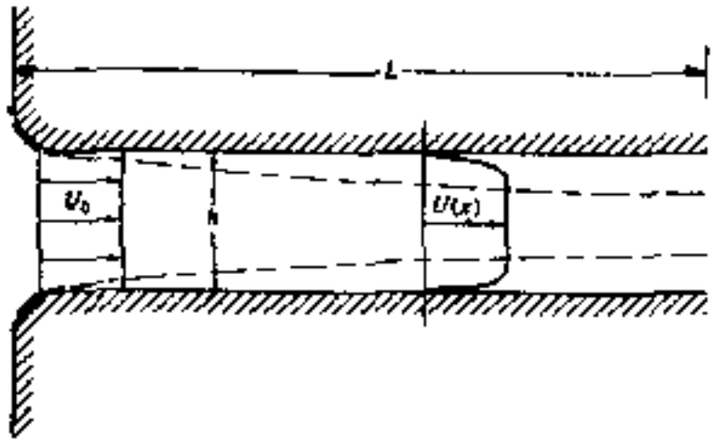
1. Find an expression for the shear force exerted on the two parallel walls of a wide channel of length L in terms of momentum thickness θ and displacement thickness δ_d. The fluid enters the channel with uniform velocity U_0 and the length of the channel is less than the development length. ((Hint: Von Kármán's integral equation $\tau_w = \rho \frac{d}{dx}(U^2\theta) + \rho \cdot \delta_d \cdot U \frac{dU}{dx}$ and the answer has the form $F = 2\rho\left\{ U_e^2 \theta_e + U_0^2 \frac{(\delta_d)_e^2}{h}\left[1 - 2\frac{(\delta_d)_e}{h}\right]^{-2}\right\}$, where the subscript e refers to the exit quantities.))
(20 %)



2. **External Viscous Flow (20%)**

Describe the Stokes' second problem (5%); derive the governing equation associated with its initial and boundary conditions for this problem (10%); is it possible to find a similarity variable for this problem? If yes, how to find it ? If no, why? (5%)

3. QUESTION (5% each)

A student would like to insulate a steam pipe line for his experiment to prevent the steam from condensing too rapidly. Let the outside diameter of the pipe line be d, while the insulator has a thermal conductivity k and a thickness t. Assume the average heat transfer coefficient outside the insulator is $\bar{h}$.

(a) Show that the overall thermal resistance from the outer surface of the pipe line to the ambient air can be evaluated from

$$R_{th} = \frac{1}{\pi d (1+2t/d)\bar{h}} + \frac{ln(1+2t/d)}{2\pi k}$$

for per unit length of pipe line.

(b) Find the critical thickness of insulator t_{crit}. {Hint}: At the particular thickness t_{crit}, the thermal resistance R_{th} reaches the minimum.

(c) Under what condition(s) would an increase in the thickness of the insulator increase the heat loss from the steam line ?

(d) Give the physical reasoning for your answer in part (c).

4. QUESTION (20%)

Andrew attempts to measure the air velocity by using a hot wire anemometer in his study for MS thesis. An electric resistance wire heater of diameter $10^{-4} m$ is placed perpendicular to the air flow. It holds a temperature of $40°C$ in a $20°C$ air flow while dissipates $17.8 W/m$ of heat to the flow. How fast is the air flowing ? Assume the air flow follows the rule

$$\overline{Nu}_d = 0.3 + 0.4857 (Re_d)^{0.5}$$

The thermal conductivities of the wire and the air are respectively $k_w = 72 W/m°C$ and $k_a = 0.0264 W/m°C$. The kinematic viscosity of the air is $\nu = 1.6 \times 10^{-5} m^2/s$.

5. Radiation Heat Transfer (20%, 5% each)

Define and discuss the following items in Radiation Heat Transfer: (a) simple radiation , (b) gray body, (c) radiosity, and (d) configuration factor.