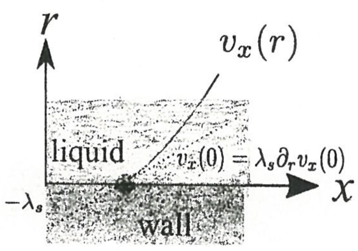
1. Consider the fluidic lab-on-a-chip dye laser system. The liquid used in the laser is ethanol with a viscosity at room temperature of $\eta = 1.197$ mPa s. The dimensions of the rectangular channel are length $L = 122$ mm, width $w = 300$ μm, and height $h = 10$ μm. For proper functioning the flow rate in the channel must be $Q = 10$ μL/h. Derive and calculate the pressure needed to run this device properly. (20%)

2. Consider a pressure-driven flow in a straight channel of length L with a circular cross-section of radius a given the Navier boundary condition with a non-zero slip length λ_S at the channel wall. This so-called Navier boundary condition reads



$$v_x(0) = \lambda_S\, \partial_r v_x(0), \quad \text{(wall at } r = 0\text{)},$$

where λ_S is the slip length or Navier length defined as the distance behind the boundary where the tangent of the velocity field intersects the x axis. Note that for $\lambda_S = 0$ we recover the usual no-slip boundary condition.

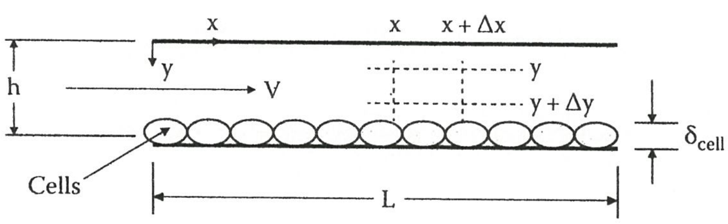
(a) Derive the expressions for the slip length dependent velocity profile $v_x(r)$ and for the hydraulic resistance $R_{hyd}(\lambda_S)$. (10%)

(b) Derive the expression for the hydraulic resistance $R_{hyd}(\lambda_S)$ based on the velocity profile derived above. (10%)

(c) Calculate the relative change in the hydraulic resistance when changing λ_S from 0 nm to 50 nm for the two values of the radius $a = 5$ μm and 0.5 μm. (10%)

3. Saturated steam at 130°C is flowing inside a ¾-in steel pipe having an ID of 0.824 in and an OD 1.05 in. The pipe is insulated with 1.5 in of insulation on the outside. The convective coefficient for the inside steam surface of the pipe is estimated as h_i=5674 W/m^2-K, and the convective coefficient on the outside of the lagging is estimated as h_o=11.348 W/m^2-K. The mean thermal conductivity of the metal is 45 W/m.K and 0.064 W/mK for the insulation. Calculate the heat loss for 1 m of pipe using resistance if the surrounding air is at 26 °C. (20%)

4. Consider a microchannel perfusion bioreactor system within which the oxygen concentration can be controlled by adjusting the flow rate of media through the device. Nutrient media flows through the bioreactor with an average velocity equal to V. On the lower surface, there is a monolayer of attached cells that consume the oxygen in the flowing stream.



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The entering oxygen concentration is C_{in} . Assuming steady-state, please

(a) derive the shell balance and the resulting differential equation for oxygen in a shell volume of the fluid with width W from x to $x + \Delta x$ and from y to $y + \Delta y$. (10%)

(b) Specify the boundary conditions and solve the differential equation by separation of variables. (20%)

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