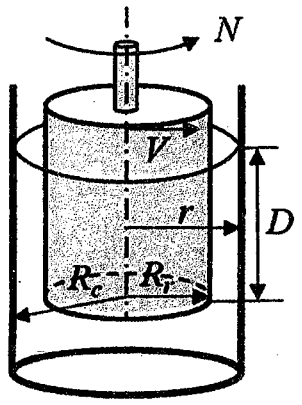
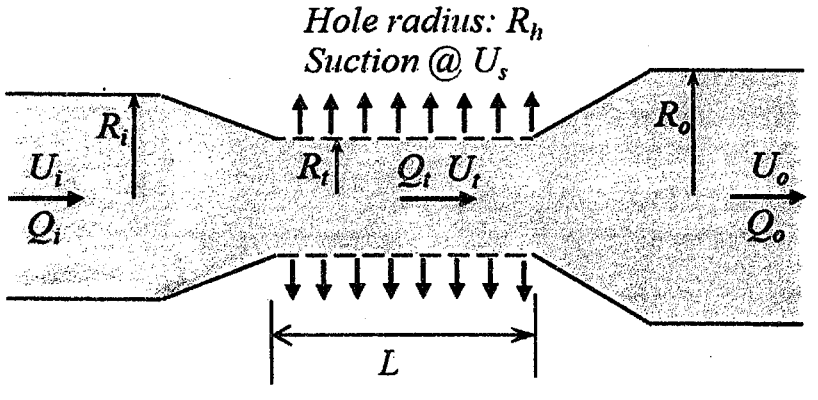
1. (25%) Coaxial cylinder viscometer is a standard tool for measuring the viscosity (μ) of a liquid. A rod is rotating inside a cylindrical container filled with liquid to be tested. A thin layer of liquid is held between the surfaces, and the immersion depth of the rod is D. The radii of the rod and the inner radius of the cylindrical container are R_r and R_c, respectively. The linear velocity on the rod surface is V, and it is determined by revolutions per minute N (rpm). To measure the viscosity μ of a liquid, a constant linear velocity V of the rod is maintained and a shear stress τ is induced on the rod surface. A constant torque T is needed to maintain the velocity V. Based on the Newton's law of viscosity, please answer the following questions.
(Note: The end effect of the rod is neglected.)
(A) (2%) This type of problem in fluid dynamics is called _____ flow.
(B) (3%) Describe the Newton's law of viscosity mathematically for this case.
(C) (5%) Derive the shear stress τ based on T, r and D.
(D) (10%) Derive the viscosity μ in terms of R_r, R_c, T, D and V.
(E) (5%) Considering the following test condition, find the viscosity of the unknown liquid.
$R_r = 20$ mm, $R_c = 25$ mm, $D = 100$ mm, $N = 60$ rpm, $T = 0.024$ mN·mm



2. (25%) Consider a wind tunnel with a narrower testing area that is porous for creating a thin viscous boundary layer. It is 5 m (L) long that contains 800 holes of 6-mm diameter (R_h) per square meter of area (800 holes/m^2). The suction velocity from each hole is 10 m/s. The velocity at entrance U_i is 40 m/s. Assuming incompressible flow, answer the following questions with the listed symbols.
(density: ρ; time: t; volume: V; area: A; radius: R; velocity: U; volume flow rate: Q; control volume: C.V.; control surface: C.S.)
(A) (3%) What is the general integral form of the continuity equation for a control volume?
(B) (6%) What is the physical meaning of each term in the continuity equation?
(C) (3%) In case of incompressible flow and steady state, write the reduced form of continuity equation?
(D) (5%) Use (C), find the resultant U_o in terms of U, R and N of the inlet, outlet, and suction holes.
(N is the total number of small holes)
(E) (8%) Find U_i, U_o and volume flow rate Q_o, where $R_i = 2$m, $R_t = 1$m, $R_o = 3$m.



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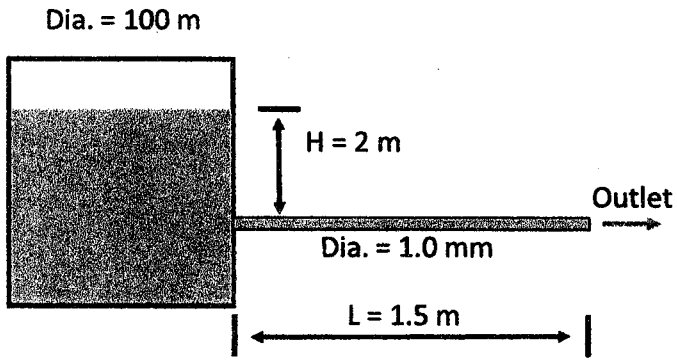
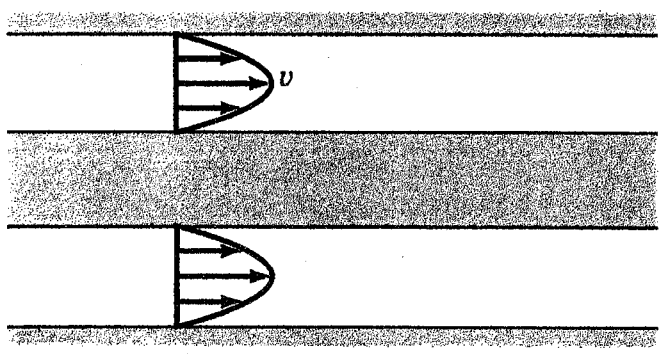
3. (25%) A 1.0 mm diameter horizontal tube is connected to a Styrofoam cylinder (diameter is 100 m) filled with water and sits on a fixed table. When we open the outlet of the horizontal tube,
   (A) (10%) What is the flow speed of the water emerging from the tube outlet?
   (B) (5%) Is it laminar or turbulence flow right before the water passing the tube outlet? And how do we distinguish them?
   (C) (10%) If 100.0 cm^3 is captured at the tube outlet in 60 s, please estimate the viscosity of the water.



4. (25%) A viscous liquid whose density ρ is 1.32×10^3 kg/m^3 and dynamic viscosity μ is 0.0065 N·s/m^2 continuously and steadily flows through a horizontal, 4 mm diameter tube at a rate of 12 ml/s.
   (A) (10%) Please determine the Reynolds number (*Re*) and pressure drop (Δp) along a 2 m length of the tube.
   (B) (10%) If a 3 mm diameter rod is placed in the 5 mm diameter tube to form a symmetric annulus. Please tell us the Reynolds number and pressure drop along a 2 m length, assuming the flowrate remains the same as in (B).
   (C) (5%) Is the pressure drop of fluid flowing in the annulus larger or smaller than that of the tube? Why?



A schematic illustration of symmetric annulus

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