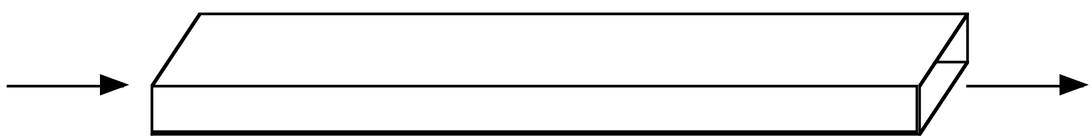
CHEG 355 TRANSPORT PHENOMENA I

First Hour Exam
10/6/09

This test is closed books and closed notes

Problem 1). (20 points) Plane Poiseuille Flow: A problem which is currently being investigated in bioengineering laboratories is the phenomenon of cell adhesion to surfaces in the presence of hydrodynamic stresses. This is very important in the design of biocompatible materials, for example. To study this, a researcher has built a rectangular flow cell which is 50μm deep, 2mm wide, and 2cm long. The objective is to have a wall shear stress (e.g., stress at the lower wall - the 2mm x 2cm surface - where cell adhesion is being studied) of 10 dyne/cm^2. Due to the ratio of length scales, you can assume unidirectional plane-Poiseuille flow. If the working fluid has the same viscosity as water (~1 cP), what should the flow rate of the pump supplying the fluid be?

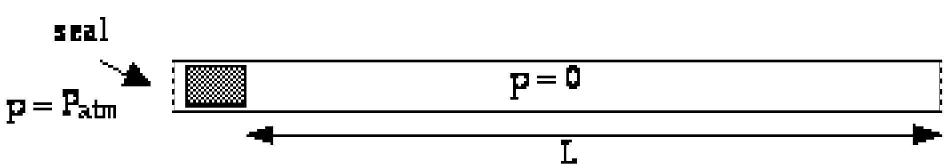


Problem 2. (20 pts) A popular student demonstration is the vacuum canon, depicted below. A projectile of mass M is placed in a tube of radius R and length L. The tube is sealed with a layer of tape at each end and evacuated using a vacuum pump. The canon is activated by popping the seal at one end, allowing atmospheric pressure to drive the projectile out of the other end at high velocity.

a. Neglecting all losses (and the inertia of the air), what is the maximum possible velocity of the projectile at exit?

b. If the atmospheric pressure is 10^6 dyne/cm^2, the tube radius is 2.54cm, the length is 100cm and the mass is 1kg, what is the numerical value of this velocity?

c. Estimate the maximum possible velocity of a very small mass projectile. (Hint: you have to include the inertia of the air! Take the density of air to be 1.2 x 10^{-3} g/cm^3.)



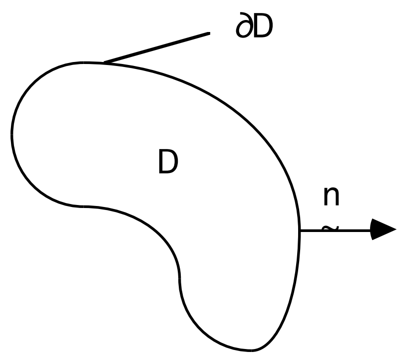
Problem 3. (20 pts) Consider the arbitrary fluid element depicted below. A fluid with thermal energy per unit volume $\rho\, C_p\, T$ (where T is the temperature and C_p is the heat capacity per unit mass) is flowing through the element with velocity $\underset{\sim}{u}$. In addition to convective heat transfer, we also have the conductive (diffusive) heat transfer flux, given by Fourier's Law of heat conduction:

$$\underset{\sim}{q} = -k \underset{\sim}{\nabla} T$$

which is analogous to the shear stress from Newton's law of viscosity. Here k is the thermal conductivity. There is also a source of thermal energy (heat generation) per unit volume S. due to chemical reactions or other sources. Both the velocity $\underset{\sim}{u}$ and the temperature T may be functions of position and time, but physical properties such as k, ρ, and C_p are taken to be constant.

a. Given the statement that thermal energy is conserved, derive an integral equation governing the thermal energy in the arbitrary control volume depicted below.

b. Using the results of part a, derive the microscopic equation governing energy transport in a flowing liquid.



Problem 4. (20 pts) Short answer questions:

1. The ratio of the centerline velocity divided by the average velocity:
   a. for laminar channel flow is:
   b. for laminar tube flow is:

2. Provide two physical interpretations for $\rho\, \underset{\sim}{u}$

3. $\rho \dfrac{u_\theta\, u_r}{r}$:
   a. What does it represent?
   b. Name one physical example where it plays an important role.

4. τ_{ij} :
   a. What is it?
   b. Is it significant for inviscid flows?

5. Write down the continuity equation for an incompressible fluid using index notation.

6. The symmetric part of the rate of strain tensor is usually given the symbol e_{ij}. What is its representation in terms of u_i? (Index notation, please!)

7. Match up the kinematic viscosities of the following materials:

1. Water	A. 0.118 cSt
2. Air	B. 1.0 cSt
3. Glycerine	C. 17.0 cSt
4. Mercury	D. 650 cSt

8. Flow visualization using the dye release technique (dye ejected from a fixed array of nozzles) reveals which of the below for **unsteady** flows?

A. Pathlines
B. Streaklines
C. Streamlines
D. All of the above

9. Using index notation, prove that the divergence of the vorticity is zero.

10. What is the most general second order **pseudo** tensor characterized by a single director p_i? (Hint: this is the one we used to show that rotation of a body of revolution with fore-and-aft symmetry was zero)