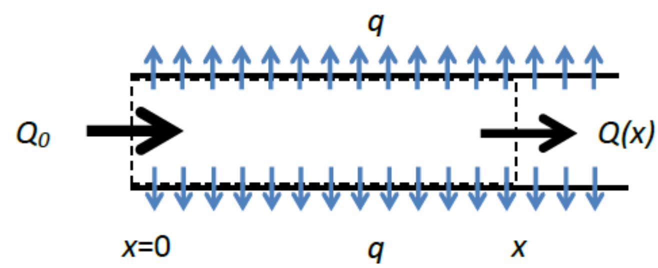
Department of Chemical Engineering, IIT Kharagpur
Mid-Semester Examination, 2015
Transport Phenomena (CH30012)
Time: 2 hrs, Full Marks: 30

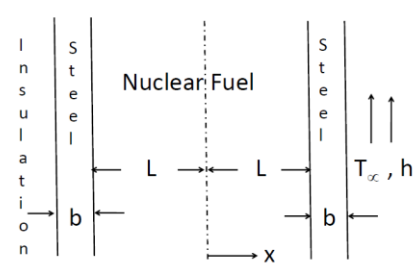
1. Epithelium is one basic type of animal tissue, which lines the cavities and surfaces of structures throughout the body. Epithelial layers contain no blood vessels, so they must receive nourishment via diffusion of substances from the underlying connective tissue, through the basement membrane.
   An apparatus has been built for testing the effect of various drugs on the rate at which an epithelium can pump fluid from its luminal side (the side facing the fluid) to its basal side (which lies on the channel wall). The cells line the top and bottom surface of a flow channel that has a separation of h (from top plate to bottom plate; ignore the thickness of cells), a length L, and a depth into the page of W. Each of these walls is porous so that any fluid pumped by the cells can leave the channel. Let each cell layer (top and bottom) pump fluid at a rate of q per unit area of the channel walls (q has thus units of length/time). The height of the channel is much less than its length ($h \ll L$).



   Fluid enters the channel at the left at a flow rate Q_0 and a gauge pressure of P_0. Because of the pumping action of the cells, the flow rate through the channel decreases as a function of x, the distance from the beginning of the channel. To determine the rate at which the cells are pumping fluid out of channel, the channel is instrumented with pressure transducers that can measure P(x). We would like to use this information to find the rate at which the cells pump fluid. The fluid in the channel has a density of ρ and a viscosity of μ. The flow is dominated by viscous effects and is steady.

   (a) Find the pressure distribution, P(x) , in the flow channel if $q = 0$.
   (b) Find the pressure distribution P(x) in the channel for $q \neq 0$.
   (c) Given that $P(x = L) = P_e$, find q .
   (d) Find the criterion necessary for the assumption that viscous flow dominates to be valid.
   All answers must be given in terms of the known quantities e.g., $x, L, W, h, Q_0, P_0, P_e,$ ρ and μ (not all of these parameters need necessarily be used). **3+6+1+3 = 13**

2. A nuclear fuel element of thickness 2L is covered with a steel cladding of thickness b on both sides as shown in the adjoining figure. Heat generated in the nuclear fuel at a rate of q (W/m^3) is removed by a fluid at T_∞ , which adjoins one surface and is characterized by a convection coefficient h. The other surface is well insulated, and the fuel and the steel have thermal conductivities k_f and k_s respectively. Obtain an expression for the temperature distribution T(x) in the nuclear fuel at steady state. Express your answers in terms of q, L, b, k_f , k_s, h and T_∞. Sketch the temperature distribution for the entire system. **6+2 = 8**



3. A long wire of diameter D = 1 mm is submerged in an oil bath of temperature T_∞ = 25C. The wire has an electrical resistance per unit length of R_e' = 0.01 ohm/m. If a current of I = 100 A flows through the wire and the convection coefficient is h = 500 W/m^2.K, what is the steady state temperature of the wire? From the time the current is applied, how long does it take for the wire to reach a temperature which is within 1C of the steady state value? The properties of the wire are ρ = 8000 kg/m^3, c = 500 J/kg.K and k = 20 W/m.K **2+7=9**