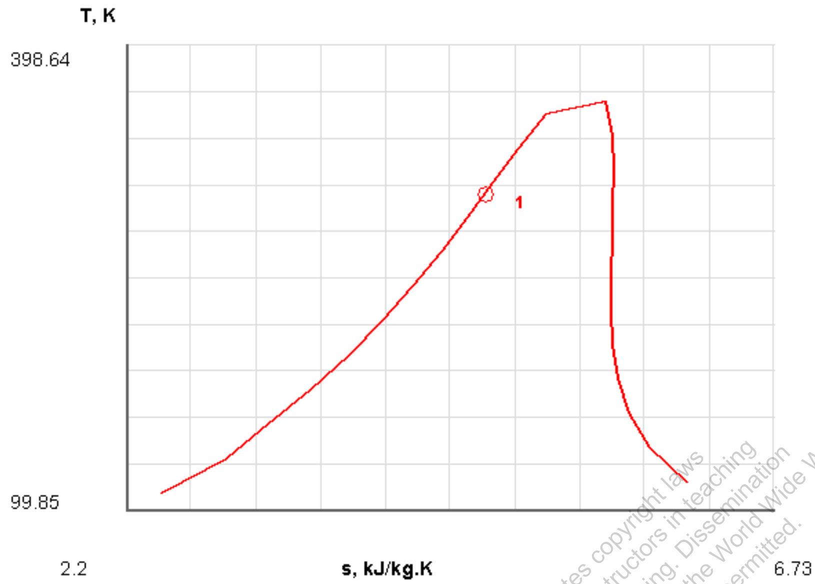
$$\% \text{ Error} = 100\left(\frac{m_{RG}}{m_{PC}} - 1\right); \qquad \Rightarrow \% \text{ Error} = 100\left(\frac{20.2}{20} - 1\right); \qquad \Rightarrow \% \text{ Error} = 1\%$$

TEST Solution:

Launch the RG 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).

3-5-8 [JH] A 10 gallon tank contains 9 gallon liquid propane and the rest vapor at 30°C. Calculate (a) the pressure (p) and (b) mass of propane by using the Lee Kesler compressibility chart. What-if Scenario: What would the (c) pressure and (d) mass be if the PC model were used?

SOLUTION



Using Table-C for propane

$$R = 0.1885 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(a) The propane in the tank is a saturated mixture, therefore

$$p = p(T, y); \qquad \Rightarrow p = p(30°\text{C}, 0.1); \qquad \Rightarrow p = 1258.32 \text{ kPa}$$

(b) Using Figure-E.2 (L. K.)

$$z = z(T_r, P_r); \qquad \Rightarrow z = 0.05404;$$

Real Gas equation of state

$$v = \frac{zRT}{p}; \qquad \Rightarrow v = \frac{(0.05404)(0.1885)(30+273.15)}{1258.32}; \qquad \Rightarrow v = 0.00245 \ \frac{\text{m}^3}{\text{kg}};$$

$$m = \frac{\forall}{v}; \qquad \Rightarrow m = \frac{0.03785}{0.00245}; \qquad \Rightarrow m = 15.42 \text{ kg}$$

(c) Using Table B-16

$$p = p_{sat@30°C}; \qquad \Rightarrow p = 1092.06 \text{ kPa}$$

(d) Using Table B-16

$$v_{liquid} = 0.002068\ \frac{\text{m}^3}{\text{kg}}; \quad \Rightarrow \rho_{liquid} = \frac{1}{v_{liquid}}; \quad \Rightarrow \rho_{liquid} = \frac{1}{0.002068}; \quad \Rightarrow \rho_{liquid} = 483.6\ \frac{\text{kg}}{\text{m}^3};$$

$$v_{vapor} = 0.043306\ \frac{\text{m}^3}{\text{kg}}; \quad \Rightarrow \rho_{liquid} = \frac{1}{v_{liquid}}; \quad \Rightarrow \rho_{liquid} = \frac{1}{0.043306}; \quad \Rightarrow \rho_{liquid} = 23.09\ \frac{\text{kg}}{\text{m}^3};$$

$$m_{liquid} = \rho_{liquid} \cancel{V}_{liquid}; \quad \Rightarrow m_{liquid} = (483.6)(0.0340687); \quad \Rightarrow m_{liquid} = 16.476\ \text{kg};$$

$$m_{vapor} = \rho_{vapor} \cancel{V}_{vapor}; \quad \Rightarrow m_{vapor} = (23.09)(0.00378541); \quad \Rightarrow m_{vapor} = 0.087405\ \text{kg};$$

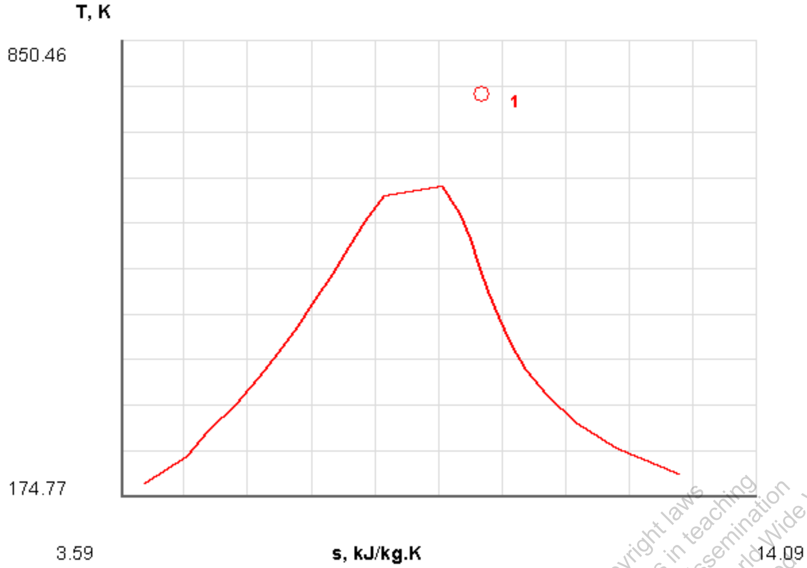
$$m = m_{liquid} + m_{vapor}; \quad \Rightarrow m = 16.563\ \text{kg}$$

TEST Solution:

Launch the RG 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).

3-5-9 [JN] A rigid tank of volume 2 m^3 contains 180 kg of water at 500°C. Calculate the pressure (p) in the tank by using (a) the Lee-Kesler chart and (b) Nelson-Obert chart. (c) What-if Scenario: What would the answer be if the PC model were used?

SOLUTION



Using Table-C for water

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

Ideal Gas equation of state

$$v = \frac{RT}{\rho}; \qquad \Rightarrow v = \frac{(0.2968)(200)}{500}; \quad \Rightarrow v = 0.11872\ \frac{\text{m}^3}{\text{kg}};$$

With pressure unknown, we will separate the variables dependent on pressure in the real gas equation

$$\frac{P}{z} = \frac{P}{z(P)}; \qquad \Rightarrow \frac{P}{z} = \frac{RT}{v}; \qquad \Rightarrow \frac{P}{z} = \frac{RTm}{\cancel{V}};$$

$$\frac{P}{z(P)} = \frac{RTm}{\cancel{V}}; \qquad \Rightarrow \frac{P}{z(P)} = \frac{(0.4615)(273+500)(180)}{2};$$

$$\Rightarrow \frac{P}{z(P)} = 32100\ \text{kPa}; \qquad \Rightarrow \frac{P}{z(P)} = 32.1\ \text{MPa};$$

(a) Using an iterative process and The L.K. chart to solve the two unknowns, the real gas equation is satisfied when
$z = 0.755,\quad P = 24.26\ \text{MPa}$

(b) Repeating this process with the N.O. chart, the real gas equation is satisfied when

$z = 0.757, \quad P = 24.33 \text{ MPa}$

(c) PC Model

$$v = \frac{V}{m}; \quad \Rightarrow v = \frac{2}{180}; \quad \Rightarrow v = 0.01111 \ \frac{\text{m}^3}{\text{kg}};$$

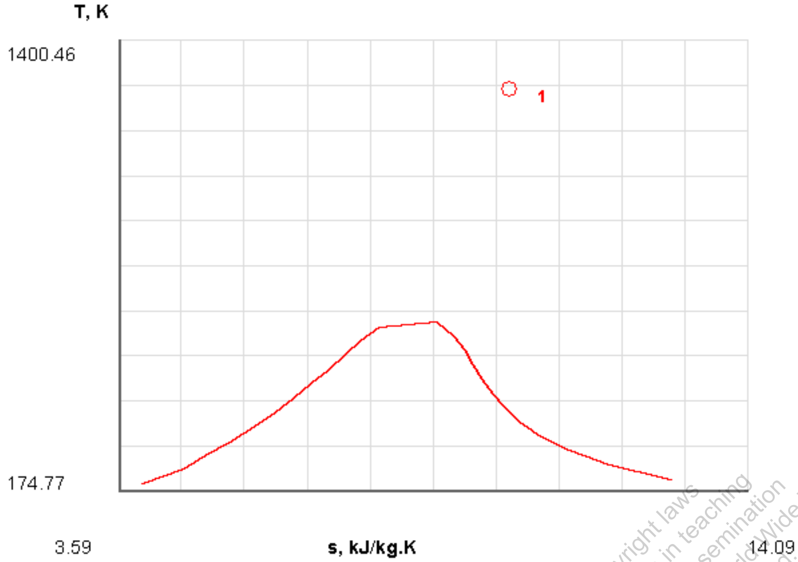
$$p = p(T, v); \quad \Rightarrow p = p(500°\text{C}, 0.01111 \ \frac{\text{m}^3}{\text{kg}}); \quad \Rightarrow p = 25.02 \text{ MPa}$$

TEST Solution:

Launch the RG 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).

3-5-10 [JE] Determine the volume of 1 kg of water pressurized to 100 MPa at 1000°C. Use (a) the RG model with the Lee-Kesler chart, (b) the RG model with the Nelson-Obert chart and (c) the PC model.

SOLUTION



Using Table-C for water

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

Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \quad \Rightarrow P_r = \frac{100}{22.09}; \quad \Rightarrow P_r = 4.527;$$

$$T_r = \frac{T}{T_{cr}}; \quad \Rightarrow T_r = \frac{273+1000}{647.3}; \quad \Rightarrow T_r = 1.967;$$

(a) Using Figure-E.2 (L. K.)

$$z = z(T_r, P_r); \quad \Rightarrow z = 0.905;$$

$$\forall = \frac{zmRT}{P}; \quad \Rightarrow \forall = \frac{(0.905)(1)(0.4615)(273+1000)}{100000};$$

$$\Rightarrow \forall = 0.0053\ \text{m}^3; \quad \Rightarrow \forall = 5.3\ \text{L}$$

(b) Using Figure-E.5 (N. O.)

$$z = z(T_r, P_r); \quad \Rightarrow z = 0.905;$$

$$\forall = \frac{zmRT}{P}; \quad \Rightarrow \forall = \frac{(0.905)(1)(0.4615)(273+1000)}{100000};$$

$$\Rightarrow \forall = 0.0053\ \text{m}^3; \quad \Rightarrow \forall = 5.3\ \text{L}$$

(c) Using the PC model and Table-B.3

$$v = v(T, P); \qquad \Rightarrow v = 0.005\ \frac{\text{m}^3}{\text{kg}};$$

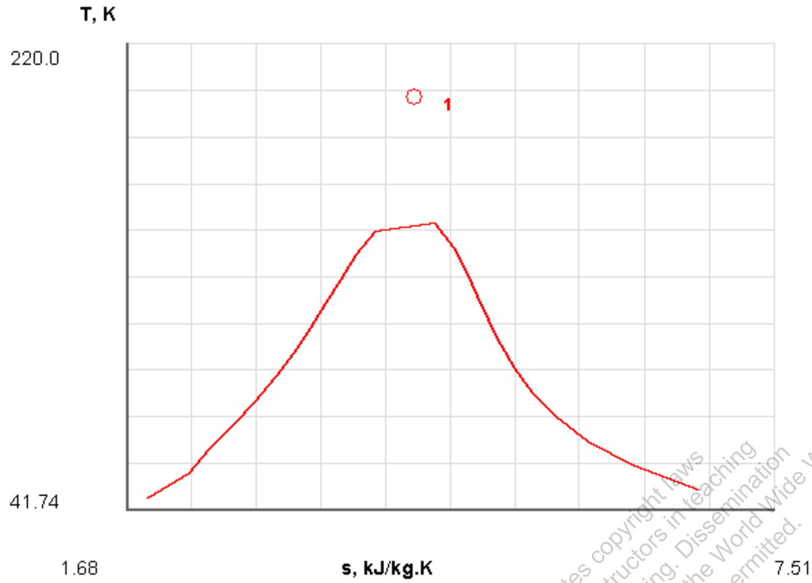
$$\cancel{V} = mv; \qquad \Rightarrow \cancel{V} = (1)(0.005); \qquad \Rightarrow \cancel{V} = 0.005\ \text{m}^3; \qquad \Rightarrow \cancel{V} = 5\ \text{L}$$

TEST Solution:

Launch the RG 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).

3-5-11 [BXQ] Predict the pressure of oxygen gas having a temperature of 200 K and a specific volume of 0.001726 m^3/kg using the real gas model. What-if Scenario: What would the pressure be if we used (b) the ideal gas equation of state, (c) the van der Waals equation, ~~(d) the BWR equation, or (e) the phase-change model~~?

SOLUTION



Using Table-C for oxygen

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

(a) With pressure unknown, we will separate the variables dependent on pressure in the real gas equation

$$\frac{P}{z} = \frac{P}{z(P)}; \qquad \Rightarrow \frac{P}{z} = \frac{RT}{v}; \qquad \Rightarrow \frac{P}{z(P)} = \frac{RT}{v};$$

$$\Rightarrow \frac{P}{z(P)} = \frac{(0.2598)(200)}{0.001726}; \qquad \Rightarrow \frac{P}{z(P)} = 30.1\ \text{MPa};$$

Using an iterative process and The L.K. chart to solve the two unknowns, the real gas equation is satisfied when

$z = 0.6935, \quad P = 20.9\ \text{MPa}$

(b) $$p = \frac{RT}{v}; \qquad \Rightarrow p = \frac{(0.2598)(200)}{0.001726}; \qquad \Rightarrow p = 30.1\ \text{MPa}$$

(c) Using Table E-1

$T_{cr} = 154.8$ K;

$p_{cr} = 5.08$ MPa;

$$a = \frac{27R^2T_{cr}^{\ 2}}{64p_{cr}}; \quad \Rightarrow a = \frac{27(0.2598)^2(154.8)^2}{64(5080)}; \quad \Rightarrow a = 0.13432 \text{ m}^6;$$

$$b = \frac{RT}{8p_{cr}}; \quad \Rightarrow b = \frac{(0.2598)(154.8)}{8(5080)}; \quad \Rightarrow b = 0.0009896 \text{ m}^3;$$

$$\left(p + \frac{a}{v^2}\right)(v-b) = RT; \quad \Rightarrow p = \frac{RT}{(v-b)} - \frac{a}{v^2}; \quad \Rightarrow p = \frac{(0.2598)(200)}{(0.001726 - 0.0009896)} - \frac{0.13432}{(0.001726)^2};$$

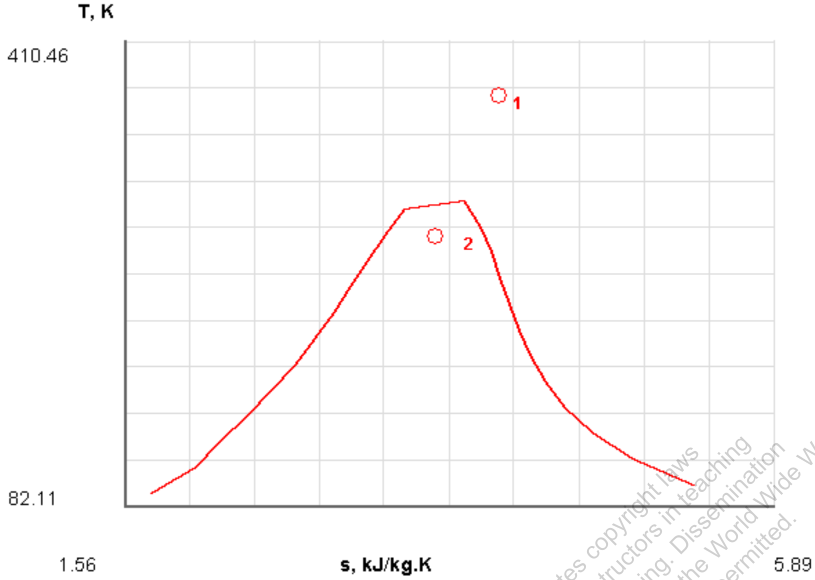
$$\Rightarrow p = 25.47 \text{ MPa}$$

TEST Solution:

Launch the RG 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).

3-5-12 [JL] A closed rigid tank contains carbon-dioxide at 10 MPa and 100°C. It is cooled until its temperature reaches 0°C. Determine the pressure at the final state (p_2). Use (a) the RG model with the Lee-Kesler chart, (b) the RG model with the Nelson-Obert chart and (b) the PC model.

SOLUTION



Using the RG model for carbon-dioxide and Table-E1:

$$P_r = \frac{P}{P_{cr}}; \quad \Rightarrow P_r = \frac{10}{7.39}; \quad \Rightarrow P_r = 1.35;$$

$$T_r = \frac{T}{T_{cr}}; \quad \Rightarrow T_r = \frac{(100+273.15)}{304.2}; \quad \Rightarrow T_r = 1.23;$$

Using Table-C:

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

(a) Using Figure-E.2 (L. K.):

$$z = z(T_r, P_r); \quad \Rightarrow z = z(1.23,\ 1.35); \quad \Rightarrow z = 0.72245;$$

Using the RG equation of state

$$v = \frac{zRT}{p}; \quad \Rightarrow v = \frac{(0.72245)(0.1889)(100+273.15)}{10000}; \quad \Rightarrow v = 0.00509 \ \frac{\text{m}^3}{\text{kg}};$$

v remains constant and with pressure unknown, we will separate the variables dependent on pressure in the real gas equation

$$\frac{P}{z} = \frac{P}{z(P)}; \quad \Rightarrow \frac{P}{z} = \frac{RT}{v}; \quad \Rightarrow \frac{P}{z(P)} = \frac{RT}{v};$$

$$\Rightarrow \frac{P}{z(P)} = \frac{(0.1889)(273.15)}{0.00509}; \quad \Rightarrow \frac{P}{z(P)} = 10.1 \text{ MPa};$$

Using an iterative process and The L.K. chart to solve the two unknowns, the real gas equation is satisfied when
$z = 0.38214, \; P = 3.872 \text{ MPa}$

(b) Using Figure-E.5 (N. O.):

$$z = z(T_r, P_r); \quad \Rightarrow z = z(1.23, \; 1.35); \quad \Rightarrow z = 0.72372;$$

Using the RG equation of state

$$v = \frac{zRT}{p}; \quad \Rightarrow v = \frac{(0.72372)(0.1889)(100 + 273.15)}{10000}; \quad \Rightarrow v = 0.005101 \; \frac{\text{m}^3}{\text{kg}};$$

v remains constant and with pressure unknown, we will separate the variables dependent on pressure in the real gas equation

$$\frac{P}{z} = \frac{P}{z(P)}; \quad \Rightarrow \frac{P}{z} = \frac{RT}{v}; \quad \Rightarrow \frac{P}{z(P)} = \frac{RT}{v};$$

$$\Rightarrow \frac{P}{z(P)} = \frac{(0.1889)(273.15)}{0.005101}; \quad \Rightarrow \frac{P}{z(P)} = 10.1 \text{ MPa};$$

Using an iterative process and The L.K. chart to solve the two unknowns, the real gas equation is satisfied when
$z = 0.38281, \; P = 3.872 \text{ MPa}$

(c) PC-Model

State-1

$$v_1 = (p, \; T); \quad \Rightarrow v_1 = (10 \text{ MPa}, \; 100°\text{C}); \quad \Rightarrow v_1 = 0.0053 \; \frac{\text{m}^3}{\text{kg}};$$

State-2

$$v_2 = v_1; \quad \Rightarrow v_2 = 0.0053 \; \frac{\text{m}^3}{\text{kg}};$$

$$p = (T, \; v); \quad \Rightarrow p = \left(0°\text{C}, \; 0.0053 \; \frac{\text{m}^3}{\text{kg}}\right); \quad \Rightarrow p = 3.48 \text{ MPa}$$

TEST Solution:

Launch the RG 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).

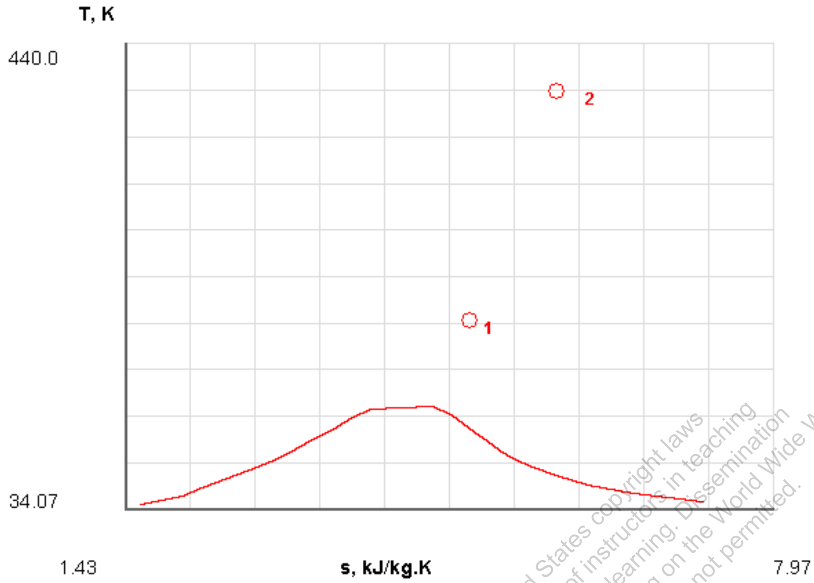
3-5-13 [JZ] A 15 L tank contains 1 kg of R-12 refrigerant at 100°C. It is heated until the temperature of the refrigerant reaches 150°C. Determine the change in (a) internal energy (ΔU), and (b) entropy, (ΔS). Use the RG model with Lee-Kesler charts.

TEST Solution:

Launch the RG 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).

3-5-14 [JI] A piston cylinder device contains 10 L of nitrogen at 10 MPa and 200 K. It is heated at a constant pressure to a temperature of 400 K. Determine (a) ΔH and (b) ΔS. Use the RG model with Lee-Kesler charts. (c) What-if Scenario: What would the answers be if the PC model were used? If the PC model is always more accurate, then why should anyone use the RG model at all?

SOLUTION



Using Table-C for nitrogen

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

$$c_p = 1.039 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

Using the RG model for oxygen and Table-E1

$$P_r = \frac{P}{P_{cr}}; \quad \Rightarrow P_r = \frac{10}{3.39}; \quad \Rightarrow P_r = 2.95;$$

$$T_{r,1} = \frac{T}{T_{cr}}; \quad \Rightarrow T_{r,1} = \frac{200}{126.2}; \quad \Rightarrow T_{r,1} = 1.58;$$

$$T_{r,2} = \frac{T}{T_{cr}}; \quad \Rightarrow T_{r,2} = \frac{400}{126.2}; \quad \Rightarrow T_{r,2} = 3.17;$$

Using Figure-E.2 (L. K.)

$$z_1 = z(T_r, P_r); \quad \Rightarrow z_1 = 0.8348;$$

Real Gas equation of state

$$m = \frac{P\cancel{V}}{z_1 RT}; \qquad \Rightarrow m = \frac{(10000)\left(\frac{10}{1000}\right)}{(0.8348)(0.2968)(200)}; \qquad \Rightarrow m = 2.02 \text{ kg};$$

Using the RG model and Table-E.3

$$z_{h,1} = z\left(T_{r,1}, P_r\right); \qquad \Rightarrow z_{h,1} = 1.33;$$

$$z_{h,2} = z\left(T_{r,1}, P_r\right); \qquad \Rightarrow z_{h,2} = 0.245;$$

Using the RG model and Table-E.4

$$z_{s,1} = z\left(T_{r,1}, P_r\right); \qquad \Rightarrow z_{s,1} = 0.64;$$

$$z_{s,2} = z\left(T_{r,1}, P_r\right); \qquad \Rightarrow z_{s,2} = 0.11;$$

(a) Using the definition of the enthalpy departure factor

$$z_h = \frac{h^{IG} - h}{RT_{cr}}; \qquad \Rightarrow \Delta h = \Delta h^{IG} - RT_{CR}\Delta z_h;$$

$$\Delta h = \Delta h^{IG} - RT_{cr}\Delta z_h; \qquad \Rightarrow \Delta h = c_p\left(T_2 - T_1\right) - RT_{cr}\Delta z_h;$$

$$\Rightarrow \Delta h = 1.039(400 - 200) - 0.2968(126.2)(0.245 - 1.33);$$

$$\Rightarrow \Delta h = 248.44 \ \frac{\text{kJ}}{\text{kg}};$$

$$\Delta H = m\Delta h; \qquad \Rightarrow \Delta H = 2.02(248.44); \qquad \Rightarrow \Delta H = 501.8 \text{ kJ}$$

(b) Using the definition of the entropy departure factor

$$z_s = \frac{s^{IG} - s}{R}; \qquad \Rightarrow \Delta s = \Delta s^{IG} - R\Delta z_s;$$

$$\Delta s = \Delta s^{IG} - R\Delta z_s; \qquad \Rightarrow \Delta s = c_p \ln\frac{T_2}{T_1} - R\Delta z_s;$$

$$\Rightarrow \Delta s = 1.039\ln\frac{400}{200} - 0.2968(0.11 - 0.64); \qquad \Rightarrow \Delta s = 0.877 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

$$\Delta S = m\Delta s; \qquad \Rightarrow \Delta S = 2.02(0.877); \qquad \Rightarrow \Delta S = 1.77 \ \frac{\text{kJ}}{\text{K}}$$

Using Table-B.14 and the PC model for nitrogen
State-1: (p = 10 MPa, T = 200 K)

$$v = v(p,T); \qquad \Rightarrow v = 0.00501 \ \frac{\text{m}^3}{\text{kg}};$$

$$h_1 = h(P,T); \qquad \Rightarrow h_1 = -150.9 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_1 = s(P,T); \qquad \Rightarrow s_1 = 4.86 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

State-2: (p = 10 MPa, T = 400 K)

$$h_2 = h(P,T); \qquad \Rightarrow h_2 = 97.55 \ \frac{\text{kJ}}{\text{kg}};$$

$$s_2 = s(P,T); \qquad \Rightarrow s_2 = 5.75 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}};$$

(c.1) Enthalpy

$$H_{PC} = m\Delta h; \qquad \Rightarrow H_{PC} = \frac{\cancel{V}}{v}(h_2 - h_1); \qquad \Rightarrow H_{PC} = \frac{\left(\frac{10}{1000}\right)}{0.00501}(97.55 - 150.9);$$

$$\Rightarrow H_{PC} = 495.9 \text{ kJ}$$

(c.2) Entropy

$$S_{PC} = m\Delta s; \qquad \Rightarrow S_{PC} = \frac{\cancel{V}}{v}(s_2 - s_1);$$

$$\Rightarrow S_{PC} = \frac{\left(\frac{10}{1000}\right)}{0.00501}(5.75 - 4.86); \qquad \Rightarrow S_{PC} = 1.77 \text{ kJ}$$

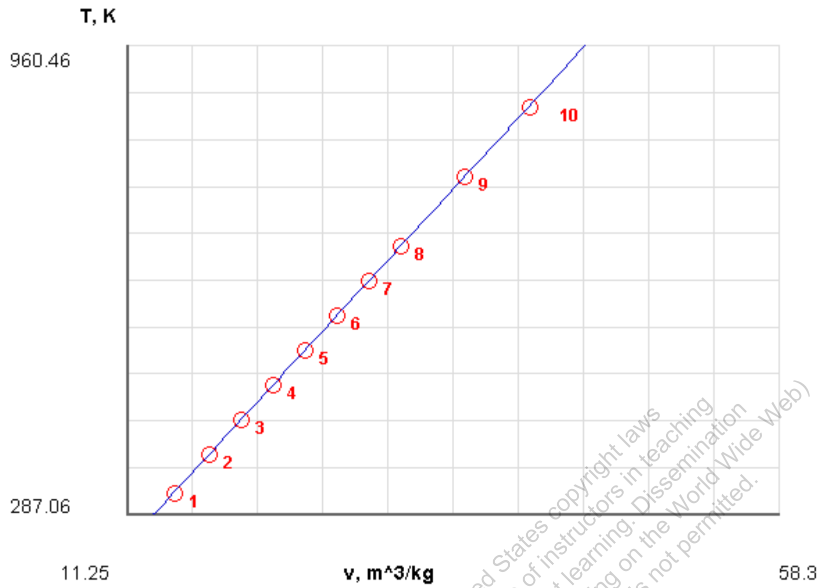
TEST Solution:

Launch the RG 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).

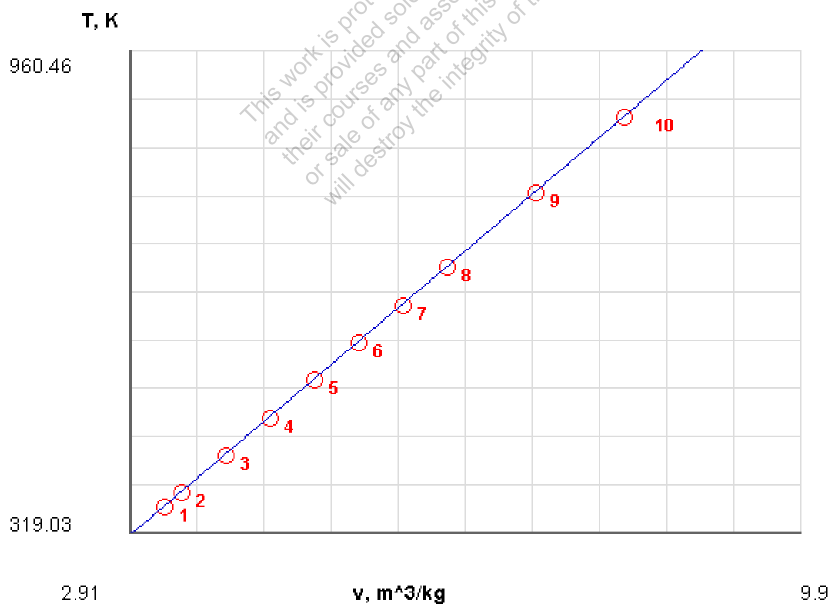
3-5-15 [JG] For H_2O, plot how the specific volume (v), varies with T in the superheated vapor region for a pressure of (a) 10 kPa, (b) 50 kPa and (c) 10 MPa. Take at least 10 points from the saturation temperature to 600°C. To reduce the data into a simple correlation, plot pv against T. (d) Explain the behavior of the reduced data.

SOLUTION

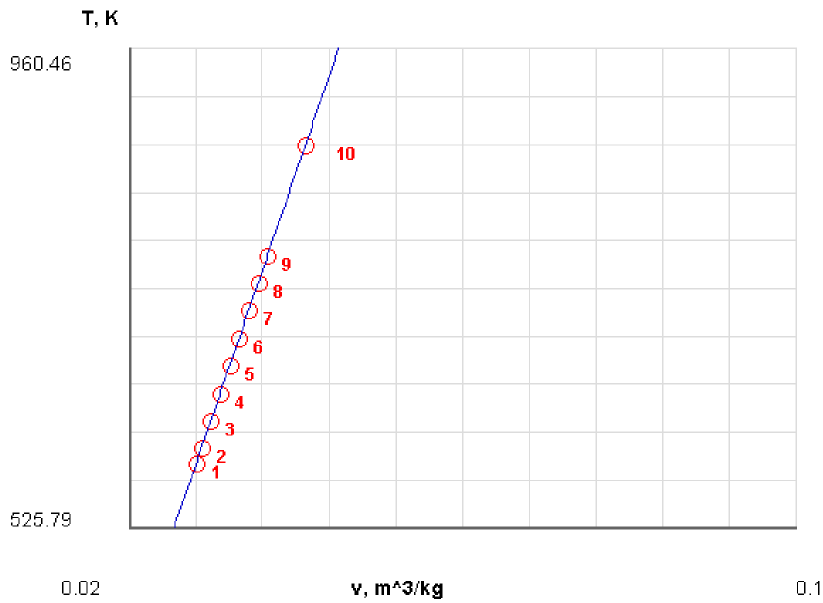
(a) 10 kPa



(b) 50 kPa



(c) 10 MPa



(d)

10 kPa

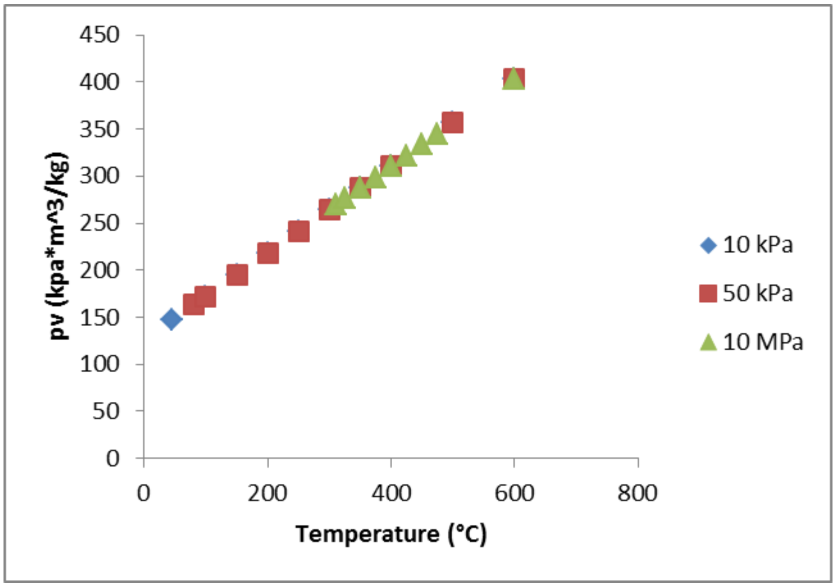
T	v	pv
45.81	14.7	147
100	17.216	172.16
150	19.52	195.2
200	21.83	218.3
250	24.1369	241.369
300	26.44	264.4
350	28.75	287.5
400	31.057	310.57
500	35.6713	356.713
600	40.285	402.85

50 kPa

T	v	pv
81.33	3.27	163.5
100	3.44	172
150	3.9	195
200	4.37	218.5
250	4.83	241.5
300	5.29	264.5
350	5.75	287.5
400	6.21	310.5
500	7.13	356.5
600	8.06	403

10 MPa

T	v	pv
311.06	0.02695	269.5
325	0.0276	276
350	0.02875	287.5
375	0.0299	299
400	0.03106	310.6
425	0.03221	322.1
450	0.03336	333.6
475	0.03452	345.2
500	0.03567	356.7
600	0.04029	402.9



pv is a constant that increases with temperature

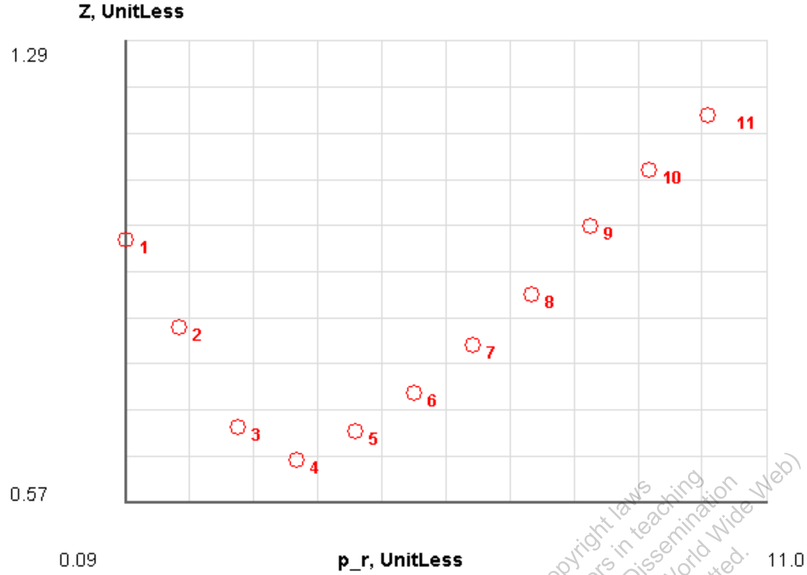
TEST Solution:

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).

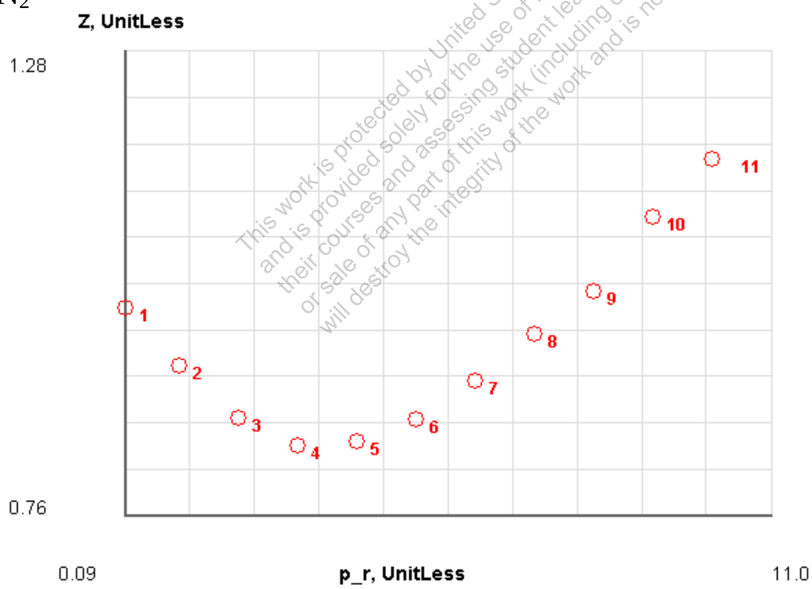
3-5-16 [JK] Use the RG model (Lee-Kesler) to generate *v* vs *p* data for (a) O_2 and (b) N_2 at 200 K over the reduced pressure range of 0.1 to 10. Evaluate *Z* and plot it against p_r.

SOLUTION

(a) O_2



(b) N_2



TEST Solution:

Launch the RG 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).