MANIPAL INSTITUTE OF TECHNOLOGY
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IV SEMESTER B.TECH. EXTERNAL EXAMINATIONS APRIL/MAY 2019

SUBJECT: HEAT AND MASS TRANSFER OPERATIONS IN BIOPROCESSING [BIO2205]

Date of Exam:**02/05/2019** Time of Exam: **2.00 PM – 5.00 PM** Max. Marks: **50**

**Instructions to Candidates:**

- Answer ALL the questions & missing data may be suitable assumed

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| **1A.** | A truncated cone 0.3 m high is constructed of Aluminum. The diameter at the top is 75 mm and diameter at the bottom is 125 mm. The lower surface is maintained at $93^0$C, the upper surface is at $540^0$C. The outer surface is insulated. Assuming one dimensional heat flow, determine the rate of heat transfer in Watts, $K_{Al}$= 230 W/mK | **4** |
| **1B.** | Prove that for a spherical surface covered with an insulation of thermal conductivity k, critical insulation radius is 2k/h, where h is the convective heat transfer coefficient outside the insulation | **3** |
| **1C** | Water flows counter-currently through two concentric pipes with inner pipe of 1" OD and outer pipe of 2"OD. Ignore the thickness of inner pipe for calculation purpose. Cold water enters inner pipe at 1m/s at $30^0$C and exits at $60^0$C. Hot water enters outer pipe at $90^0$C at a velocity of 0.5 m/s. Compute LMTD.<br>$C_p$=4180 J/kg K, $\rho$ = 990kg/$m^3$ | **3** |
| **2A.** | Air at 3 atm and $200^0$C is heated as it flows through a tube with a diameter of 2.54 cm at a velocity of 15 m/s.<br>i. Calculate the heat transfer per unit length of tube if the wall temperature is at $20^0$C above the air temperature all along the length of the tube and constant flux condition is maintained at the wall.<br>ii. How much would bulk temperature increase over a 4 m length of the tube?<br>**Air properties**: $\mu$= 2.57 x$10^{-5}$ kg/m.s, k = 0.0386 W/mK, $C_p$ = 1.025kJ/kgK. | **5** |
| **2B.** | Saturated steam at one atmospheric pressure condenses on a 3m height (H) and 4 m wide (W) vertical plate that is maintained at $90^0$ C by circulating cooling water through the other side. Determine,<br>i. Total rate of heat transfer by condensation to the plate, kW<br>ii. The average heat transfer coefficient over the entire plate kW/$m^2$K<br>iii. The rate at which the condensate drips off the plate at the bottom in kg/s.,<br>**Average properties of condensate**: $\rho$ = 962 kg/$m^3$, k = 0.677 W/mK, $\mu$ = 3x$10^{-4}$ kg/m.s, latent heat = 2.27 x$10^6$ J/kg.<br>$$h = 0.944\left(\frac{k^3\rho^2 g\,\lambda}{\Delta T\, H\mu}\right)^{1/4}$$ | **5** |

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| **3A.** | A heated vertical wall of 0.75 m high of an oven for baking food with free surface at 500K is in contact with air at 300K. Calculate heat transfer coefficient and heat transfer per meter width of wall. Note that heat transfer by radiation need not be considered. Physical properties of air $\mu = 2.32\text{x}10^{-5}$Pa.s, Pr = 0.690, k=0.065W/mK, $Nu=0.59(Gr.Pr)^{0.25}$ $$Gr = \frac{L^3\rho^2 g\beta\Delta T}{\mu^2}$$ | **4** |
| **3B.** | Two parallel infinite plane surfaces are maintained at 200 $^0$C and 300$^0$C. Determine the net rate of radiation heat transfer per unit area when (a) the two surfaces are grey with emissivity of 0.7 (b) the two surfaces are black | **3** |
| **3C.** | Explain different regimes of boiling and the factors affecting them –(a) Natural convection (b) Nucleate (c) Transition | **3** |
| **4A.** | Oxygen is diffusing through a non-diffusing layer of methane 5 mm thick. The temperature is 20$^0$C and the pressure is 1 atm. Calculate the rate of diffusion of oxygen in kg/h through 1 m$^2$of methane film when the concentration of oxygen on two sides of the methane film are 15% and 5% by volume respectively. The diffusivity of oxygen through methane at 0$^0$C and 1 atm is 0.184 cm$^2$/s. | **4** |
| **4B.** | Explain the following – (i) Penetration theory (ii) HETP (iii) Schmidt Number | **3** |
| **4C.** | Solubility of $CO_2$ in PET polymer is 0.73 cm$^3$(STP)/[cm$^3$(polymer).atm]. A sachet of PET film of 25 μm thickness containing food product is packed under positive pressure of $CO_2$ at 38 mm Hg. Compute the rate of diffusion of $CO_2$ in g($O_2$)/m$^2$.d. Diffusivity of $CO_2$ through PET is 2x10$^{-9}$cm$^2$/s. | **3** |
| **5A.** | What are the desirable characteristics of plastic films for food packaging | **2** |
| **5B.** | Mass transfer coefficient of $O_2$ from a bubble rising in water is calculated using Winnikow equation (1967) at 25$^0$C. $Sh = \frac{2}{\sqrt{\pi}}[1 - \frac{2.89}{\sqrt{Re}}]^{0.5}\sqrt{Pe}$<br>Compute the flux of oxygen from rising air bubbles (g-$O_2$/m$^2$.s).<br>**Data:** Average bubble diameter =3 mm; Rise velocity = 5cm/s;<br>Viscosity of water = 8.9x10$^{-4}$Pa.s; density of water=995 kg/m$^3$;<br>Diffusivity of oxygen in water =2x10$^{-5}$cm$^2$/s; Saturation Oxygen concentration in water = 8 ppm (by wt, g/g), Concentration of oxygen in bulk =4 ppm (by wt, g/g).<br>Assume that saturation exists at bubble interface. | **4** |
| **5C.** | During absorption of $CCl_4$ from a mixture of air-$CCl_4$ by an organic oil, the individual gas and liquid phase mass transfer have been estimated to be 0.32 and 5.26 kmol/[hr. m$^2$. mol fraction] respectively. At a given location, the mole fractions of $CCl_4$ is found to be 0.3 and 0.01 in gas and liquid respectively. The equilibrium relationship under operating condition is given by y = 20*x, where x and y are mole fractions of $CCl_4$ in gas and liquid phases respectively.<br>(i) Estimate overall mass transfer coefficients $K_x$ and $K_y$ in kmol/[hr. m$^2$. mol fraction]<br>(ii) Estimate the flux of $CCl_4$ in kmol/(hr. m$^2$)<br>(iii) Determine interfacial composition | **4** |