Problem 1 (10%)

(1) Calculate the thermal efficiency of a Carnot cycle heat engine operating between reservoirs at 300 °C and 45 °C. (5%)
(2) What does it imply if the compressibility factor system is larger than 1? (5%)

Problem 2 (18%)

Sketch the paths of the following processes on the PH, TS and HS diagrams.
(1) Adiabatic reversible expansion of saturated vapor. (9%)
(2) Continuous throttling of saturated liquid. (9%)

Problem 3 (12%)

An approximation for the saturation pressure can be ln Psat = A – B/T, where A and B are constants. Which phase transition is that suitable for, and what kind of property variations are assumed?

Problem 4 (10%)

The equation for the second virial coefficient for spherical molecules is
$B = 2\pi\int_0^\infty [1-\exp(-\phi(r)/kT)]r^2 dr$ . A square well intermolecular pair potential model is

$$\phi(r) = \begin{cases} \infty & 0 \le r < \sigma \\ -\epsilon & \sigma \le r < R\sigma \\ 0 & r > R\sigma \end{cases}$$

Derive an expression for second virial coefficient B in terms of $R$, $\sigma$, $\epsilon$, and $T$.

Problem 5 (15%)

The following three reactor design equations for a general reaction [A + (b/a) B → (c/a) C + (d/a) D] are derived from general mole balance in which each term remains its meaning in a reaction engineering textbook.

$$V = F_{A0}\int_0^X \frac{dX}{-r_A} \qquad \text{(a)}$$

$$t = N_{A0}\int_0^X \frac{dX}{-r_A V} \qquad \text{(b)}$$

$$V = \frac{F_{A0}X}{-r_A} \qquad \text{(c)}$$

Please describe the reactor types for the above three equations and derive equations (a), (b) and (c) according to general mole balance, respectively. For derivation, appropriate assumptions should be made.

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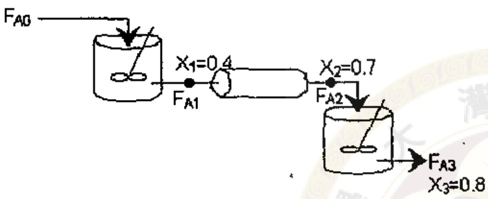
Problem 6 (20%)

(1) Operating time of a batch reactor: An isothermal, liquid-phase chemical reaction $2A + B \rightarrow 2C$ is carried out in a 2000 L batch reactor. The rate equation is $-r_A = kC_A^2$, where k = 1 min/mM. The initial concentrations of reactants A and B are both 100 mM. The product C is absent at the beginning. (a) Please calculate the time to reduce $C_A$ by a factor of 10. (6%); (b) Concentration of B at that time = ? (2%)

(2) Reactors connected in series: An isothermal, liquid-phase chemical reaction $A \rightarrow B$ is carried out in the CSTR-PFR-CSTR reactors connected in series as illustrated below. The desired conversions at the outlets of reactor 1 (CSTR), reactor 2 (PFR), and reactor 3 (CSTR) are 0.4, 0.7 and 0.8, respectively. The kinetic data for this reaction are summarized in the following table. Calculate the reactor volumes (a) $V_1$, (b) $V_2$, and (c) $V_3$ when $F_{A0}$ is 20 mol/s. (12%)




| X | 0 | 0.2 | 0.4 | 0.6 | 0.8 |
|---|---|---|---|---|---|
| $-r_A\left(\frac{mol}{dm^3 \cdot s}\right)$ | 0.010 | 0.009 | 0.008 | 0.005 | 0.002 |

Problem 7 (15%)

(1) Enzyme kinetics with product inhibition: When glucose (S) is converted to fructose (P) by glucose isomerase (ES), the slow product formation step is also reversible as:

$$S + E \underset{k_2}{\overset{k_1}{\rightleftharpoons}} ES \underset{k_4}{\overset{k_3}{\rightleftharpoons}} P + E$$

Derive the rate equation ($r_P$) by employing the Michaelis-Menten approach.(10%)

(2) Evaluation of enzyme kinetics: The initial rate of reaction for the enzymatic cleavage of deoxyguanosine *triphosphate was measured as a function of initial substrate concentration as follows.*

| Substrate concentration (μmol/L) | Initial reaction rate (μmol/L min) |
|---|---|
| 6.7 | 0.60 |
| 3.5 | 0.50 |
| 1.7 | 0.32 |

*Determine the Michaelis-Menten constant of this reaction (5%).*

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