Engineering Thermodynamics

Problem Set I

1 – Calculate the partial pressure of carbon monoxide, P_{CO} from the following equation

$$18.2P_{CO}^2 + 96.2\, P_{CO} - 6.9 = 0$$

Hint: Use graphical and numerical methods and compare the solutions

2- Vapor pressure of Pb is related to temperature in the following form:

$$\log P_{Pb} = -10130/T - 0.985 \log T + 8.279$$

where P_{Pb} is in atmosphere and T is in Kelvin. Calculate the normal boiling point of lead where P_{Pb} = 1 atm

3 – The composition of Pb-Zn alloy for a special application was given by the following equation

$$2.08\, X^2 - 1.81\, X^3 + \log X = -0.4157$$

where X represents the mole fraction of zinc in the alloy ($0<X<0.5$). Find the mole fraction of Zn in a Pb-rich alloy that is suitable for the present application

4 – What pressure increase is needed to make a cubic block of magnesium metal retain its initial volume while it is being heated from 0 to 50^0C? The average linear expansion coefficient $\alpha_L = 2.5\text{x}10^{-7}\ K^{-1}$, the isothermal compressibility factor $\beta = 2.95\text{x}10^{-10}\ (N/cm^2)^{-1}$.

Hint: $dV=(\delta V/\delta T)dT + (\delta V/\delta P)dP$, $\alpha=1/V(\delta V/\delta T)_P$, $=-1/V(\delta V/\delta P)_T$

5 - A 5-g lead bullet moving at 200 m/s embeds itself into a wooden block. Half of its initial energy is absorbed by the bullet. What is the increase in temperature of the bullet?

6 - A solar collector has an area of 5 m^2 and the power of sunlight is delivered at 550 W/m^2. This power is used to increase the temperature of 200 g of water from 20^0C to 50^0C. How much time is required?

7 - How many grams of steam at 100^0C must be added to 30 g of ice at 0^0C in order to produce an equilibrium temperature of 40^0C?

8 - A large, insulated container holds 120 g of coffee at 85^0C. How much ice at 0^0C must be added to cool the coffee to 50^0C? Now, how much coffee at 100^0C must be added to return the contents to 85^0C? How many grams are finally in the container?

9 - What equilibrium temperature is reached when 2 lb of ice at 0^0F is dropped into a 3-lb aluminum cup containing 7.5 lb of water? The cup and water are initially at 200^0F.

10 - In an experiment to determine the latent heat of vaporization for water, a student measures the mass of an aluminum calorimeter cup to be 50 g. After a quantity of water is added, the combined mass of the water and cup is 120 g. The initial temperature of the cup and water is 18^0C. A quantity of steam at 100^0C is passed into the calorimeter, and the system is observed to reach equilibrium at 47.4^0C. The total mass of the final mixture is 124 g. What value will the student obtain for the heat of vaporization?

11 - Four 200-g blocks are constructed out of copper, aluminum, Silver, and Lead so that they have the same mass and the same base area (although of different heights). The temperature of each block is raised from 20^0C to 100^0C by applying heat at the rate of 200 J/s. Find the time required for each block to reach 100^0C.

12 - Each of the blocks in the previous example are placed on a large block of ice. Find out how much ice is melted by each block when all reach equilibrium at 0^0C? Which sinks deepest and which sinks the least?

13 Show that $C_P - C_V = \beta^2 VT/\kappa$ for any material

14 Two moles of an ideal gas at 3 atm and 300 K in a cylinder fitted with a piston is compressed isothermally to half of the initial volume by an external pressure of 7 atm. Find the change in internal energy,heat and work

15 A sample of gas initially occupies a volume of 1 liter under a pressure of 1 atm. The gas

is reversibly taken through the following cycle:

a. Heated at constant volume until P=2 atm
b. Heated at constant pressure until V=2 liters
c. Cooled at constant volume until P=1 liter
d. Cooled at constant pressure until V=1 liter

Calculate the total change in internal energy, heat and work for the complete cycle

16 -Calculate the isothermal enthalpy change at 1000 K for the following process at 298 K

$Pb(l) + CO_2(g) = PbO(s) + CO(g)$

CO(g) ΔH_{298}=-110510 J/mol Cp= 28.42 + 0.0041T – 46000/T^2 J/molK

CO2(g) ΔH_{298}=-394000 J/mole, Cp=44.3+0.0088T-860000/T^2 J/molK

PbO(s) ΔH_{298}=-219350 J/mole, Cp=37.9+0.0268T J/molK, $H_T - H_{298}$= -3508 + 28.46T J/mol

17 Calculate the standard enthalpy change fo the following reaction at 298 K:

$Al_2O3(s)+3H_2(g) \rightarrow 2Al(s)+3H_2O(g)$

ΔH_{298} (H_2O)= -285.8 J/mol

ΔH_{298} (Al_2O_3)= -1669.8 J/mol

18 Liquid copper at 1150 °C is being poured into a water cooled continous casting mould. Mould has $0.02 m^3$ of volume. The casting rate is $10\ cm^3/s$. Calculate the minimum flow rate of water entering at 15 °C, required to yield a discharge temperature of 80 °C. The average temperature at the bottom of the mould is 1083 °C and copper is in solid state

$C_p(Cu(l)) = 31.3$ J/mole.K
$\Delta H_m(Cu) = 13000$ J/mole at $T_m = 1083$ °C
$C_P(H_2O(l)) = 75.47$ J/mole.K

19 A mixture of 50% H_2, 25% CO, and 25% CO_2 by volume at 1 atm is passed into a reaction chamber at 727 C at a flow rate of $2\ m^3/min$. How much heat has to be given or taken through the walls of the reaction chamber in order to keep the temperature constant? Equilibrium between $CO\text{-}CO_2\text{-}H_2\text{-}H_2O$ is established inside the reaction chamber.
Take C_p for monatomic gases as 5/2R, C_p for diatomic gases as 7/2R and C_p for polyatomic gases as 4R

20 1 ton of limestone ($CaCO_3$) is calcined at 727 C according to reaction
$CaCO_3(s) = CaO(s) + CO_2(g)$
180 kg of coke containing 100% C was used as fuel. If limestone, coke and air enter the furnace at room temperature, calculate

a) The heat required for calcination
b) The heat available when coke is burned with air (21% O_2, 79% N_2) to yield an exhaust gas (CO_2-N_2) at 727 C
c) Thermal efficiency (ratio of the required heat to available heat of the process

$CaCO_3(s)$ ΔH_{298}=-1207 kJ/mole $C_p=104.57+0.02193T-2595000/T^2$ J/molK
C(s) $C_p=16.87+0.00477T-854000/T^2$ J/molK
CaO ΔH_{298}=-635.5 kJ/mole, $C_p=49.95+0.00489T-352000/T^2$ J/molK
$O_2(g)$ $C_p=29.97+0.00419T-167000/T^2$ J/moleK
$N_2(g)$ $C_p=27.88+0.00427T$ J/molK $(H_T-H_{298})= -8502+27.88T+0.00213T2$
$CO_2(g)$ $C_p=22.24+0.0598T-349900/T^2$ J/molK

21 One gram of supercooled liquid zinc at 400 C is in a container of large heat capacity. Find the enthalpy change of zinc during solidification
Zn(s) Cp=22.4 + 0.01005 J/molK ΔHm= 7388 J/mole at 420 C
Zn(l) Cp= 31.4 J/molK

22 Mg powder is condensed from a supercooled gaseous phase at 600 C in the production of magnesium by Pidgeon process. Calculate the enthalpy change for the system
Mg(s) $Cp=25.7 + 0.00628T + 327000/T^2$ J/molK, ΔHm= 9040 J/mol at 923K
Mg(l) Cp=30.98 J/molK, ΔHv=131860 J/mol at 1363K
Mg(g) Cp=20.80 J/molK