ME 24-221
Thermodynamics I

Solution to Assignment No: 2
Due Date: 15 September 2000
Fall 2000
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3.9 A 1-m^3 rigid tank with air at 1 MPa, 400 K is connected to an air line as shown in Fig. P3.9. The valve is opened and air flows into the tank until the pressure reaches 5 MPa, at which point the valve is closed and the temperature inside is 450K.
a. What is the mass of air in the tank before and after the process?
b. The tank eventually cools to room temperature, 300 K. What is the pressure inside the tank then?

Solution:

P, T known at both states and assume the air behaves as an ideal gas.

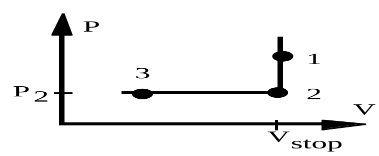
$$m_{air1} = \frac{P_1 V}{RT_1} = \frac{1000 \times 1}{0.287 \times 400} = \mathbf{8.711\ kg}$$

$$m_{air2} = \frac{P_2 V}{RT_2} = \frac{5000 \times 1}{0.287 \times 450} = \mathbf{38.715\ kg}$$

Process 2 $\rightarrow$ 3 is constant V, constant mass cooling to T_3

$$P_3 = P_2 \times (T_3/T_2) = 5000 \times (300/450) = \mathbf{3.33\ MPa}$$

3.11 A piston/cylinder arrangement, shown in Fig. P3.11, contains air at 250 kPa, 300°C. The 50-kg piston has a diameter of 0.1 m and initially pushes against the stops. The atmosphere is at 100 kPa and 20°C. The cylinder now cools as heat is transferred to the ambient.
a. At what temperature does the piston begin to move down?
b. How far has the piston dropped when the temperature reaches ambient?
Solution:



Piston $A_p = \frac{\pi}{4} \times 0.1^2 = 0.00785\ m^2$

Balance forces when piston floats:

$$P_{float} = P_o + \frac{m_p g}{A_p} = 100 + \frac{50 \times 9.807}{0.00785 \times 1000}$$
$$= 162.5\ kPa = P_2 = P_3$$

To find temperature at 2 assume ideal gas:

$$T_2 = T_1 \times \frac{P_2}{P_1} = 573.15 \times \frac{162.5}{250} = \mathbf{372.5\ K}$$

b) Process 2 -> 3 is constant pressure as piston floats to $T_3 = T_o = 293.15$ K

$$V_2 = V_1 = A_p \times H = 0.00785 \times 0.25 = 0.00196\ m^3 = 1.96\ L$$

Ideal gas and $P_2 = P_3$ => $V_3 = V_2 \times \frac{T_3}{T_2} = 1.96 \times \frac{293.15}{372.5} = \mathbf{1.54\ L}$

$$\Delta H = (V_2 - V_3)/A = (1.96-1.54) \times 0.001/0.00785 = \mathbf{0.053\ m = 5.3\ cm}$$

3.16 A cylinder is fitted with a 10-cm-diameter piston that is restrained by a linear spring (force proportional to distance) as shown in Fig. P3.16. The spring force constant is 80 kN/m and the piston initially rests on the stops, with a cylinder volume of 1 L. The valve to the air line is opened and the piston begins to rise when the cylinder pressure is 150 kPa. When the valve is closed, the cylinder volume is 1.5 L and the temperature is 80°C. What mass of air is inside the cylinder?

Solution:

$F_s = k_s \Delta x = k_s\ \Delta V/A_p$; $V_1 = 1$ L $= 0.001$ m^3, $A_p = \frac{\pi}{4} 0.1^2 = 0.007854$ m^2

State 2: $V_3 = 1.5$ L $= 0.0015$ m^3; $T_3 = 80°C = 353.15$ K

The pressure varies linearly with volume seen from a force balance as:

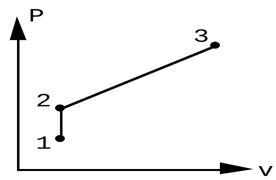
$$PA_p = P_0\ A_p + m_p\ g + k_s(V - V_0)/A_p$$

Between the states 1 and 2 only volume varies so:

$$P_3 = P_2 + \frac{k_s(V_3\text{-}V_2)}{A_p^{\ 2}} = 150 + \frac{80\times10^3(0.0015 - 0.001)}{0.007854^2 \times 1000}$$

$= 798.5$ kPa

$$m = \frac{P_3V_3}{RT_3} = \frac{798.5 \times 0.0015}{0.287 \times 353.15} = \mathbf{0.012\ kg}$$



3.26 Determine the quality (if saturated) or temperature (if superheated) of the following substances at the given two states:

Solution:

a) Water, H_2O, use Table B.1.1 or B.1.2

1) 120°C, 1 m^3/kg => $v > v_g$ superheated vapor, T = 120 °C

2) 10 MPa, 0.01 m^3/kg => two-phase $v < v_g$

$x = (0.01 – 0.001452) / 0.01657 = 0.516$

b) Nitrogen, N_2, table B.6

1) 1 MPa, 0.03 m^3/kg => superheated vapor since $v > v_g$

Interpolate between sat. vapor and superheated vapor B.6.2:

$T \cong 103.73 + (0.03\text{-}0.02416)\times(120\text{-}103.73)/(0.03117\text{-}0.02416) =$ **117 K**

2) 100 K, 0.03 m^3/kg => sat. liquid + vapor as two-phase $v < v_g$

$v = 0.03 = 0.001452 + x \times 0.029764 \Rightarrow$ **x = 0.959**

c) Ammonia, NH_3, table B.2

1) 400 kPa, 0.327 m^3/kg => $v > v_g = 0.3094$ m^3/kg at 400 kPa

Table B.2.2 superheated vapor $T \cong 10$ °C

2) 1 MPa, 0.1 m^3/kg => $v < v_g$ 2-phase roughly at 25 °C

$x = (0.1 – 0.001658) / 0.012647 = 0.7776$

d) R-22, table B.4

1) 130 kPa, 0.1 m^3/kg => sat. liquid + vapor as $v < v_g$

$v_f \cong 0.000716$ m^3/kg, $v_g \cong 0.1684$ m^3/kg

$v = 0.1 = 0.000716 + x \times 0.16768 \Rightarrow x = 0.592$

2) 150 kPa, 0.17 m^3/kg => $v > v_g$ superheated vapor, $T \cong 0°C$

3.30 Find the phase, quality *x* if applicable and the missing property *P* or *T*.

Solution:

a. H_2O $T = 120°C$ $v = 0.5\ m^3/kg\ < v_g$ Table B.1.1

sat. liq. + vap. P = **198.5 kPa,** x = (0.5 - 0.00106)/0.8908 = 0.56

b. H_2O $P = 100$ kPa $v = 1.8\ m^3/kg$ Table B.1.2 $v > v_g$

sup. vap., interpolate in Table B.1.3

$$T = \frac{1.8 - 1.694}{1.93636 - 1.694}(150 - 99.62) + 99.62 = \mathbf{121.65\ °C}$$

c. H_2O $T = 263$ K $v = 200\ m^3/kg$ Table B.1.5

sat. solid + vap., P = **0.26 kPa**, x = (200-0.001)/466.756 = 0.4285

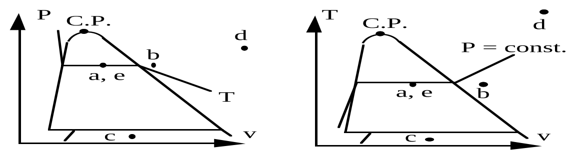
d. Ne $P = 750$ kPa $v = 0.2\ m^3/kg$; Table A.5

ideal gas, $T = \frac{Pv}{R} = \frac{750 \times 0.2}{0.41195} = \mathbf{364.1\ K}$

e. NH_3 $T = 20°C$ $v = 0.1\ m^3/kg$ Table B.2.1

sat. liq. + vap. , P = **857.5 kPa,** x = (0.1-0.00164)/0.14758 = 0.666

States shown are placed relative to the two-phase region, not to each other.



3.31 Give the phase and the missing properties of *P*, *T*, *v* and *x*.

Solution:

a. R-22 $T = 10°C$ $v = 0.01\ m^3/kg$ Table B.4.1

sat. liq. + vap. P = 680.7 kPa, x = (0.01-0.0008)/0.03391 = 0.2713

b. H_2O $T = 350°C$ $v = 0.2\ m^3/kg$ Table B.1.1 $v > v_g$

sup. vap. P ≅ 1.40 MPa, x = undefined

c. CO_2 $T = 800$ K $P = 200$ kPa Table A.5

ideal gas $v = \frac{RT}{P} = \frac{0.18892 \times 800}{200} = 0.756\ m^3/kg$

d. N_2 $T = 200$ K $P = 100$ kPa Table B.6.2 T > Tc

sup. vap. $v = 0.592\ m^3/kg$

e. CH_4 $T = 190$ K $x = 0.75$ Table B.7.1 P = 4520 kPa

sat. liq + vap. $v = 0.00497 + x \times 0.003 = 0.00722\ m^3/kg$

States shown are placed relative to the two-phase region, not to each other.