BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE (BITS) PILANI – Pilani Campus

SECOND SEMESTER, 2022 – 2023 | CHE G552 Advanced Transport Phenomena | Comprehensive Examination

Time: **3.00 to 6.00 PM** **Maximum Marks: 80 (40%) | Date:** 17. 05. 2023 (Wednesday) | **CLOSE and OPEN BOOK**

INSTRUCTIONS

1. **This question paper consists of two parts. Part A is close book and Part B is open (only text) book.**
2. **Part-B answer book will be supplied after you return Part-A answer book.**
3. **Make and state suitable, logical and scientifically justifiable assumptions if necessary.**

❖ **Give just 2 iterations for iterative procedure(s), if any.**

❖ **Be to the point. Show all steps systematically.**

PART A (CLOSE BOOK)

Q1. [Marks 8] Recall the discussion, we had in classes, on "diffusion and chemical reaction inside a porous catalyst". Can you conceptualize the phenomena involved? Give an algorithm which can help you to get the concentration profile of the reactant(s) along the radius of the catalyst (particle). Draw this profile qualitatively. How do *Thiele modulus* and *effectiveness factor* surface in your formulation?

Q2. [Marks 25] **(a)** Derive equation of motion. Give the physical significance of each term.; **(b)** How can this equation give you equations of **(i)** mechanical energy and **(ii)** angular momentum? **(c)** How do you simplify it to the following equations: **(i)** Navier-Stokes; **(ii)** Stokes flow; **(iii)** Euler and **(iv)** Bernoulli. What about creeping flow equation? Is it the 5^{th} simplification? **(d)** Illustrate the physical significance of: *Re, Gr, Pe, Pr and Sc* (dimensional groups/number).; **(e)** Define, systematically, partial, total and substantial time derivatives.

Q3. [Marks 12] **(a)** What is Reynolds decomposition? How does one build time-smoothened equations of change? **(b)** Give the expressions for turbulent molar, momentum and heat fluxes.; **(c)** Define eddy transport properties for 3 transport phenomena, giving 3 (corresponding) defining expressions/equations.; **(d)** What analogy did Prandtl take for mixing length? **(e)** What is referred to as closure problem? In this context, how does ***k-ε*** empiricism help to get velocity and pressure distributions?

PART B (ONLY OPEN TEXT BOOK)

Q4. [Marks 15] A sphere of radius *R* and thermal conductivity k_1 is embedded in an infinite solid of thermal conductivity k_o. The center of the sphere is located at the origin of coordinates, and there is a constant temperature gradient *A* in the positive *z* direction far from the sphere. The temperature at the center of the sphere is T^o. The steady-state temperature distributions in the sphere T_1 and in the surrounding medium T_o have been shown to be:

$T_1(r,\theta) - T^\circ = \left[\frac{3k_0}{k_1 + 2k_0}\right] Ar\cos\theta \qquad r \le R$ [1]	$T_0(r,\theta) - T^\circ = \left[1 - \frac{k_1 - k_0}{k_1 + 2k_0}\left(\frac{R}{r}\right)^3\right] Ar\cos\theta \qquad r \ge R$ [2]
(a) What are the partial differential equations that must be satisfied by Eqs. 1 & 2? **(b)** Write down the boundary conditions that apply at r = R.	**(c)** Show that T_1 and T_o satisfy their respective partial differential equations in **(a).** **(d)** Show that Eqs. 1 and 2 satisfy the boundary conditions in **(b).**

Q5. [Marks 20] (a) A solid sphere of substance *A* is suspended in a liquid *B* in which it is slightly soluble, and with which it undergoes a first-order chemical reaction with rate constant k_1''. At steady state the diffusion is exactly balanced by the chemical reaction. Show that the concentration profile is:

$\frac{c_A}{c_{A0}} = \frac{R}{r}\frac{e^{-br/R}}{e^{-b}}$	$b^2 = k_1''' R^2/\mathfrak{D}_{AB}$.	in which R is the radius of the sphere, C_{Ao} is the molar solubility of *A* in *B*.

(b) Show by quasi-steady-state arguments how to calculate the gradual decrease in diameter of the sphere as *A* dissolves and reacts. Show that the radius of the sphere is given by:

$\sqrt{\frac{k_1''}{\mathfrak{D}_{AB}}}(R - R_0) - \ln\frac{1 + \sqrt{k_1''/\mathfrak{D}_{AB}}R}{1 + \sqrt{k_1''/\mathfrak{D}_{AB}}R_0} = -\frac{k_1'' c_{A0} M_A}{\rho_{sph}}(t - t_0)$	in which R_o is the sphere radius at time t_o, and ρ_{sph} is the density of the sphere.

END