

ME 201

Thermodynamics

Homework #4 Solutions

1. (3 pts) Assuming an ideal gas calculate the specific volume in the appropriate units for:

a. N₂ at 500 kPa and 900 K

b. Neon at 1 psia and 500 R

c. Air at 14.7 psia and 72°F

Solution: We will use $v = \frac{R_u T}{MW \cdot P}$ with the molecular weight coming from Table A-1 or Table A-1E.

a. MW = 28.013 $R_u = 8.314 \text{ kPa} \cdot \text{m}^3 / (\text{kgmole} \cdot \text{K})$

$$v = (8.314)(900) / [(28.013)(500)] = 0.534 \text{ m}^3/\text{kg}$$

b. MW = 20.183 $R_u = 10.73 \text{ psia} \cdot \text{ft}^3 / (\text{lb}_m \text{mole} \cdot \text{R})$

$$v = (10.73)(500) / [(20.183)(1)] = 265.82 \text{ ft}^3/\text{lb}_m$$

c. MW = 28.97 $R_u = 10.73 \text{ psia} \cdot \text{ft}^3 / (\text{lb}_m \text{mole} \cdot \text{R})$

$$v = (10.73)(460+72) / [(28.97)(14.7)] = 13.40 \text{ ft}^3/\text{lb}_m$$

2. (5 pts) Calculate the specific internal energy change for H₂ by assuming a temperature variation in c_v (i.e., integrating) at 700 kPa as its temperature changes from 350 K to 1300 K.

Solution: Recall from class that we have

$$\Delta u = \int_{T_1}^{T_2} c_v dT$$

but

$$\begin{aligned} c_v &= c_p - R = \frac{1}{MW} [a + bT + cT^2 + dT^3] - R \\ &= \frac{1}{MW} [(a - R_u) + bT + cT^2 + dT^3] \end{aligned}$$

so substituting

$$\begin{aligned}\Delta u &= \frac{1}{MW} \int_{T_1}^{T_2} \left[(a - R_u) + bT + cT^2 + dT^3 \right] dT \\ &= \frac{1}{MW} \left[(a - R_u)(T_2 - T_1) + \frac{b}{2}(T_2^2 - T_1^2) + \frac{c}{3}(T_2^3 - T_1^3) + \frac{d}{4}(T_2^4 - T_1^4) \right]\end{aligned}$$

From Tables A-1 and A-2(c) we have for H₂

$$MW = 2.016, a = 29.11, b = -0.1916 \times 10^{-2}, c = 0.4003 \times 10^{-5}, d = -0.8704 \times 10^{-9}$$

Now substituting

$$\begin{aligned}\Delta u &= \frac{1}{2.016} \left[(29.11 - 8.314)(1300 - 350) + \frac{-0.1916 \times 10^{-2}}{2} (1300^2 - 350^2) \right. \\ &\quad \left. + \frac{0.4003 \times 10^{-5}}{3} (1300^3 - 350^3) + \frac{-0.8704 \times 10^{-9}}{4} (1300^4 - 350^4) \right] \\ &= 10,174 \text{ kJ/kg}\end{aligned}$$

3. (6 pts) Calculate the specific enthalpy change (in the appropriate units) for the following ideal gas processes by first using an average c_p and then by using the ideal gas tables.

- CO₂ at 2000 kPa goes from 500 K to 1300 K
- CO₂ at 2000 kPa goes from 500 K to 600 K
- Air at 40 psia and 270°F goes to 11 psia and 270°F

Solution:

(a).

(i) At $(500+1300)/2 = 900$ K, we have $c_{p,avg} = 1.204$ kJ/(kg·K) from Table A-2(b), then

$$\Delta h = c_{p,avg} \Delta T = (1.204)(1300 - 500) = 963.2 \text{ kJ/kg}$$

(ii) From Table A-20, $\bar{h}(500\text{K}) = 17,678$ kJ/kgmole, $\bar{h}(1300\text{K}) = 59,522$ kJ/kgmole

$$\Delta h = \{ \bar{h}(1300\text{K}) - \bar{h}(500\text{K}) \} / MW = \{ 59,522 - 17,678 \} / 44.01 = 950.8 \text{ kJ/kg}$$

(b).

(i) At $(600+500)/2 = 550$ K, we have $c_{p,avg} = 1.046$ kJ/(kg·K) from Table A-2(b), then

$$\Delta h = c_{p,avg} \Delta T = (1.046)(600 - 500) = 104.6 \text{ kJ/kg}$$

(ii) From Table A-20, $\bar{h}(600\text{K}) = 22,280$ kJ/kgmole, $\bar{h}(500\text{K}) = 17,678$ kJ/kgmole

$$\Delta h = \{ \bar{h}(600\text{K}) - \bar{h}(500\text{K}) \} / MW = \{ 22,280 - 17,678 \} / 44.01 = 104.6 \text{ kJ/kg}$$

Note how much closer the Δh 's are when the temperature change is smaller.

(c) Since for an ideal gas the enthalpy only depends on the temperature, $\Delta h = 0$ Btu/lb_m for both cases

4. (4 pts) Carefully draw the following graph using air as an ideal gas.

a. temperature versus pressure showing lines of constant specific volume and specific enthalpy

