

# 國立清華大學 105 學年度碩士班考試入學試題

系所班組別：化學工程學系碩士班

考試科目（代碼）：化工熱力學及化學反應工程(0902)

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## Problem 1 (10%)

The Carnot-engine cycle operates reversibly and consists of two isothermal steps and two adiabatic steps.

- (a) Show the Carnot cycle on a  $T$  (temperature)- $S$  (entropy) diagram.
- (b) Show the Carnot cycle on a  $P$  (pressure)- $H$  (enthalpy) diagram.
- (c) Show the Carnot cycle on an  $H$  (enthalpy)- $S$  (entropy) diagram.

## Problem 2 (10%)

A Carnot engine receives 500 kJ/s of heat from a heat-source reservoir at 600°C and rejects heat to a heat-sink reservoir at 50°C.

- (a) What is the thermal efficiency of the Carnot engine?
- (b) Does the thermal efficiency of Carnot engine depend on the working substance of the engine?
- (c) What are the power developed and the heat rejected?

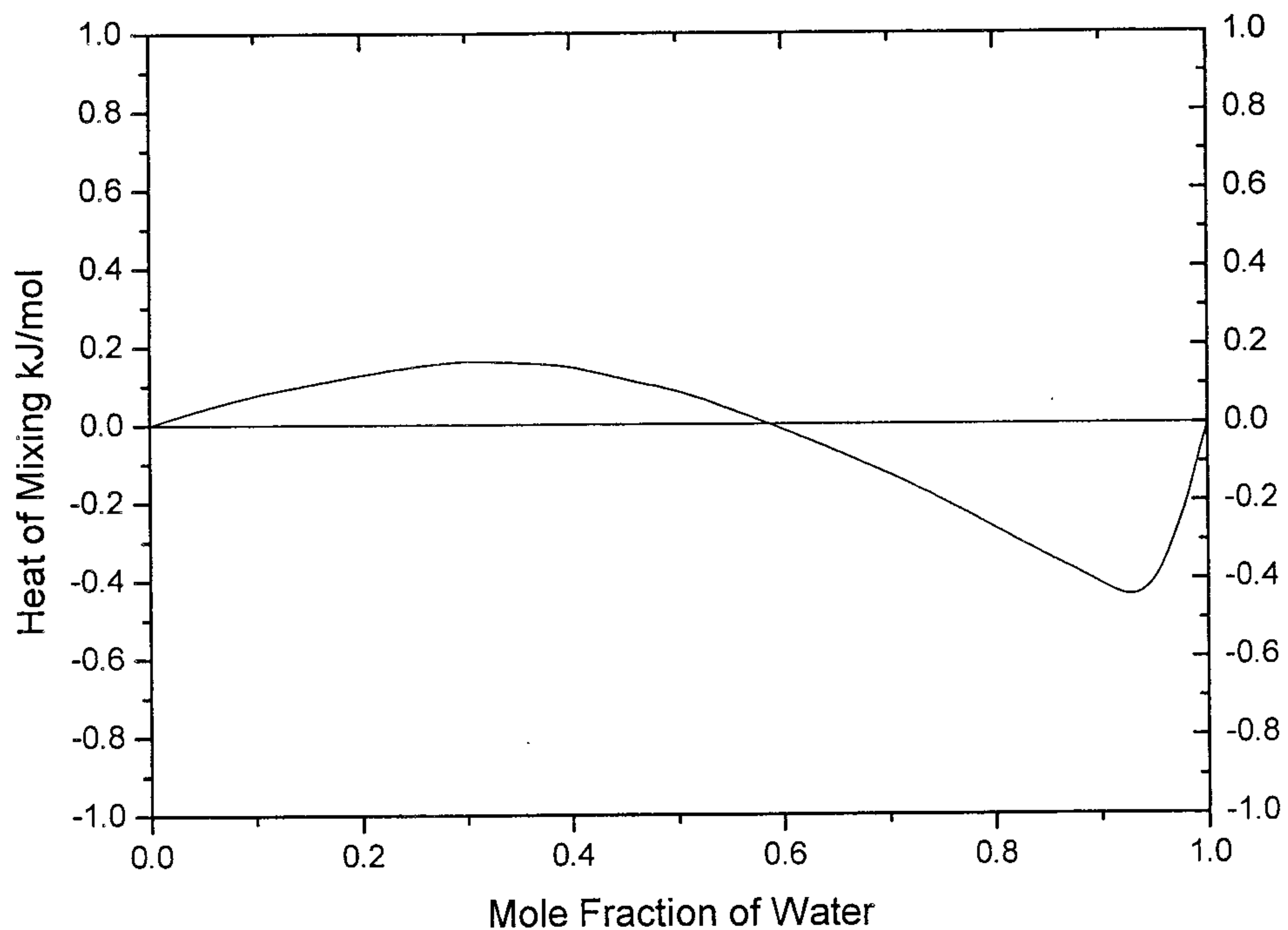
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**Problem 3 (10%)** When water and n-propanol mix isothermally, heat may be released or absorbed. The following is a plot of the heat of mixing at various compositions



- Is heat released or absorbed when a small amount of n-propanol is added to water (1%)
- Is heat released or absorbed when a small amount of water is added to n-propanol (1%)
- Calculate the difference between partial molar enthalpy and the pure molar enthalpy of water  $\bar{H}_W - H_W^o$  at  $x_W = 0.35$  (2%)
- Calculate the difference between partial molar enthalpy and the pure molar enthalpy of n-propanol  $\bar{H}_{NPA} - H_{NPA}^o$  at  $x_W = 0.35$  (2%)
- Calculate the difference between partial molar enthalpy and the pure molar enthalpy of water  $\bar{H}_W - H_W^o$  at  $x_W = 0.60$  (2%)
- Calculate the difference between partial molar enthalpy and the pure molar enthalpy of n-propanol  $\bar{H}_{NPA} - H_{NPA}^o$  at  $x_W = 0.60$  (2%)

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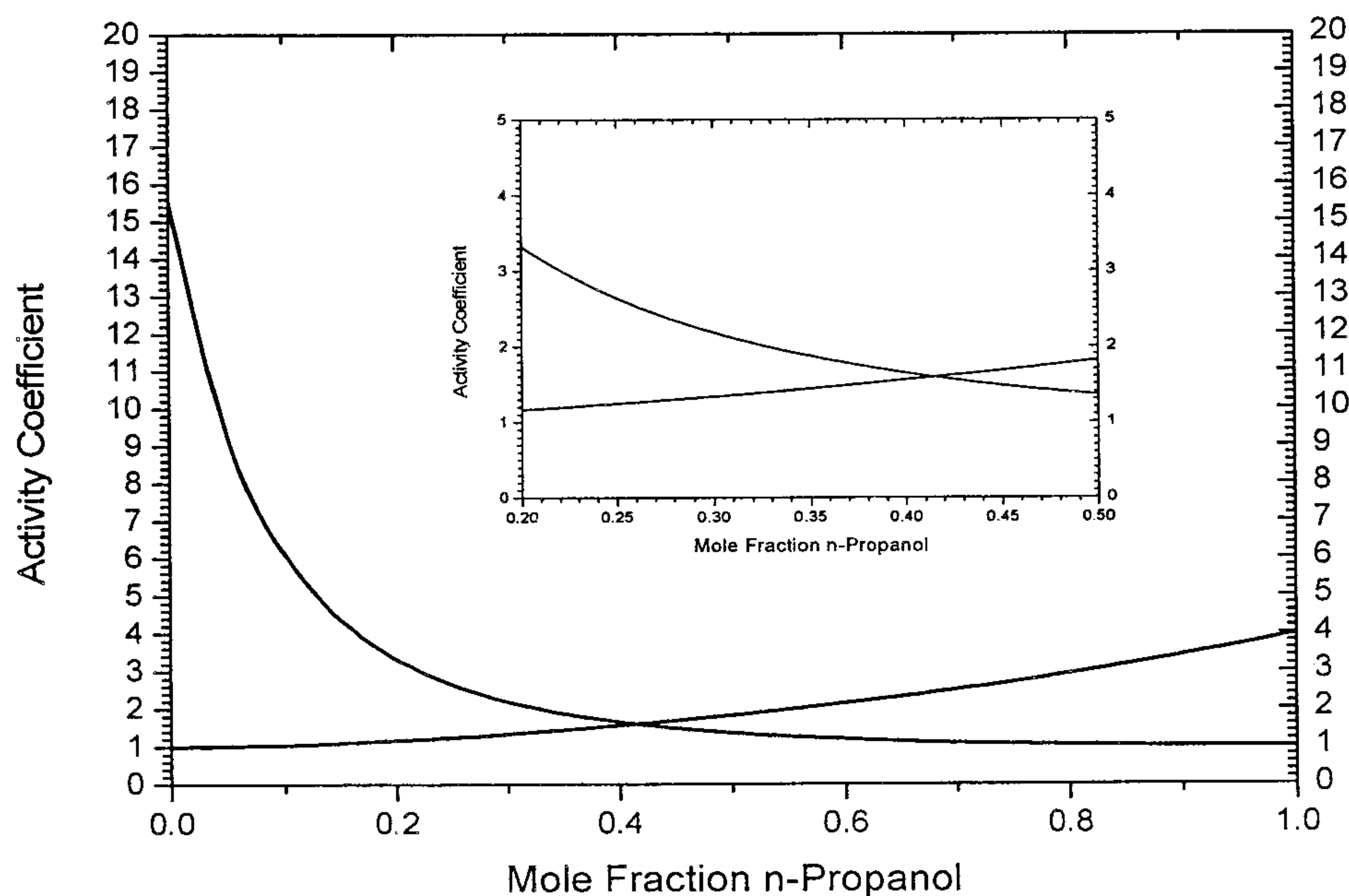
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## Problem 4 (10%)

The activity coefficients of water-n-propanol as a function of n-propanol mole fraction at 25°C is shown below (the inset is an enlarged image in range of n-propanol mole fraction from 0.2 to 0.5)

- Find the activity coefficient of n-propanol in a mixture containing 0.35 mol% of n-propanol (1%)
- Find the activity coefficient of water in a mixture containing 0.35 mol% of n-propanol (1%)
- Find the excess Gibbs free energy of mixing for a mixture containing 0.35 mol% of n-propanol (2%)
- Find the Gibbs free energy of mixing for a mixture containing 0.35 mol% of methanol (2%)
- Find the infinite dilution activity coefficient of n-propanol in water. (2%)
- The vapor pressure of n-propanol at 25°C is 28.08 mBar. Find the Henry's Law coefficient  $\lim_{x_{NPA} \rightarrow 0} \frac{P_{NPA}}{x_{NPA}}$  of n-propanol in water,  $P_{NPA}$  being the partial pressure of n-propanol (2%)

$$R = 8.314 \frac{J}{mol \cdot K}$$



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**Problem 5 (10%)**

The following data are available for an organic solvent

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 $\ln P^{\text{sub}}(\text{solid}) = 29 - 6150/T$       P in Pa

$\ln P^{\text{vap}}(\text{liquid}) = 26 - 5430/T$       T in K  
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- (a) Compute the triple-point temperature and pressure of this organic solvent. (4%)  
(b) Compute the heat of vaporization, the heat of sublimation and the heat of fusion of the organic solvent at its triple point. (6%)

**Problem 6 (10%)**

For a mixture of A and B components at 320 K at which  $\ln P_A^{\text{vap}} = 10.5 - (27000/RT)$  and  $\ln P_B^{\text{vap}} = 11.4 - (35000/RT)$  for P in bar, T in K and  $R=8.314 \text{ J}/(\text{mol K})$ . Note that the vapor phase follows ideal gas condition.

- (a) Please compute the dew-point pressure of the mixture at 320K while the molar fraction of component A in the mixture is 0.5 and the mixture can be treated as an ideal liquid mixture. (6 %)  
(b) If the mixture is not an ideal liquid mixture, please briefly describe your approach (or list the equations) to solve the problem (a). (4 %)

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## Problem 7 (10%)

**Non-isothermal homogeneous reactor:**

The energy balance of a CSTR can be expressed as:

$$-x(\Delta H^0_{Rx}) = C_{PO}(1+\kappa)(T-T_C)$$

Where  $x$ =conversion,  $\Delta H^0_{Rx}$ =standard heat of reaction,  $C_{PO}$ =overall heat capacity of the reactant(s),  $\kappa$  = non-adiabatic parameter =  $\frac{UA}{F_{A0}C_{PO}}$ ,

$T_C$  = critical temperature =  $\frac{\kappa T_a + T_0}{1+\kappa}$ . The left-hand side of above energy balance equation is referred as the heat-generated term,  $G(T)$  and the right-hand side is referred as the heat-removed term,  $R(T)$ . Now a non-adiabatic CSTR is operated under the following conditions:

$$C_{PO} = 20 \text{ cal/mol } ^\circ\text{C}$$

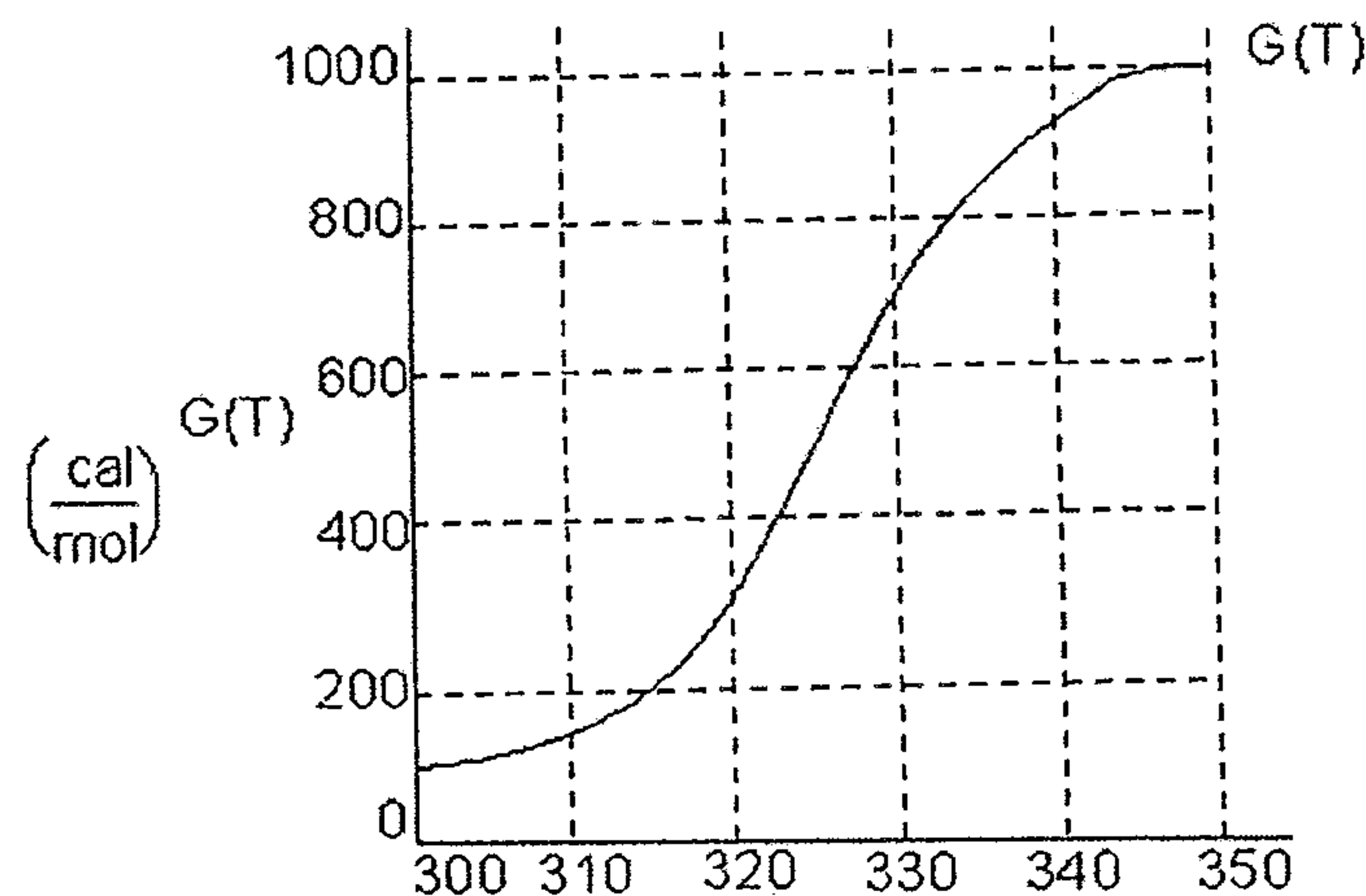
$$UA = 2000 \text{ cal/min } ^\circ\text{C}$$

$$F_{A0} = 50 \text{ mol/min}$$

$T_0$ =feed temperature,  $T_a$ =ambient temperature

Given  $G(T)$  of a first-order, liquid phase reaction as below figure,

- (a) For an entering temperature of 340 K and an ambient temperature of 310 K, find the reactor temperature(s) and conversion(s). (5%)
- (b) If the molar flow rate of A is increased by a factor of 4 and the inlet temperature is 330K and the ambient temperature is 270 K., find the reactor temperature(s) and conversion(s) (5%)



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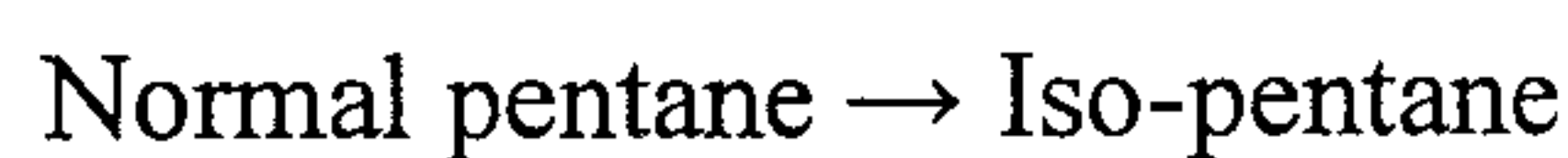
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### Problem 8 (10%)

#### **Isothermal fixed bed reactor:**

A first order isothermal, irreversible gas phase reaction



is to be carried out in a packed bed reactor. Currently 1,000 kg of catalyst is packed in a 4 cm diameter pipe. The catalyst particles are 0.5 cm in diameter and the bulk density of the packed catalyst is 1,000 kg/m<sup>3</sup>. Currently 25% conversion is realized. The entering pressure is 20 atm and the pressure at the exit of the reactor is 9.0 atmospheres. What conversion could be achieved in a CSTR with the same catalyst weight and no pressure drop?

### Problem 9 (10%)

The water-gas shift reaction,  $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$ , is to be carried out at 1250 °F and 75 psi. For an equal-molar mixture of CO and H<sub>2</sub>O, please calculate the equilibrium conversion.

*Data:* at 1250 °F and 75 psi, the Gibbs free energies of formation are  $G^\circ_{\text{CO}} = -47800$  cal/mol;  $G^\circ_{\text{H}_2\text{O}} = -46100$  cal/mol;  $G^\circ_{\text{CO}_2} = -94630$  cal/mol;  $G^\circ_{\text{H}_2} = 0$ .

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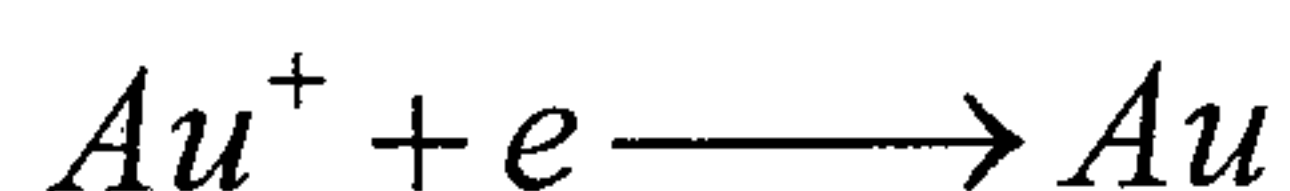
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### Problem 10 (10%)

The reactor volume of a batch-recirculation gold-bump electroplating reactor is  $V_R$ , where the reservoir volume is  $V_T$ . Initially, there is only reactant  $Au^+$  in the reservoir and the electroplating reaction is expressed as follow:



Note that  $V_T$  is much larger than  $V_R$  (e.g.,  $V_T > 50V_R$ ) and the electrolyte volume in pipe can be negligible. The liquid electrolyte volume flow rate is  $Q$ . The electroplating reaction in the reactor is under mass transfer control with a spatially-average mass transport coefficient of  $k_L$  and  $A$  is the total reaction surface area for electroplating.  $\tau_T$  and  $\tau_R$  are the resident times of reservoir and reactor, respectively; i.e.,  $V/Q = \tau$ . If the reactor can be considered to be a CSTR, please show that the overall fractional conversion for this system (i.e., conversion based on the reservoir) is:

$$X_{Au,T}^{CSTR} = 1 - \exp\left(-\frac{t}{\tau_T} X_{Au}\right); \text{ where } X_{Au} = 1 - \left(\frac{1}{1 + (k_L A / V_R) \tau_R}\right)$$