BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI - HYDERABAD CAMPUS

FIRST SEMESTER 2022-2023

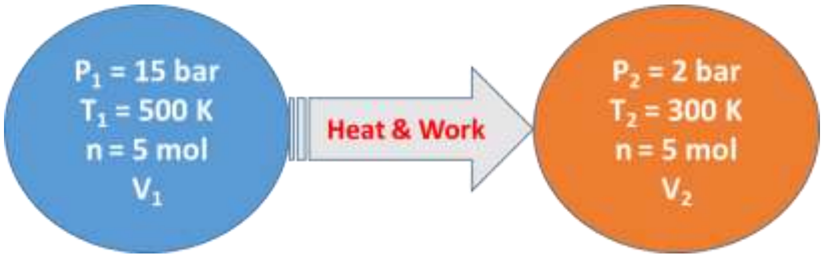
CHEMICAL ENGINEERING THERMODYNAMICS (CHE F213)

Date: 04 November 2022 | Mid Exam (Closed Book) | Duration: 90 min | Maximum Marks: 60 M

Instructions:

- All the questions are mandatory.
- State and take suitable assumptions, if required.

Q1) A diatomic ideal gas (with $\gamma = C_p/C_v = 1.4$) at state-1 undergoes ***reversible*** process to reach state-2.



Find heat (${}_1Q_2$), work (${}_1W_2$) interactions and change in internal energy (ΔU), enthalpy (ΔH) and entropy (ΔS) for

(a) Isothermal process at 500 K with pressure variation from 15 to 2 bar, followed by isobaric process at 2 bar to reach final state-2,

(b) Isochoric process till the intermediate temperature of 400 K followed by adiabatic process to reach final state-2,

(c) Show all these processes in PV diagram and identify the states

(d) If the same problem is given for ***irreversible*** process then how different are the energy interaction (${}_1Q_2$, ${}_1W_2$, ΔU, ΔH and ΔS) compared to a ***reversible*** process. Use inequality notation to explain your answer.

(5 + 5 + 2 + 2 = 14 M)

Q2) One of the exciting ongoing research on H_2 storage requires High pressure adsorption analyzer to test the materials storage ability. As the materials testing is essential at extreme conditions, scientists at BITS planned experimental conditions at (i) 0°C, 100 bar (ii) 100°C, 100 bar of H_2. Find the specific molar volume and density (in kg/m^3) at both conditions using,

(a) ideal gas equation of state,

(b) van dar Waals equation of state $\left(P = \frac{RT}{V-b} - \frac{a}{V^2}\right)$. Here, $a = \frac{27}{64}\frac{R^2T_c^2}{P_c}$ and $b = \frac{1}{8}\frac{RT_c}{P_c}$.

(c) Pitzer correlations for 2nd virial coefficient $\left(Z = 1 + B^0\frac{P_r}{T_r} + \omega B^1\frac{P_r}{T_r}\right)$. Here, ω is the acentric factor, $B^0 = 0.083 - \frac{0.422}{T_r^{1.6}}$ and $B^1 = 0.139 - \frac{0.172}{T_r^{4.2}}$.

(d) What is phase of H_2 at the stated conditions? Which calculation could be the accurate among (a), (b) and (c)?

(2 + 4 + 4 + 2 = 12 M)

Q3) (a) Find the standard heat of reaction for Haber's process to generate ammonia.

(b) Find the theoretical flame temperature considering stoichiometric ratio of the feed mixture.

(c) What could be the temperature change if 50% excess H_2 is supplied? **(1 + 4 + 5 = 10 M)**

Q4) (a) Write the fundamental property relations for U, H, A and G.

(b) Develop the Maxwell relations using part (a). **(2 + 2 = 4 M)**

Q5) Prove that

(a) $\left(\frac{\partial C_V}{\partial V}\right)_T = T\left(\frac{\partial\left(\beta/\kappa\right)}{\partial T}\right)_V$. Here, β is volume expansivity and κ is isothermal compressibility.

(b) $dS = \frac{\kappa C_V}{\beta T}dP + \frac{C_p}{\beta T V}dV$ **(2 + 2 = 4 M)**

Q6) A space capsule built with Aluminum alloy descends to earth surface from outer space (3 K, 13.22 Pa). After reaching into the stratosphere, the reentry capsule interacts with air molecules and generates lot of heat, often the surface temperatures go beyond 1500°C at atmospheric pressure before landing into ocean.

(a) Consider enthalpy and entropy as a function of (T, P) and develop the expressions for dH and dS that consists of C_p, β, V, T, dT and dP.

(b) Find ΔH and ΔS considering final state as $T_2 = T_{avg} = 780°C$, $P_2 = 101325$ Pa & initial state as $T_1 = 3$ K, $P_1 = 13.22$ Pa.

(c) Comment on the effect of pressure on ΔH and ΔS. **(4 + 5 + 1 = 10 M)**

Data: Volume expansivity (β) = 17.3×10^{-6} K^{-1}; Density of the alloy = 7850 kg/m^3; M. Wt. of alloy = 35; heat capacity relation for the alloy, $\frac{C_p}{R} = 10.92 + 18.73\times10^{-3}T + \frac{0.276\times10^5}{T^2}$, here, T is in K & R is universal gas constant.

Q7) A steady-flow adiabatic unit has input of 5 mol/s of an ideal gas (with γ = 1.34) at conditions $T_{in} = 700$ K, $P_{in} = 12$ bar and discharges at $T_{out} = 370$ K, $P_{out} = 1.8$ bar. Determine (a) actual work using first law of thermodynamics (or energy balance) for open system, (b) reversible ideal work from by combining energy and entropy balance for open system, and (c) entropy generation. Consider surrounding temperature as 300 K. **(2 + 2 + 2 = 6 M)**

~~~ *Wish you all the best* ~~~
~~~