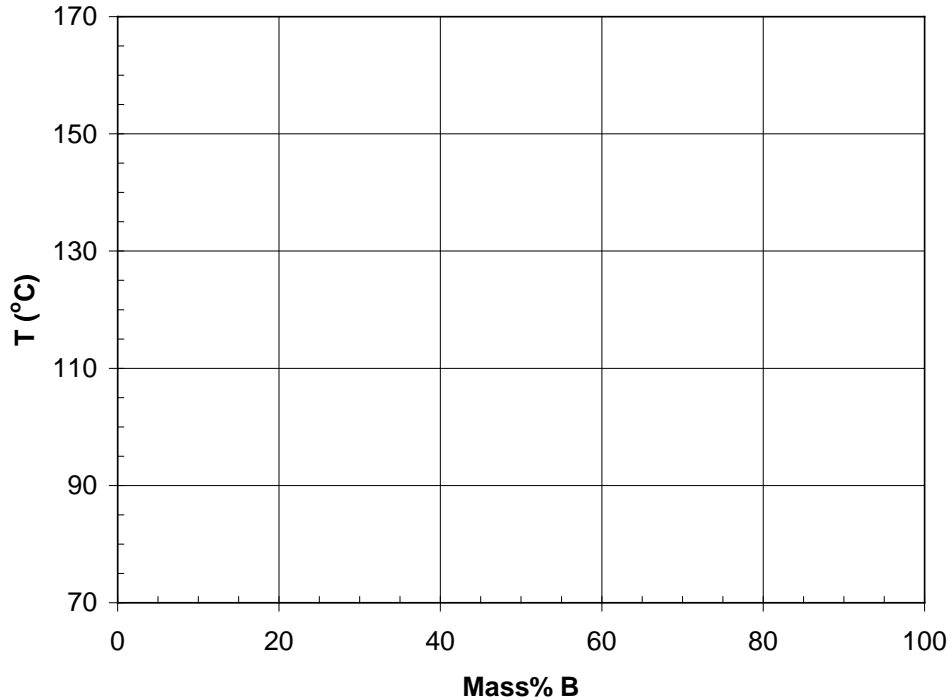


Question Number I (15 Marks ~ 27 minutes)

Consider the following data for a binary mixture of A ($M = 100 \text{ g/mol}$) and B ($M = 50 \text{ g/mol}$). Use this data to answer the questions below.

- Pure A melts at 150°C .
- Pure B melts at 130°C .
- The eutectic temperature is 110°C and the eutectic mixture is 40 mass% A.
- The maximum solubility of A in B is 20 mass%.
- The maximum solubility of B in A is 40 mass%.
- At 90°C the solubility of A in B is 10 mass% and the solubility of B in A is 20 mass%.



- a) Draw a phase diagram in the chart above, and identify all single and multiple phase regions (i.e. name the phases). **(/2)**
- b) Calculate the eutectic composition on a molar basis. **(/2)**
- c) Estimate two temperatures at which the solubility of B in A is 30 mass%. **(/2)**
- d) At 160°C , 1 kg of A is mixed with 1 kg of B, and the mixture is cooled.
 - i) Estimate the temperature at which the first solid is formed, and the composition of that solid. **(/2)**
 - ii) Determine the temperature at which all the liquid becomes solid, the number and name of phases present in the system at this temperature, and the amount (kg) of each phase. **(/2)**
 - iii) Give the number of phases, the amount (kg) in each phase, and the composition of each phase after cooling the mixture to 100°C . **(/3)**
 - iv) How much B would have to be added or removed (specify which) to obtain a single phase at 100°C ? **(/2)**

Question Number II (15 Marks ~ 27 minutes)

A 6 kmol mixture of gases is held in a rigid gas containment balloon at 29°C. The balloon is spherical in shape with a fixed volume equal to 2 m³. The composition of the gas mixture is summarized in the following table.

Gas	M (g/mol)	T _c (K)	P _c (atm)	ω	Mole Fraction
Methane	16	190.6	45.4	0.008	0.76
Propane	44	369.8	41.9	0.152	0.14
Schlichium	56	225.6	43.4	0.12	0.10

- What is the average molar mass of the gas mixture? **(/1)**
- If the gas mixture behaves as an ideal gas, calculate the pressure of the gas in the balloon. **(/2)**
- Determine if the gas mixture can be adequately represented as an ideal gas by determining the compressibility factor of the gas mixture at these conditions of Part b). Use the method of corresponding states and the Pitzer-Curl Table. **(/3)**
- After heating with a giant flame, the temperature of the balloon is raised to 93°C. Determine the pressure of the gas mixture by using the Van der Waals equation of state. **(/5)**
- The maximum pressure rating of the balloon is 100 atm (at greater pressure, the balloon goes boom). What is the maximum mass, in kg, of gas (with mole fractions given in the above table) that can be stored in the balloon at 29°C? Use the Compressibility Chart Method. **(/4)**

Question Number III (15 Marks ~ 27 minutes)

Acetic acid (M=60.05 kg/kmol) has a normal boiling point of 118.1°C and a latent heat of vaporization of 24.33x10³ kJ/kmol near the normal boiling point. Ethanol (M=46.07 kg/kmol) has a vapor pressure of 800 mmHg at 80°C and a boiling point of 160°C at a pressure of 9200 mmHg. Do not use Trouton's Rule for any of the following questions.

- Calculate the vapour pressure (kPa) of acetic acid and ethanol at 101°C. **(/5)**
- Calculate the average latent heat of vaporization of ethanol between 80 and 160°C. **(/1)**
- Calculate the dew point pressure of a vapour mixture of 40 mole% acetic acid and 60 mole% ethanol at 101°C. **(/4)**
- How much energy would it take to boil 5 kg of liquid acetic acid (C_{pL}=2.25 kJ/kgK) at 85°C to vapor (C_{pV}=1.30 kJ/kgK) at 120°C at a pressure of 1 atm? **(/3)**
- Describe (using a diagram) how a pycnometer, isoteniscope or barometer (pick the primary instrument) could be used to measure the vapor pressure of acetic acid over the temperature range of 80 to 160°C. **(/2)**

Question Number IV (20 Marks ~ 36 minutes)

This question deal with a mud-oil mixture (density 1200 kg/m³) commonly found in petroleum engineering. A large 50 m diameter tank open to the atmosphere is used to store some of the mixture. A small 2.4 cm diameter commercial steel pipeline drains the mixture from the tank to a railcar filling facility. The inlet of the pipeline is located 4 m above the ground and the height of the liquid in the tank is 6 m above the

elevation of the pipeline inlet. The length of the pipeline is 275 m and its exit elevation and pressure are 2 m and 101 kPa, respectively. The atmospheric pressure is 101 kPa.

- a) In the following analysis, make the assumption that the mud-oil mixture acts as a Newtonian liquid with apparent viscosity equal to 2.5 mPa s. A pump is installed at the entrance of the pipeline to obtain a flow rate equal to 100 m³/day.
- i) What is the average speed, in m/s, of the mixture at the exit of the pipeline? **(/2)**
 - ii) What is the Reynolds' number of the flow in the pipeline, and is the flow laminar or turbulent? State the units of the Reynolds number **(/3)**
 - iii) What is the pressure, in kPa, at the exit of the pump? **(/3)**
 - iv) What is the power, in MW, supplied by the pump? **(/2)**
 - v) You are told that another commercial steel pipeline is available with diameter equal to 5 cm to replace the existing one. What would be the flow rate, in m³/hour, of the fluid in pipeline under the same pressure drop you determined in part (iii)? **(/4)**
- b) The mud-oil mixture is tested in a viscometer. The following shear stress versus strain rate data is found.

τ , Pa	du/dy , s ⁻¹
30.05	15
58.90	35

- i) Show that the mud-oil mixture is not Newtonian. **(/1)**
- ii) If you suppose that the mixture is a power law fluid, what are the power law parameters K and n? Make sure you state the units of K and n. **(/3)**
- iii) If the strain rate at the wall of the pipeline is 22 s⁻¹, what is the shear stress at the wall of the pipeline, and the apparent viscosity at the wall? **(/2)**

Question Number V (20 Marks ~ 27 minutes)

- a) Iron atoms ($M = 55.85$ kg/kmol, molecular diameter = 2.5 Å) are arranged in a face-centered cubic lattice (FCC) above 1180 K, and a different structure below 1180 K (density below 1180K = 7.71 g/cm³).
- i. Calculate the mass of 1 m³ of iron above 1180 K. **(/2)**
 - ii. What is the void fraction in iron above 1180 K? **(/1.5)**
 - iii. Determine the structure of iron below 1180 K. **(/1.5)**
 - iv. What would be the change in radius for a spherical sample of iron with a mass of 1000 kg transitioning from below 1180 to above 1180 K? **(/2)**
- b) A 100 m steel pipe (Inner diameter = 4cm, thickness = 0.5 cm, $k = 50$ W/mK) carries steam at 500°C for a process. One layer of insulation and a layer of concrete are added to the outside of the pipe so that the rate of heat loss is lowered. The inner layer is 1 cm thick polyurethane foam with a thermal conductivity of 0.05 W/mK, and the outer layer is concrete with a thermal conductivity of 1.40 W/mK. Perform the following calculations for a cold winter day when the ambient temperature is -30°C.

- i. Calculate the heat loss through the uninsulated pipe (i.e. no polyurethane or concrete) in one day. **(/3)**
- ii. Calculate the thickness of concrete added if the rate of heat loss is 47 kW for the insulated/concreted pipe. **(/3)**
- iii. What is the temperature at the outer edge of the polyurethane insulation layer (i.e. where it meets the concrete) if the rate of heat loss is 47 kW for the insulated/concreted pipe? **(/2)**

Question Number VI (20 Marks ~ 36 minutes)

- a) The crystal formation rate (nucleation rate) (B^o) (nuclei/cm³s) for crystals forming from solutions is calculated using the following formula:

$$B^o = C \exp \left[\frac{16\pi V_m^2 N_a \sigma_a^3}{3(RT)^3 v^2 s^2} \right]$$

Where:

C	= rate of formation of critical size crystals
V_m	= molar volume, N_a = Avogadro's number
σ_a	= surface tension, R = ideal gas constant
T	= temperature, v = number of ions per molecule (dimensionless)
s	= fractional supersaturation (solution concentration / saturated solution concentration)

- i) Knowing that the term inside the exponential function is dimensionless, determine the dimensions of the surface tension term. **(/3)**
 - ii) What are the units of the constant C? **(/1)**
- b) Nitrogen (M=28 kg/kmol) at high temperatures and low pressures can be thought to behave like an ideal gas.
- i) What is the ratio of the mean distance nitrogen molecules will travel between collisions and the average distance between molecules at 700°C and 1 atm? The collision diameter of nitrogen can be approximated at 3.7Å. **(/3)**
 - ii) Calculate the average speed that the nitrogen molecules would have at 700°C and 1 atm. **(/2)**
 - iii) Nitrogen diffuses through a 2 cm diameter hole from a room with 10mol/L nitrogen to a room with no nitrogen. Determine the ratio of the flux of nitrogen due to diffusion in this situation at 700°C and 1 atm to that at 350°C and 2 atm. **(/3)**
- c) Nitrogen freezes at -210°C, and the Lennard Jones parameters for nitrogen are $\epsilon/k=96.3$ K and $b_0=0.0636$ m³/kmol.
- i) Determine the separation distance where the potential energy between two nitrogen molecules will be a minimum. **(/2)**
 - ii) What are the values of the potential energy and the force between 2 nitrogen molecules at the distance in i)? **(/1)**
 - iii) How far apart are the nitrogen molecules when the potential energy is zero? **(/1)**
 - iv) What is the value of the force between two nitrogen molecules at a separation distance equal to 5x the minimum potential energy distance? **(/4)**