1. **(20%)** The dehydrogenation of butene to butadiene is an endothermic reaction:

$$C_4H_8\,(g) = C_4H_6\,(g) + H_2\,(g).$$

This reaction is to be carried out adiabatically and at atmospheric pressure and in order to minimize the temperature drop, the reactor feed will consist of 10 mol of steam per mol of butene. The steam is nonreactive. The feed mixture enters the reactor at 900 K and at atmospheric pressure. What will be the reactor effluent temperature when 20% of the butene has been converted?

**[Note]** You need to write down the path for the calculation of heat effect. The following data will be needed.

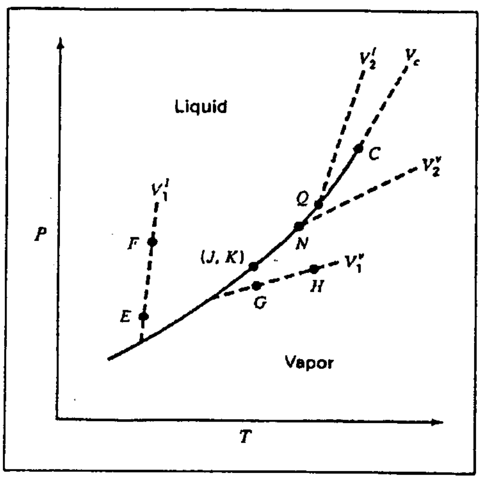
| | $\langle C_p \rangle_H$ (for 298~900 K) (kJ/kmol·K) | $\Delta H^f_{298}$ (kJ/kmol) |
|---|---|---|
| Butene | 148.7 | -130 |
| Butadiene | 131.2 | 110,200 |
| Steam | 36.6 | — |
| Hydrogen | 29.4 | 0 |

2. **(10%)** Wet steam containing 2% by weight of entrained liquid (98% quality) at 5 bar is available at the rate of 1 kg/s. It is desired to mix this wet steam with steam at 5 bar and 200°C to obtain dry saturated steam at 5 bar. The mixing will be considered adiabatic. At what rate should the superheated steam be added?

**[Note]** The enthalpy values for saturated liquid and saturated vapor at 5 bar are 640.23 kJ/kg and 2748.7 kJ/kg. The enthalpy for a superheated vapor is 2855.4 kJ/kg.

3. **(3%)** If a tube is only partially filled with liquid (the remainder being vapor in equilibrium with the liquid), heating at first causes changes that can be described by a certain path shown in the vapor-pressure curve. As the process is further heated, a path regarding the change from this process can be found from the figure. Please find the curve corresponds to this process.

(a) $E, F, V_1^l$;
(b) $J, K, Q, V_2^l$;
(c) $J, K, Q, C, V_c$;
(d) $G, H, V_l^v$;
(e) $J, K, N, V_2^v$.



4. **(10%)** There are three types of engines filled with ideal gases. They are distinguished by how their abilities to absorb/release heat $|Q|$ depend on temperature $T$ (in K): (I) $|Q| \propto T^{1/2}$, (II) $|Q| \propto T$, and (III) $|Q| \propto T^2$. Suppose that these engines are operating between hot and cool reservoirs at temperatures $T_H$ and $T_C$, respectively.

   (a) Address the feasibility for each engine. Provide explanations. **(5%)**
   (b) Which type is the most efficient one? Why? **(3%)**
   (c) For an irreversible process, which type of engine could be? Why? **(2%)**

5. **(23%)** Consider a closed gas system. The PVT behaviors of the gas can be described by the following equation of state:

$$P = \frac{RT}{V-\delta},$$

   where δ is a constant.

   (a) At constant $T$, plot respective P-V curves for $\delta < 0$, $\delta = 0$ and $\delta > 0$. **(2%)**
   (b)The physical meaning of δ can be suggested by the PV diagram shown in (a). Explain it in a viewpoint of intermolecular interactions. **(4%)**
   (c) At constant $T$, calculate the Gibbs free energy $G$ at pressure $P$. **(3%)**
   (d) For $\delta > 0$, calculate the residual Gibbs free energy $G^R$, enthalpy $H^R$ and entropy $S^R$ of (c). Explain your answers physically. **(8%)**
   (e) Consider a gas with $\delta > 0$ undergoing an adiabatic expansion. The system starts at $(T_1, V_1)$, and expands to a volume of $V_2 = 2V_1$. Suppose that the process is <u>irreversible</u>, will $T_2$ be higher or lower than that of a reversible process? State your arguments. **(6%)**

6. **(10%)** Consider a closed system consisting of $N$ different species present in two phases in equilibrium. Within this closed system, each individual phase is an open system, free to transfer mass to the other. What are the criteria for the phase equilibrium in this closed system? Please detail your deductions to your answers/conclusions, as well as label all variables used in your deduction clearly.

7. **(10%)** If a single-liquid-phase system contains only two species at fixed temperature $\boldsymbol{T}$ and pressure $\boldsymbol{P}$, the excess enthalpy $\boldsymbol{H^E}$, resulted from mixing, could be represented by the equation:

$$H^E = x_1 \cdot x_2 \cdot (40x_1 + 20x_2)$$

   where $x_1$ and $x_2$ stand for the molar fraction of species *1* and *2* in this liquid mixture. Please determine the partial molar enthalpies of species *1* and *2* as functions of $x_1$. Please detail your algorithm leading to your answers and label all variables clearly.

8. **(14%)** Let substance $A$ be a pure solid as a component in an ideal solution and $x_A$ represent the mole fraction of substance $A$ in this ideal solution. You may also consider $x_A$ as the solubility of substance $A$, expressed as a mole fraction, in this solution.

(1) What is the temperature effect on $x_A$, when the pressure is held constant?

(2) If naphthalene ($C_{10}H_8$) at **1 atm** has its melting-point at **80.05°C** and enthalpy of melting at **18.58 kJ/mol**, what is its ideal solubility at **20 °C**?

Please detail your algorithm leading to your answers/conclusions, as well as label all variables used in your deduction clearly.