CBE 30355 TRANSPORT PHENOMENA I

First Hour Exam
10/8/13

This test is closed books and closed notes

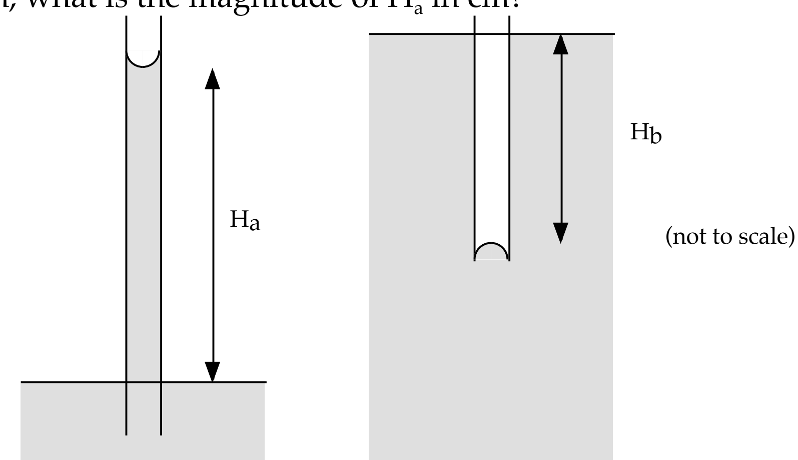
Problem 1. (15 pts) Hydrostatics: Consider the system depicted below. A tube of radius a is inserted into a liquid (say, water) of density ρ and viscosity μ as shown below. The surface tension in both cases is given by Γ, and the capillary pressure is given by $\Delta P_{cap} = 2\Gamma/a$.

a. If the tube material is wetted by the water (hydrophyllic), the liquid will rise into the tube. What is the equilibrium height of this capillary rise H_a given the parameters of the problem?

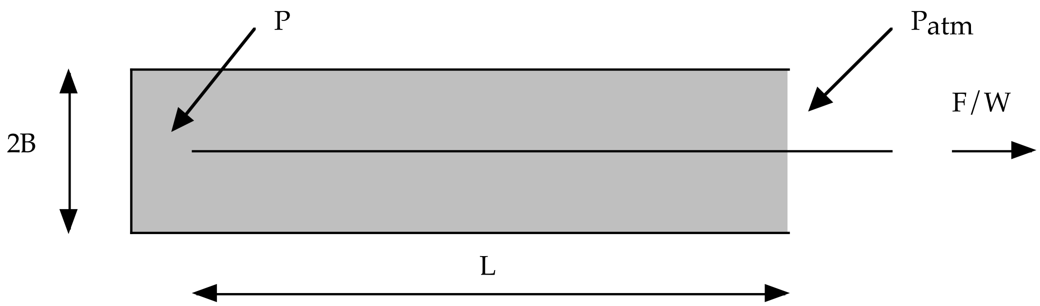
b. If the tube interior is coated with a hydrophobic material (say, a water repellent coating), water will resist entry into the capillary. How far below the surface of the water H_b can we stick the tube before water begins to enter?

c. If we insert the tube to twice the depth determined in part b, what happens?

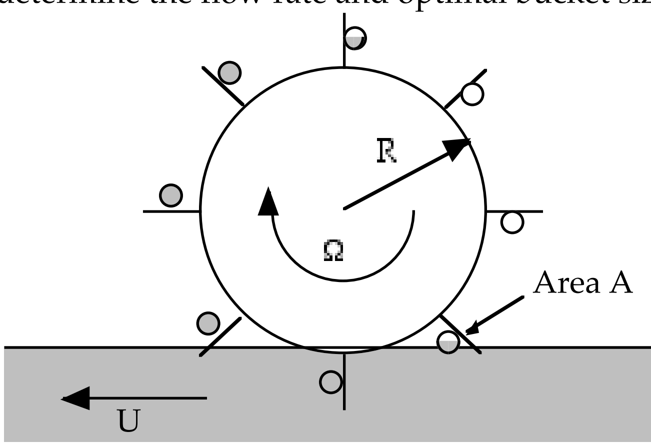
d. If the fluid is water (the surface tension for clean water is 70 dynes/cm), and the tube radius is 100μm, what is the magnitude of H_a in cm?



Problem 2. (15 pts) Viscous dampers and cavitation. A plate (of extension W into the paper and negligible thickness) is used as a viscous vibration damper as depicted below. The cavity (of width b on either side of the plate) is filled with a viscous fluid of viscosity μ. In this problem we ignore transients and fluid inertia (e.g., we are at low Re), and we take all flows to be unidirectional. The force/unit width F/W pulling the plate outwards is resisted by the resulting fluid flow exerting a shear stress on the plate. If you pull on it too hard, however, the pressure in the fluid at the end of the cavity will get so low that the fluid will cavitate: essentially when the local pressure equals the vapor pressure of the fluid the liquid boils. For simplicity, we take this vapor pressure to be zero. What is the maximum force F/W that can be applied to the plate before cavitation occurs?



Problem 3. (15 pts) Off I 26 in Orangeburg, SC (on the route to Hilton Head) is Edisto Memorial Gardens. Probably the most photographed feature of the gardens is a 70 year old waterwheel that was once used to pump water from the slow moving Edisto blackwater river to a nearby pond. Such undershot waterwheels were often used to irrigate rice paddies, for example. The operation is simple: the flowing water applies a force to the vanes of area A, causing the wheel to turn. As each vane enters the water a bucket fills with water and then empties at the top of the arc. Your mission is to determine the flow rate and optimal bucket size.



a. This problem isn't as "clean" mathematically as the idealized Pelton wheel solved in class, but the physical principle is the same. It is easiest to work with the total volume of all the buckets V_T, as then the number of vanes doesn't play a large role (assuming there are a lot of them, and one of area A is perpendicular to the stream at all times). Making any further assumptions necessary (but state them clearly so I can see how you get your answer!), develop an approximate equation for the flow rate Q of this pump.

b. What is the optimum value of V_T for a fixed river speed U? What is the maximum value of V_T for which the equation obtained in part a is valid?

Hint: The torque exerted on the wheel due to the filled buckets on one side (total filled volume $V_T/2$) is approximately $\rho\, g\, V_T\, R\, /\, \pi$.

Problem 4. (15 pts) Short Answer / Index notation / Additional Readings

1. Order according to their date of death (oldest -> most recent):
   A. Hero of Alexandria
   B. G. I. Taylor
   C. Osbourne Reynolds
   D. James Clerk Maxwell

2. Crooke's Radiometer works because of:
   A. Maxwell said it should
   B. Hot gas on the black face of the vane
   C. Thermal transpiration
   D. The momentum of light

3. If the center of a strong low pressure system is in Rochester, IN (e.g., about 50 miles south of here), which direction does the wind come from in South Bend? Note: A south wind is one that comes from the south and goes to the north, for example.

4. Write down the isotropic part of the total stress tensor in index notation.

5. Write down the continuity equation for an inc**ompressible** fluid using index notation.

6. (2pts) What is the most general isotropic third order tensor? What are its symmetries, if any?

7. (2 pts) What is the representation of the deviatoric stress τ_{ij} in terms of the velocity for an incompressible Newtonian fluid? (Index notation, please!)

(2 pts each) Identify the physical mechanism behind the following terms, **and provide an example of where they would play a role**:

8. $\rho \underset{\sim}{u}$ (two interpretations!)

9. $-\dfrac{\partial p}{\partial x}$

10. $\rho \dfrac{v_r v_\theta}{r}$