ASSIGNMENT-1

Subject- **Chemical Engg Thermodynamics**

1. A spherical ball of mass 10 kg is dropped from 15 m height. What is its potential energy at the time of release? Consider the potential energy of the ball is transformed into kinetic energy when it strikes the ground. Determine the velocity at which the ball strikes the ground.

2. A skin diver descends to a depth of 30 m in a salt lake where the density is 1030 kg/m^3. What is the pressure on the diver's body at this depth? .

3. A system consisting of a gas confined in a cylinder in a cylinder undergoes a series of processes shown in figure below. During the process A-1-B, 70 kJ of heat is added while it does 45 kJ of work. Then the system follows the process A-2-B during which 55 kJ of work is performed on the system. How much heat flows into the system during the process A-2-B. Then the system returns to the initial state along the path B-3-A and 80 kJ of work is done on the system. Calculate the amount of heat transferred between the system and the surroundings during process B-3-A.

4. 10 moles of an ideal gas at 37 C are allowed to expand isothermally from an initial pressure of 15 atm to a final pressure of 5 atms against a constant external pressure of 1 atm. Calculate ΔU, ΔH, Q, and W for the process.

5. In an adiabatic change for an ideal gas, show that the work done in an adiabatic expansion-

$$W = \frac{P_1V_1}{\gamma-1}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

6. 5 kg of N_2 is heated from an initial state of 37 C and 101.33 kPa until its temperature reaches 237C. Calculate ΔU, Q, W, and ΔH for the following processes-

   i) isochoric process

   ii) isobaric process

   N_2 is assumed to be an ideal gas. Given, C_P = 29.10 J/mole-K and C_V = 20.78 J/mole-K Molecular weight of nitrogen = 28

7. Find the second. Third and fourth virial coefficients of van der Walls equation of state

8. Calculate the pressure of 1.0 kmol of methane occupied a volume of 0.9 m^3 in a vessel at a constant temperature of 533 K by using a) ideal gas equation, b) van der Waals equation of state when a = 0.4233 Nm^4/mol^2 and b = 3.73 x 10^{-5} m^3/mol and c) Redlich-Kwong equation of state when P_C = 123.2 bar and T_C = 398 K

9. Calculate the acentric factor for ethanol. The vapour pressure of methanol can be estimated from the following equation-

$$\log_{10} P^{sat} = 8.1122 - \frac{1592.864}{t + 226.184}$$

10. The Berthelot equation of state is given by $\left(P+\frac{a}{TV^2}\right)(V-b)=RT$, where a and b are constants. Show that

$$a=\frac{27R^2T_C^{\ 3}}{64P_C},\ b=\frac{RT_C}{8P_C},\ Z_C=\frac{3}{8}$$ from the knowledge of point of inflexion at critical isotherms .

11. A Carnot engine working between a high-temperature source at 373 K and low temperature sink at 275 K and receives 50 kJ of heat from high-temperature region. Determine i) the minimum work required ii) efficiency and iii) amount of heat rejected

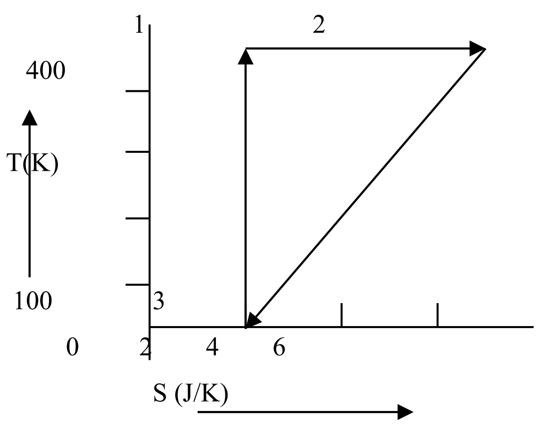
12. An ideal gas (Cp = 5 kcal/kmol^{0}C, Cv = 3 kcal/kmol^{0}C) is changed from 1 atm and 22.4 m^3 to 10 atm and 2.24 m^3 by the following reversible process:

a) Isothermal compression

b) Adiabatic compression followed by cooling at constant volume.

c) Heating at constant volume followed by cooling at constant pressure, Calculate Q, W, ΔU and ΔH of the overall process in each case.

13. Figure shows the relationship between temperature and entropy for a closed PVT system during a reversible process. Calculate the heat added to the system for each of the three steps 1-2. 2-3. 3-1 and for the entire process.



14. A steel casting at a temperature 725 K and weighing 35 kg is quenched in 150 kg oil at 275 K. If there is no heat losses, determine the change in entropy. The specific heat (Cp) of steel is 0.88 kJ/kg-K and that of oil is 2.5 kJ/kg-K.

15. The heat capacity at I atm pressure of solid magnesium in the temperature range of 0 to 560 °C is given by the expression

$$C_P=6.2+1.33\times10^{-3}T+6.78\times10^{4}T^{-2}\ \text{cal/deg. gm atom}$$

Determine the increase of entropy, per gm atom, for an increase of temperature from 300 K to 800 K at 1atm pressure.

16. Two iron blocks of same size are at distinct temperatures T_1 and T_2, brought in thermal contact with each other. The transfer process is allowed to take place until the thermal equilibrium is attained. Suppose, after the attainment of equilibrium, blocks are at final temperature ‘T’. Show that the change in entropy of the process is given by

$$\Delta S = C_P \ln\left[\frac{(T_2 - T_1)^2}{4T_1T_2} + 1\right]$$

17. Show that $\left(\frac{\partial U}{\partial V}\right)_T = \frac{T\beta}{\kappa} - P$,

where, β = coefficient of volume expansion and

κ = isothermal compressibility

18. Calculate the pressure in a cylinder having a volume of 360 litre and containing 70 kg of carbon dioxide gas at 62 ^{0}C. Assume CO_2 to obey a) ideal gas equation, b) van der Waals equation of state and c) virial equation of state, Z 1 + B/V, d) Redlich-Kwong equation of state when P_C = 73.83 bar, V_C = 94.0 cm^3/mol T_C = 304.2 K, and Z_C= 0.274

19. A perfect insulated container of volume V is divided into two equal halves by a partition. One side is under vacuum while the other side has one mol of an ideal gas (with constant heat capacity) at 298k. If the partition is removed, what is the final temperature of the gas in the container?

20. 100m^3 of carbon dioxide initially at 423K and 50 bar is to be isothermally compressed in a frictionless piston-cylinder device to a final pressure of 300 bar. Assuming ideal gas behaviour, calculate the a) work-done to compress the carbon dioxide gas, and b) heat flow on compression.

21. Prove that $\left(\frac{\partial \beta}{\partial P}\right)_T = -\left(\frac{\partial \alpha}{\partial T}\right)_P$,

where, β = coefficient of volume expansion and

α = isothermal compressibility

22. For a particular substance β = 1/T and α = 1/P. Obtain the equation of state f (P, V, T) = 0 for the substance.

23. A particular gas obeys the relation

$$\left(P + \frac{a}{TV^2}\right)(V - b) = RT$$

Where a, b and R are constants. Suppose the gas is allowed to expand reversibly and at constant temperature from V_1 to V_2, calculate the work done by the gas.

24. The isobaric molar heat capacity of ethane is given by

$$C_P = 4.493 + 182.229\times10^{-3}T - 74.843\times10^{-6}T^2 + 10.797\times10^{-6}T^2$$

Where C_P is in J/mol K and T in K . Calculate the energy required to raise the temperature of 100 mol methane from 298 K to 370 K at constant pressure.

25. A heat exchanger is to be designed to raise the temperature of 10 kmol per hour of ammonia from 300 K to 400 K. The inlet and exit pressure of ammonia in the heat exchanger are almost identical. Determine the amount of energy to be transferred to ammonia in the heat exchanger if the isobaric molar heat capacity of ammonia is given by

$$C_P = 29.747 + 25.108\times10^{-3}T - 1.546\times10^{5}T^{-2}$$

Where C_P is in J/mol K and T in K .

26. Two Carnot engines A and B operate in series between three thermal reservoirs. The engine A absorbs energy as heat from the reservoir at T_1 and rejects energy to a reservoir from the reservoir at T, while the engine B absorbs the same

amount of energy which is rejected by engine A, from the reservoir at T and rejects energy to the reservoir at T_2. If the engines A and B have the same efficiency, find a relation between T, T_1 and T_2.

27. It is planned to maintain a large lecture hall at 25^0C in Summer as well as in winter. The minimum temperature in winter is 3C while the maximum temperature in summer is 40 C. the rate of energy loss through the walls and roofing is estimated at 20 kJ/s. determine the minimum power required to maintain the hall in summer and in winter if the same device is used as a refrigerator in summer and as a heat pump in winter.
28. A Carnot refrigerator consumes 200 W power in summer when the ambient temperature is 40C. The rate at which energy is lost as heat is estimated at 15 W per degree Celsius temperature difference between the ambient and the cold space. Determine the cold space temperature, if the refrigerator is opening continuously.
29. Assume that the P-V-T relationship for nitrogen gas can be approximated by the ideal gas equation PV = nRT, where R = 8.314 kJ/kmolK. The heat capacities are C_V = 20.786 kJ/kmol K and Cp = 29.1 5 kJ/kmol K. Nitrogen which was initially at 1 bar and 280 K, is compressed to 5 bar and 280K by two different reversible processes:

   a) Cooling at constant pressure followed by heating at constant volume

   b) Heating at constant volume followed by cooling at constant pressure

   For each of the above paths, determine Q, W, ΔU and ΔH
30. Prove that $COP_{HP} = COP_R + 1$ where, COP_{HP} = coefficient of performance of heat pump

   COP_R = coefficient of performance of refrigerator