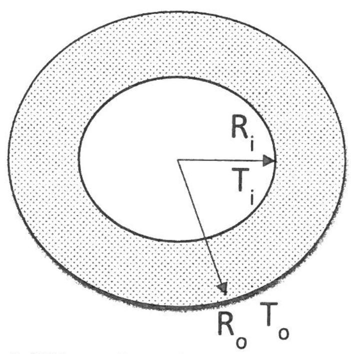
1. Explain the following terms: (a) momentum diffusivity; (b) the Reynolds stresses; (c) substantial derivative; (d) entrance length. [total 20 points; 5 points for each item]

2. A spherical tank of radius R and its drainpipe at the bottom of length L and diameter D are completely filled with a heavy oil. (a) Derive the expression of the total mass of the remaining oil when the height of the fluid reaches $h(t)$ at a certain time t during the draining process. [10 points] (b) Given the Hagen-Poiseuille equation for the mass flow rate in the drainpipe $w = \dfrac{\pi \Delta p D^4 \rho}{128 \mu L}$, where Δp is the pressure drop across the drainpipe, ρ is the fluid density, and μ is the fluid viscosity, derive the expression for the time t_{efflux} required to drain the tank. Assume there is an air vent at the very top of the spherical tank, and the volume of liquid in the tank is changing slowly with time so that the "quasi-state-state" approximation may be utilized. [20 points]

3. A long hollow cylinder, as shown in below, has fixed temperatures T_i and T_o at R_i and R_o, respectively. There is no heat generation inside the cylinder. Please find (a) the temperature distribution [10 points], (b) the heat flux [10 points], and (c) thermal resistance at steady-state condition for the long hollow cylinder [5 points]. Assume k is the thermal conductivity.



4. Gas A diffuses through a stagnant gas film to the surface of a nonporous spherical catalyst particle (radius= R) where it undergoes the reaction $3A \xrightarrow{k_1} B$. Gas B then diffuses from the catalyst surface and is swept away. Neglect diffusion and reaction on the ends of the particle. If the reaction is a very fast reaction, please derive (a) an expression for concentration profile of A in the stagnant film surrounding the sphere [15 points], and (b) the molar flux of A at R [10 points]. Assume that the thickness of the gas film is δR and $y_A = y_{A\delta}$. Denote D_{AB} as diffusion coefficient and y_A as concentration of A.