



FACULTY OF ENGINEERING AND ENVIRONMENT
DEPARTMENT OF METALLURGICAL ENGINEERING
HEAT AND MASS TRANSFER
EMR/ EMG 3101
Final Examination Paper
September 2024

This examination paper consists of 4 pages

Time Allowed: 3 hours

Total Marks: 100

Examiner's Name: Dr Fortune Nkomo

INSTRUCTIONS

1. Answer **ALL** questions in Section A and **Any TWO** from Section B
2. Each question carries 25 marks
3. Use of calculators is permissible

Additional Requirements

Graph paper

MARK ALLOCATION

All Question	25 Marks
Part Questions	As shown in each part question
Total Attainable	100

ANSWER ALL QUESTIONS IN SECTION A

Question A1

- a) Explain the mechanisms of heat conduction in metals and insulators **[6 Marks]**
- b) The interior of an oven is maintained at the temperature of 850°C by means of a suitable control apparatus. The oven walls are 500mm thick and are fabricated from a material of thermal conductivity 0.3 W/m-deg. For an outside wall temperature of 250°C determine
- The resistance to heat flow **[3 Marks]**
 - Heat flow per square metre of the wall surface **[3 Marks]**
 - The temperature at a point 200mm from the interior side **[3 Marks]**
- c) An electric heater of exposed surface area 0.09m² and output 600 watts is designed to operate fully submerged in water. Calculate the surface temperature of the heater when the water is at 37°C and the surface coefficient of heat transfer is 283.5W/m²-deg. How will this value be affected if the heater is mistakenly operated at 37°C air with surface coefficient of 8.5 W/m²deg **[5 Marks]**
- d) An uninsulated steam pipe passes through a room in which the air and walls are at 25°C. The outside diameter of the pipe is 70mm and its surface temperature and emissivity are 200°C and 0.8 respectively (*Stefan Boltzman Constant*= $5.67 \times 10^{-8} \text{W/m}^2\text{K}^4$).
- Determine the surface emissive power and irradiation? **[5 Marks]**
 - If the coefficient associated with free convection heat transfer from the surface to the air is 15W/m²-K, what is the rate of heat loss from the surface per unit length of pipe? **[3 Marks]**

Question A2

- a) Explain the following terms when applied to mass transfer
- Absorption **[3 Marks]**
 - Stripping **[3 Marks]**

- b) A binary mixture of oxygen and nitrogen with partial pressure in the ratio 0.21 and 0.79 is contained in a vessel at 300K. If the total pressure of the mixture is $1 \times 10^5 \text{ N/m}^2$, calculate the molar concentration, mass density, molar fraction and mass fraction of each species [10 Marks]
- c) Hydrogen gas at 2 bar and 300K flows through a metal tubing of 10mm inside radius and 20mm outside radius. The diffusivity of the hydrogen through the metal alloy is stated to be $0.75 \times 10^{-4} \text{ m}^2/\text{hr}$ and the solubility of hydrogen is 0.052 m^3 of hydrogen/ m^3 of metal at 1atm. What will be the diffusion loss of hydrogen per meter length of the metal tubing. Assume the resistance to diffusion of hydrogen from the outer surface of the tube is negligible [9 Marks]

SECTION B ANSWER ANY TWO (2) QUESTIONS

Question B1

- a) It is desired to absorb 95% of hydrogen sulphide (H_2S) by a solvent from a mixture of hydrogen sulphide and nitrogen containing 1.5% of the component in a counter current tray tower. Total gas input is 30 kmol/hr and the solvent enters the tower at a rate of 90 kmol/hr. The tower operates at 27°C and 1 atm. The equilibrium relation is $Y=2.53X$. Determine the number of ideal stages necessary for the separation using graphical method. [20 Marks]
- b) You are required to choose a suitable solvent for the operation in (a) what factors would you consider? [5 Marks]

Question B2

A counter flow concentric tube heat exchanger is used to cool the lubricating oil for a large coke oven turbine. The flow rate of cooling water through the inner tube ($D_i=25\text{mm}$) is 0.2kg/s while the flow rate of oil through the outer annulus ($D_o=45\text{mm}$) is 0.1kg/s . The oil and water enter at temperature of 100 and 30°C , respectively. Determine the length of the tube if the outlet temperature of the oil is to be 60°C [25 Marks]

(Data- Lubricating oil ($T=80^{\circ}\text{C}=353\text{K}$) - $C_p=2121\text{J/kg.K}$, $\mu=3.25\times 10^{-2}\text{N.s/m}^2$, $k=0.138\text{W/m.K}$

Water ($T=35^{\circ}\text{C}=308\text{K}$) $C_p=4178\text{J/kg.K}$, $\mu=725\times 10^{-2}\text{N.s/m}^2$, $k=0.138\text{W/m.K}$, $Pr=4.85$,

For turbulent flow $Nu= 0.023(Re_D)^{4/5}Pr^{0.4}$, Laminar flow $Nu= h_oD_h/k$)

Question B3

A mixture of benzene and toluene containing 40 mole per cent benzene is to be separated to give a product containing 90 mole per cent benzene at the top, and a bottom product containing not more than 10 mole per cent benzene. The feed enters the column at its boiling point, and the vapour leaving the column which is condensed but not cooled, provides reflux and product. It is proposed to operate the unit with a reflux ratio of 3 kmol/kmol product. It is required to find the number of theoretical tray needed and the position of entry for the feed. The equilibrium data at 100 kN/m² is shown in Table B3

Table B3

X	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Y	0.0	0.22	0.38	0.50	0.60	0.68	0.75	0.82	0.88	0.94	0.99

- Determine the operating line equation of the rectifying section of the distillation column. **[10 Marks]**
- Determine the operating line equation of stripping section of the distillation column. **[3 Marks]**
- What is the number of theoretical plates needed? **[8 Marks]**
- The Murphree Tray Efficiency (E^o) based on the gas phase is 0.80. Determine the actual number of trays needed and comment on the difference between this number and the answer calculated in (c). **[4 Marks]**

END OF QUESTION PAPER