CHME420
Winter 2016
Exam 2
2/25/16
Time Limit: 125 Minutes

Name (Print): ______________________

This exam contains 9 pages and 4 problems. Check for missing pages.

The exam contains closed book and open book sections. Complete the closed book section and exchange it for the open book section with your instructor. No cell phone use allowed during the exam.

You are required to show your work on each problem. The following rules apply:

- **Read the problem statements carefully**. Do what is requested in each problem. Show your work at every step to communicate your knowledge and thinking process.
- **Organize your work** neatly and coherently in the space provided. Scattered work without a clear order and difficult to understand will receive very little credit.
- **Mysterious or unsupported answers will not receive full credit**. A correct answer that is unsupported by calculations or explanation, will receive no credit; an incorrect answer supported by substantially correct calculations and explanations might still receive substantial partial credit. A correct answer accompanied randomly by an incorrect one will undergo a deduction.
- If you need more space, request extra blank pages from the instructor. Label each additional blank page with your name, the problem number, and the page number for that particular problem. Place your additional pages in the right order and staple them together.

Do not write in this table:

Question	Points	Bonus Points	Score
1	30	0	
2	25	3	
3	25	3	
4	20	3	
Total:	100	9	

Closed book

1. (30 points) Answer the following questions using words and equations if necessary:

   (a) (5 points) The Hagen-Poiseuille equation relates the mass flow rate (w) to the pressure drop in a pipe:

   $$w = \frac{\pi(P_0 - P_L)R^4\rho}{8\mu L}$$

   where R is the radius of the pipe, L is its length, $(P_0 - P_L)$ is the pressure drop, ρ is the density of the fluid, and μ is its viscosity. State as many assumptions as you can for the use of this equation. How can we use this equation and approximately account for a compressible fluid?

   (b) (5 points) Why is it important to specify the coordinate system, its orientation, and its origin when solving transport problems?

   (c) (5 points) What type of quantity is $(2\pi RL)(\tau_{rz}|_{r=R})$ likely calculating? In what coordinate system? What is the likely physical significance of the quantities in each parenthesis? Be as detailed as you can.

(d) (5 points) How does the "fin approximation" simplify transport problems? How do we accomplish this simplification?

(e) (5 points) You are free falling from an airplane while simultaneously measuring the local CO_2 concentration with a handy smart-phone app. What kind of time derivative are you measuring? Explain.

(f) (5 points) You develop a model for fluid flow in a pentagonal duct driven by a pressure drop. You are very proud. Your lab partner is doing flow experiments on a pentagonal duct and he is measuring the pressure drop as a function of flow rate. He provides you with some data and you notice that up to a specific flow rate your model is very good at predicting the pressure drop. However, for flow rates above this "critical" flow rate, your model is very poor. What is the likely reason?

Open Book

2. (25 points) We have discussed the flow of two immiscible fluids inside a slit (§2.5 of your textbok, **open it now**). Consider that fluid I has a density of $1500\,\mathrm{kg/m^3}$ and a viscsoity of 1.1 cp. Fluid II has $\rho = 1000\,\mathrm{kg/m^3}$ and $\mu = 0.9\,\mathrm{cp}$. The pressure drop driving the flow is 2 atm. The dimensions of the slit are 1 m in length (z-direction), 10 m in width (y-direction), and 0.02 m in thickness (x-direction). Using the results and reference frame of §2.5, do the following:

   (a) (6 points) Calculate the forces on the upper and lower wall.

   (b) (4 points) In what direction are the forces on the upper and lower wall?

   (c) (4 points) What is the stress at the liquid-liquid interface?

   (d) (6 points) Calculate the average velocities of the two fluids and the total volumetric flow rate.

   (e) (5 points) Can this model predict the location of the liquid-liquid interface? If yes, how would you predict it? If no, why?

   (f) (3 points (bonus)) Given your answers above, can you point out a potential problem with the flow described in this problem?

3. (25 points) Figure 1 shows an annular fin (hollow cylinder) attached to a wall. Your objective is to obtain the heat flux and temperature profiles in the fin using the "fin approximation". You may assume that the wall is at temperature T_w, the ambient is at temperature T_a, and you may neglect the heat transfer at the end of the fin. You may assume that the heat transfer coefficient (h) is the same in the inside and outside surfaces of the fin. The fin material has a thermal conductivity k. Using a cylindrical coordinate system with the z-axis aligned with the center of the fin and the origin ($z = 0$) located at the wall, do the following:

   (a) (6 points) Write the correct postulates and boundary conditions.

   (b) (4 points) What are the areas for thermal conduction and for convection in this fin model?

   (c) (7 points) Use a shell balance to obtain the differential equation relating the temperature (T) and a spatial variable.

   (d) (6 points) Non-dimensionalize the differential equation and boundary conditions using $\hat{z} = z/L$ and $\Theta = \frac{T-T_a}{T_w-T_a}$ as the non-dimensional variables. Show your work in detail. Your work should be consistent with your answer in Part (c) to be eligible for partial credit.

   (e) (2 points) What is the solution to this non-dimensional equation? You may write it down without derivations.

   (f) (3 points (bonus)) What assumptions in the development of the model are likely flawed in a real physical situation?

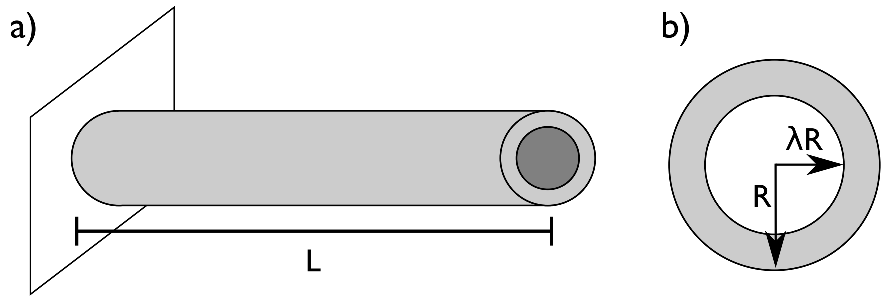

Figure 1: a) A semi-perspective view of an annular fin. b) A view of the cross-section of an annular fin.

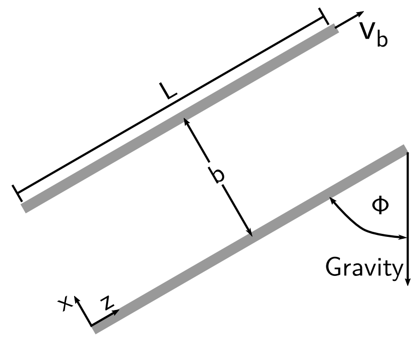

Figure 2: A slit in which the top plate is moving relative to the bottom plate.

4. (20 points) Two plates for a slit at an angle (ϕ) with respect to gravity as shown in Figure 2. The separation between the plates is b and the top plate moves at a velocity v_b. Using the coordinate system shown in the figure, do the following:

   (a) (6 points) Write a set of postulates and boundary conditions that are consistent with the problem statement and Figure 2.

   (b) (6 points) Obtain a differential equation relating the velocity in the z direction to the position in the x-direction.

   (c) (4 points) Solve the equation and obtain the integration constants.

   (d) (4 points) Derive an equation for the volumetric flow rate as a function of the problem parameters (all integrals should be performed). How fast should the upper plate be moving to obtain a volumetric flow rate of zero?

   (e) (3 points (bonus)) For the situation described in Part (d), draw a good sketch of the velocity profile that shows qualitatively how the flow rate can be zero.