ME 201
Thermodynamics

Homework #5 Solutions

1. (5 pts) Calculate the entropy change for N_2 as it goes from 250 K and 1000 kPa to 1300 K and 60 kPa.

Solution:

Substance Type: Ideal Gas (N_2)

Problem Type: Process

State 1	State2
$T_1 = 250$ K	$T_2 = 1300$ K
$P_1 = 1000$ kPa	$P_2 = 60$ kPa

Using our air tables the entropy change will be given by

$$\Delta s = \phi_2 - \phi_1 - R \cdot \ln\left(\frac{P_2}{P_1}\right)$$

From the N_2 tables we have

$$\phi_2 = 236.831 / 28.013 = 8.454 \text{ kJ / kg} \cdot \text{K}$$

$$\phi_1 = 186.370 / 28.013 = 6.653 \text{ kJ / kg} \cdot \text{K}$$

The gas constant for N_2 is $R = 0.2968$ kJ/kg·K, so that upon substituting we get

$$\Delta s = 8.454 - 6.653 - (0.2968)\ln\left(\frac{60}{1000}\right) = 2.636 \text{ kJ / kg} \cdot \text{K}$$

2. (20 pts) For the two processes given below, determine the final temperature, pressure, specific volume, and the changes in internal energy, enthalpy, and entropy.

a. Air at 8400 R and 66 psia goes isothermally to 1.7 psia.

Solution:

Substance Type: Ideal Gas (Air)

Problem Type: Process (Isothermal)

State 1	State2
T_1 = 8400 R	T_2 = **8400 R**
P_1 = 66 psia	P_2 = 1.7 psia

Bold values are calculated

We note that to fix state 2 we need another property, but since the process is isothermal we must have

$$T_2 = T_1 = 8400\text{ R}$$

Then the final specific volume can be calculated from the ideal gas law or

$$v_2 = \frac{RT_2}{P_2} = \frac{(10.73/28.97)(8400)}{1.7} = 1830\text{ ft}^3/\text{lb}_m$$

To calculate the property changes we find that for the air tables we do not go up to 8400 R. Fortunately, we know that since air is an ideal gas and the process is isothermal (no temperature change) we must have

$\Delta u = 0$ Btu/lb$_m$ and $\Delta h = 0$ Btu/lb$_m$

For the entropy change, we will have

$$\begin{aligned}\Delta s &= -R\cdot\ln\left(\frac{P_2}{P_1}\right)\\ &= -(1.986/28.97)\ln\left(\frac{1.7}{66}\right)\\ &= 0.251\text{ Btu/lb}_m\cdot\text{R}\end{aligned}$$

b. Helium at 3200°F and 1.3 atm goes isentropically to 435°F.

Solution:

Substance Type: Ideal Gas (Helium)
Problem Type: Process (Isentropic)

State 1	State2
T_1 = 3200°F = 3660 R	T_2 = 435°F = 895 R
P_1 = 1.3 atm = 19.11 psia	P_2 = **0.55 psia**

Bold values are calculated

We note that to fix state 2 we need another property, but since the process is isentropic, we will have

$$\Delta s = 0 = c_{P,avg} \cdot \ln\left(\frac{T_2}{T_1}\right) - R \cdot \ln\left(\frac{P_2}{P_1}\right)$$

We have written this in terms of our constant c_P because we do not have ideal gas tables for He. We will use the $c_{P,avg}$ from our table A-2E(a) at 80°F since He does not appear either on Table A-2E(b) or (c). This is appropriate because the c_P for inert gases, like He, do not depend on temperature. Solving for P_2

$$P_2 = P_1 \cdot \left(\frac{T_2}{T_1}\right)^{\frac{c_{P,avg}}{R}} = 19.11 \cdot \left(\frac{895}{3660}\right)^{\frac{1.25}{0.4961}} = 0.55 \text{ psia}$$

Now solving for the specific volume from the ideal gas law

$$v_2 = \frac{RT_2}{P_2}$$
$$= \frac{(10.73 / 4.003)(895)}{0.55} = 4{,}362 \ \text{ft}^3 / \text{lb}_m$$

Our internal energy change is

$$\Delta u = (c_P - R)(T_2 - T_1)$$
$$= (1.25 - 0.4961)(895 - 3660)$$
$$= -2085 \text{ Btu} / \text{lb}_m$$

and our enthalpy change is

$$\begin{aligned}\Delta h &= (c_P)(T_2 - T_1) \\ &= (1.25)(895 - 3660) \\ &= -3456 \text{ Btu / lb}_m\end{aligned}$$

3. (5 pts) Calculate the final temperature and change in specific internal energy as magnesium at 30 psia and 500°F goes insenthalpically to 90 psia.

Solution:

Substance Type: Incompressible (magnesium)
Problem Type: Process (isenthalpic, constant h)

State 1	State2
T_1 = 500°F = 960 R	T_2 = **960.1 R**
P_1 = 30 psia	P_2 = 90 psia

Bold values are calculated

We note that to fix state 2 we need another property, but since the process is isenthalpic, we will have

$$\Delta h = 0 = c_{P,avg}\left(T_2 - T_1\right) + v_{avg}\left(P_2 - P_1\right)$$

or solving for T_2

$$T_2 = T_1 - \frac{v_{avg}\left(P_2 - P_1\right)}{c_{P,avg}}$$

From Table A-3E(b) we find the density, ρ, of magnesium to be 108 ft^3/lb_m and the specific heat to be 0.238 Btu/(lb_m·R). These are given a room temperature, but that is the best we can do. Then

$$v_{avg} = \frac{1}{\rho} = \frac{1}{108} = 0.0093 \text{ ft}^3 / \text{lb}_m$$

and

$$T_2 = 960 - \frac{(1/108)(90-30)(144 \text{ in}^2/\text{ft}^2)}{(0.238)(778.17 \text{ ft}\cdot\text{lb}_f/\text{Btu})} = 959.6 \text{ R}$$

Then the change in internal energy is

$$\Delta u = c_{P,avg}\left(T_2 - T_1\right) = (0.238)(-0.4) = -0.103 \text{ Btu}/\text{lb}_m$$

4. (10 pts) Determine the changes in internal energy, enthalpy, and entropy as liquid petroleum at 70 kPa and 300 K goes to 100 kPa and 430 K.

Solution:

Substance Type: Incompressible (Liquid Petroleum)

Problem Type: Process

State 1	State2
$T_1 = 300$ K	$T_2 = 430$ K
$P_1 = 70$ kPa	$P_2 = 100$ kPa

For liquid petroleum, we only have c_P and ρ from Table A-3(a) at only one temperature. Taking that value, we have

$$c_{P,avg} = 2.0 \text{ kJ}/(\text{kg}\cdot\text{K})$$

$$\rho = 640 \text{ kg}/\text{m}^3$$

$$v_{avg} = \frac{1}{\rho} = \frac{1}{640} = 1.563 \text{ x } 10^{-3} \text{ m}^3/\text{kg}$$

which gives

$$\Delta u = c_{P,avg}(T_2 - T_1) = (2.0)(430 - 300) = 260 \text{ kJ}/\text{kg}$$

$$\Delta h = c_{P,avg}(T_2 - T_1) + v_{avg}(P_2 - P_1)$$

$$= (2.0)(430 - 300) + (1.563 \text{ x } 10^{-3})(100 - 70) = 260.05 \text{ kJ}/\text{kg}$$

$$\Delta s = c_{P,avg} \ln\left(\frac{T_2}{T_1}\right) = (2.0)\ln\left(\frac{430}{300}\right) = 0.72 \text{ kJ}/\text{kg}\cdot\text{K}$$