BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI Pilani Campus
Second Semester 2022-2023
CHE F414 Transport Phenomena
Comprehensive Exam (Open Book)

Date: 16.05.2023, FN **Duration: 180 Min.** **Total Marks: 40**

- **State and justify any assumptions that you make. Nomenclature and symbols used must be defined properly.**

Q.1 **[4×3 M=12 M]**

a. A horizontal annulus of 8.25 m length has an inner radius of 12.6 mm and an outer radius of 28 mm. A 60% aqueous solution of sucrose is pumped through the annulus at 20°C. A this temperature the solution density is 2190 kg/m^3 and the viscosity is 56.55 cp (centi Poise). Calculate the volume flow rate in m^3/hr when the pressure difference is 37.15 kPa.

b. An oil is acting as a lubricant for a pair of cylindrical surfaces. The angular velocity of the outer cylinder is 8000 rpm. The outer cylinder has a radius of 5 cm, and the clearance between the cylinder is 0.025 cm. Both walls are maintained at 70°C. The viscosity of the oil is 92.3 cp. The density of oil is 1.22 g/cm^3. The thermal conductivity is $0.0055\ \mathrm{cal/(s.cm.°C)}$. Determine the maximum temperature in the oil.

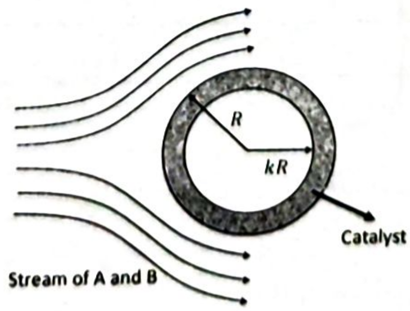
c. A liquid of chloropicrin (CCl_3NO_2) is in a cylindrical beaker at 25°C and evaporating into air. Air can be assumed as pure substance. The total pressure is 770 mmHg. The diffusivity of CCl_3NO_2-air pair is 0.088 cm^2/s. The vapour pressure of CCl_3NO_2 is 23.81 mmHg. The distance of from the liquid surface to the top of the beaker is 10 cm. The density of liquid CCl_3NO_2 is 1.65 g/cm^3. The surface area of liquid exposed for evaporation is 3 cm^2. What is the evaporation rate in g/s of CCl_3NO_2.

d. Air at 1 atm and 20°C flows tangentially on both sides of a thin, smooth flat plate of width 3 m, and the length 1 m in the direction of the flow. The velocity outside the boundary layer is constant at 6 m/s. Laminar flow conditions can be assumed. (i) Compute the approximate boundary-layer thickness (in meters) at the trailing edge. (ii) compute the total drag on the plate (in Newton). The viscosity of air is $1.8 \times 10^{-5}\,Pa.s$. The density of air is 1.205 kg/m^3.

Q.2 **[8 Marks]**

Consider a stream of A flowing over a spherical catalyst with an active ingredient of the catalyst present in the annular region between $r = kR$ and $r = R$. A first order reaction (A → B) occurs in the active catalyst region. Assume that there is no mass transfer resistance between the bulk fluid stream and the catalyst interface.

(a) Write the shell mass balance and derive the governing equations, (b) using equation of change for multicomponent system derive the governing equation, (f) write all applicable the boundary conditions, (g) determine the concentration profile in the active catalyst region and inactive region, and (h) evaluate the total molar rate of conversion of A in a single particle.



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Q.3 **[8 Marks]**

Two large flat porous horizontal plates are separated by a small distance L. The upper plate at $y = L$ is at temperature of T_L, and the lower one at $y = 0$ is to be maintained at a lower temperature T_0. An ideal gas at temperature T_0 is blown upward through both plates at a steady rate. Develop an expression for the temperature distribution, (b) the amount of heat that must be removed from the cold plate per unit area as function of the fluid properties and gas flow rate. Assume negligible change in pressure with distance and negligible viscous dissipation.

Use abbreviation $\phi = \rho \hat{C}_p v_y L/k$.

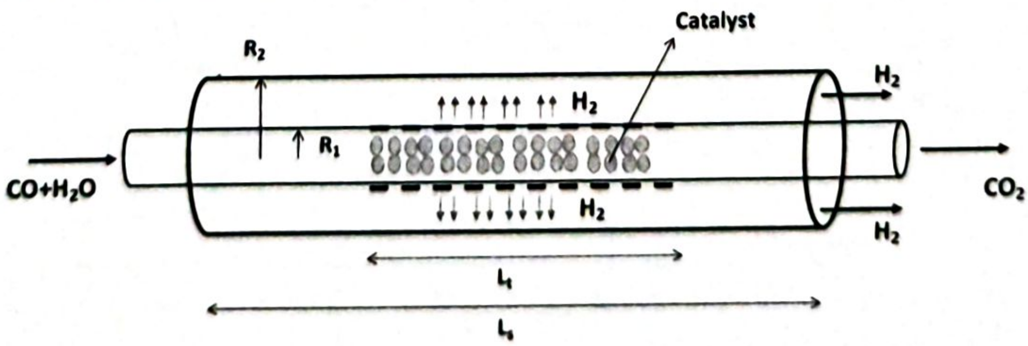
Q.4 **[8 Marks]**

A rod of radius kR moves upward with a constant velocity v_0 through a cylindrical container of inner radius R containing a Newtonian liquid. The liquid circulates in the cylinder moving upward along the fixed container wall. The mass is conserved. The thin-slit assumption is not valid here. (a) Derive the governing equations and write the boundary conditions. (b) Determine the velocity distribution, v_z.

Use dimensionless variable $\phi = \frac{v_z}{v_0}$ and $\xi = r/R$

Q.5 **[4 Marks]**

It is proposed to produce hydrogen (H_2) from water-gas-shift reaction ($CO + H_2O \leftrightarrow CO_2 + H_2$) in a catalyst membrane reactor as shown in the figure. The configuration is a shell-tube type where the catalyst is packed in the tube side with porous length (L_t). The porous tube is coated with a membrane capable for selectively removal of H_2. The reaction is slightly exothermic therefore, there will be heat rise in the catalyst. Develop the model for studying the flow, mass and energy in the system. Write all governing equations and relevant boundary conditions. Explain how the model can be simplified and solved to get the concentration profiles, velocity profiles and temperature profile in the tube side and shell side. [NOTE: Do not solve equations]



~ALL THE BEST~