20CH30005

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR
Mid-Autumn Semester Examination 2023-24

Date of Examination: 21.09.2023 Session AN Duration 2 hrs
Subject No. : CH62049 Subject Name: Microscale Transport Process
Department/Center/School: Chemical Engineering
Specific charts, graph paper, log book etc., required: No
Special Instructions (if any): Assume any data you feel are missing

Q1. Explain using **not more than two** sentences and/or mathematical expressions and/or drawing

i) Importance of optical transparency of a photoresist
ii) Purpose of vacuum in PVD and spin coating
iii) Applicability of continuum assumption vis a vis channel dimension
iv) Filling of a capillary (with one end closed) during molding
v) Shapes of etched volume after dry etching by physical, chemical, and physicochemical means respectively
vi) Change of velocity with progression of interface in a tube (open at both ends) by capillary force
vii) The directions of diffusion and convection considered in Taylor dispersion
viii) Nature of electric field in case of electrophoresis and dielectrophoresis respectively
ix) Mixing quality and mixer effectiveness
x) anodic bonding and fusion bonding

10×1 = 10 Marks

Q2. One end of a carbon nanotube is open to a gas phase, and the other end is impermeable. There is uniform deposition of active metal over the inner wall of the tube. The transport of gas within the tube follows Knudsen diffusion with flux $=-D_k\frac{\partial C}{\partial x}$; where D_k is the Knudsen diffusivity, C is the concentration of solute in the gas at a distance x, measured from the closed end of the nanotube. That is, $x = L$ at the open end of the nanotube. The chemisorption of solute from the gas phase to the tube wall follows Henry's law, with surface concentration $C_s=HC$. The reaction rate per unit area of inner wall is first order with respect to the surface concentration, and is equal to kC_s. The concentration gradient in lateral direction is insignificant.

i) Develop the steady state mass balance equation and write the boundary conditions.
ii) Show that the solution for the concentration distribution within the nanotube is given as $\frac{C}{C_0}=\frac{Cosh(\frac{\alpha x}{L})}{Cosh(\alpha)}$, where $\alpha^2=\frac{2kHL^2}{RD_k}$, and R,L are radius and length of the nanotube. **3+2 = 5 Marks**

Q3. In the *Book of Nonsense* by Edward Lear the following song can be found:

"They went to sea in a sieve, they did,
In a sieve they went to sea.
In spite of all their friends could say,
On a winter's morn, or a sunny day,
In a sieve they went to sea"

Considering the sieve to be a vessel of area 0.5 m^2 having pores of radius of 0.1 mm, evaluate whether the above poem is complete nonsense or it may be possible for a person with a certain weight (evaluate the weight) to float in such a sieve. The surface tension of water is to be taken as 72 mN/m. **[4 Marks]**

Q4. Consider the following statements and mark them true or false (even if only a part is incorrect) or true. You must give a **one-line** explanation for your answer. **[5x1=5 marks]**

a) i) For high flow rates, small channels induce a higher-pressure loss due to their high surface-to-volume ratio. Hence, low viscosity fluids are preferred for application in microchannels due to a tolerable pressure loss. ii) In curved channels, the hydraulic diameter influences the pressure loss only marginally, but convective effects determine the pressure loss coefficient ξ. With decreasing device dimensions, the pressure loss becomes proportional to the square of the Reynolds number.

.....continued

b) i) The square-cube law states that when an object undergoes proportional increase in size, its new volume is proportional to the cube of the multiplier and surface area is proportional to the square of the multiplier.
ii) In general, when the system size decreases, the properties that are a function of the area of interaction decrease rapidly than properties that depend on the curved surface area.

(c) Micro heat-pipes (MHPs) have angled corners that facilitate the return of condensate from the colder region to the warmer region of the heat pipe. Since the liquid transport is via the capillary action caused due to the angled corners, it is highly advantageous to design MHPs with several corners as opposed to a few.

(d) i) In a positive photoresist, the portion that is exposed to light does not become soluble to the photoresist developer. The unexposed portion of the photoresist remains soluble to the photoresist developer.
ii) A negative photoresist, on the other hand, is a type of photoresist in which the portion of the photoresist that is exposed to light becomes soluble to the photoresist developer. The unexposed portion of the photoresist is not dissolved by the photoresist developer.

(e) Choose the incorrect statement(s) from the following.
i) Bottom up processes are more economical as compared to top-down processes as it does not waste materials to etching
ii) The smallest of geometries can be created by photolithography as compared to any other bottom-up process.
iii) Bottom-up processes are usually employed to pattern organic semiconductors.
iv) The bottom-up approach is the opposite of top-down approach.

Q5. Give short answers with justification **[3x2 = 6 Marks]**

a. For heat transfer in a straight channel with laminar flow, the characteristic time, t_h is defined as

$$t_h = \frac{\rho c_p d_h^2}{3.65\pi\lambda}$$

Utilizing this relation and associated concepts answer and/or comment on the following questions/statements, citing clear reasons in each case.
i) The equation suggests that there is a clear advantage of using microchannels in heat transfer. Is it true always?
ii) Does this equation in any way help in choosing a coolant liquid/material of construction?
iii) Based on this equation and related concepts can you justify using microchannels for any specific type of mass transfer operations as well?

b. Using square-cube law, predict and then show how the shape of a water droplet will change with decreasing radius. You may take the surface tension of water to be 0.72 Nm

c. A thin layer of silicon dioxide is grown on the surface of a silicon wafer using thermal oxidation during photolithography. Explain why this phenomenon makes micro fabrication very efficient. Discuss at least two reasons.

Useful relations

$$\Delta p = \left(C_f \frac{l}{d_h} + \zeta \mathrm{Re}\right) \frac{\rho v^2}{2} \frac{\mathrm{Re}}{d_h^2}$$

$$\Delta p = P_L - P_V = -\sigma K$$

$$\Delta P = \sigma_{lv}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \sigma_{lv} K$$

$$\Delta p = \left(C_f \eta l + \zeta \frac{V}{N}\right) \frac{\rho}{2} \frac{V}{N d_h^4}$$

$$\Delta p = \left(C_f \nu \frac{l}{d_h} + \zeta d_h \bar{w}\right) \frac{\rho}{2} \frac{\bar{w}}{d_h} = C_f \frac{\eta l}{2 d_h} \bar{w} + \zeta \frac{\rho}{2} \bar{w}^2$$

$$Ca = \frac{\mu V}{\sigma} \qquad We = \frac{LG^2}{\rho\sigma} \qquad Bo = \frac{g(\rho_l - \rho_v)L^2}{\sigma}$$