1. Explain the following terms in detail: (12 pts)
   (a) Hagen-Poiseuille equation  (b) drag force  (c) relative volatility
   (d) two-film theory  (e) azeotropic distillation  (f) Nusselt number

2. Consider a binary mixture of A and B with the average velocity $u$.
   (a) What are the definitions of the average velocity $(u)$ and the molar flux of A $(J_A)$? (4 pts)
   (b) Derive the molar flux, $N_A = -D_{AB} \nabla C_A + y_A (N_A + N_B)$ and explain the physical meaning of the two terms in
       the right-hand side. Where $D_{AB}$=diffusivity, $y_A$= mole fraction of component A. (6 pts)
   (c) Under what condition the second term can be neglected? (2 pts)

3. A pure naphthalene ball of a radius $R$ is suspended in an infinite, still vapor-free air. The naphthalene is
   vaporized from the ball surface and diffuses outwards. The saturated vapor pressure of naphthalene at
   system temperature is $P_{sat}$, while the binary diffusivity of naphthalene vapor in air is $D_v$. Estimate the time
   required for the ball radius to shrink from $R$ to $0.9R$. (Hint: $\frac{\partial C}{\partial t} = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial C}{\partial r} \right) + \frac{q}{\rho C_p} \frac{\partial T}{\partial t}$) (10 pts)

4. To determine the temperature distribution in a medium, it is necessary to solve the appropriate form of the heat
   diffusion equation as follows, $\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) + \frac{1}{r^2} \frac{\partial}{\partial \theta} (k \frac{\partial T}{\partial \theta}) + \frac{\partial}{\partial z} (k \frac{\partial T}{\partial z}) + \frac{\partial q}{\partial r} = \rho C_p \frac{\partial T}{\partial t}$
   (a) How many boundary condition(s) and initial condition(s) needed in solving the above equation? (4 pts)
   (b) With regard to the boundary conditions, List at least three common used boundary conditions for the
       above equation at the surface. (6 pts)

5. A sphere thermocouple junction ($\rho=8500 \text{ kg/m}^3$, $c=400 \text{ J/kg K}$, and $k=20 \text{ W/m K}$) is used to measure the
   temperature in a gas stream. The convection coefficient between the junction surface and the gas is $400 \text{ W/m}^2\text{K}$.
   Determine (10 pts)
   (a) The junction diameter needed for the thermocouple to have a time constant $\tau = 1 \text{ second}$.
   (b) If the junction is at $25 \degree \text{ C}$ and is placed in $300 \degree \text{ C}$, how long will it take for the junction to reach $299 \degree \text{ C}$?
       (Hint): 1. $\tau = \frac{\rho V_c}{kA}$  2. $t = \tau \ln \frac{T-T_m}{T-T_m}$

6. Based on the following figure, write down the equation of conservation of energy for a steady-flow, open
   system. ($u_i$: internal energy, $q$:heat flow rate, $z$:height, $p$:pressure,$v$:volume, $\dot{W}$: work, and $V$:velocity)
   (6 pts)
7. A thick-walled tube of stainless steel \((k=19.0 \text{ W/m K})\) with 2-cm inner diameter (ID) and 4-cm outer diameter (OD) is covered with a 3-cm layer of asbestos insulation \((k=0.2 \text{ W/m K})\). If the inside/outside wall temperature for the composite pipe is maintained at 400 °C and 200 °C, respectively. Calculate the heat loss per unit length and the tube-insulation interface temperature. (8 pts)

8. Define the overall heat transfer coefficient \((U)\) by the following figure. (8 pts)

9. A pump draws a solution of specific gravity 1.84 and viscosity 1.20 cP from a storage tank through a 75-mm pipe (with roughness = \(1.5 \times 10^{-4}\) ft). The efficiency of the pump is 60%. The velocity in the suction line is 0.914 m/s. The pump discharges through a 50-mm in diameter and 30 meter in length pipe to an overhead tank. The end of the discharge pipe is 15.2 m above the level of the solution in the feed bank. Friction losses in the entire piping system are 29.9 J/kg. (16 pts)
   (a) What is the Reynolds number and mass flow rate in the suction line?
   (b) If \(f = 0.026 (k/D)^{0.24}\), what is the pressure drop due to the skin friction, \((-\Delta p_s)\), in the suction line?
   (c) What pressure must the pump develop?
   (d) What is the power delivered to the fluid by the pump?

10. Write down the physical meaning of Reynolds number in detail. Also, Compute the Reynolds number for oil with a specific gravity of 0.78 and a viscosity of 20 cP flowing at 5 ft/s in a 2-in pipe. (8 pts)