Homework 3

CM3110

Fall

Exam 3 October 26, 2010 12-U115, 6:30pm-8:00pm

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1. Geankoplis 2.7-9. Water having a density of 998 kg/m^3 is flowing at the rate of 1.676m/s in a 3.068-in.-diameter horizontal pipe at a pressure p_1 of 68.9 kPa abs. It then passes to a pipe having an inside diameter of 2.067-in.
   - **a.** Calculate the new pressure p_2 in the 2.067-in. pipe. Assume no friction losses **(Answer p_2=63.5kPa)**
   - **b.** If the piping is vertical and the flow is upward, calculate the new pressure p_2. The pressure tap for p_2 is 0.457 m above the tap for p_1 **(Answer p_2=59.1kPa)**

2. Geankoplis2.6-4. Bulk Velocity for flow between parallel plates. A fluid flowing in laminar flow in the x direction between two parallel plates has a velocity profile given by the following:

$$v_x = v_{x\,max}\left[1 - \left(\frac{y}{y_o}\right)^2\right]$$

   Where $2y_o$ is the distance between the plates, y is the distance from the center line, and v_x is the velocity in the x direction at position y. Derive and equation relating $v_{x,av}$ (bulk or average velocity) to $v_{x,max}$ **(Answer V_{av}=2/3V_{xmax})**

3. Geankoplis 3.2-1 Flow measurement using a pitot tube. A pitot tube is used to measure the flow rate of water at 20^{o}C in the center of a pipe having an inside diameter of 102.3 mm. The manometer reading is 78 mm of carbon tetrachloride at 20^{o}C. The pitot tube coefficient is 0.98.
   - a. Calculate the velocity at the center and the average velocity (**Answer: v_{max}=0.9372 m/s, v_{av}=0.773 m/s**) and
   - b. Calculate the volumetric flow rate of water (**Answer: 6.35 x 10^{-3} m^3/s**).

4. What is the average flow rate for the steady flow of a power-law fluid in pressure-driven flow in a tube? The fluid is a power-law fluid and the viscosity follows the power law $\eta = m\dot{\gamma}^{n-1}$, where η is the viscosity in Pa s, $\dot{\gamma} = -\frac{dv_z}{dr}$ is the shear rate in s^{-1}. You may neglect the effect of gravity (**Answer: see updated lecture 7, p15**).

5. Geankoplis 3.5-1 Pressure drop of a power-law fluid, banana puree. A power-law biological fluid, banana puree, is flowing at 23.9^{o}C, with a velocity of 1.018 m/s, through a smooth tube

6.10 m long having an inside diameter of 12.67 mm. The fluid is a power-law fluid and the viscosity follows the power law $\eta = m\dot{\gamma}^{n-1}$, where η is the viscosity in Pa s, $\dot{\gamma} = -\frac{dv_z}{dr}$ is the shear rate in s^{-1}, and for banana puree m=K=6.00 (in the appropriate SI units) and n=0.454. The density of banana puree is 976 kg/m^3. Calculate the pressure drop for the flow in the pipe. (**Answer: 245 kN/m^2**)

6. Geankoplis 2.8-5 Force of water stream on a wall. Water at 298 K discharges from a nozzle and travels horizontally, hitting a flat wall inclined 45^o to the vertical. The nozzle has a diameter of 12mm, and the water leaves the nozzle with a flat velocity profile at a velocity of 6.0 m/s. The flow is frictionless and you may assume no loss of energy. The amount of fluid splitting in each direction along the plate can be determined by using the continuity equation and a macroscopic momentum balance. Calculate this flow division and the force vector on the wall. **Answer: m_2=0.5774 kg/s, m_3=0.09907 kg/s, R(force on wall)=-2.030N e_x+2.030 Ne_y**

7. A chromatography column is being designed, and we desire to calculate the expected pressure drop as a function of flow rate with water as the mobile phase. The fluid packing material has a surface area/volume of 5.0 x 10^3 m^2/m^3, and after packing the column, the void fraction of the column was measured to be 0.18. The column is 1.0 cm inner diameter and 1.0 meter long. Calculate the pressure drop for water flow rates of 1ml/min, 5ml/min, and 10 ml/min. **Answer: at 10 ml/min Δp=2.64E+04 Pa (3.8psi).**

8. What is the hydraulic diameter of a rectangular duct of height 5.0 in and width 12 in? For room temperature air flowing at a Reynolds number of 5.0e+04 through this duct, what is the average velocity? What is the friction factor? What is the pressure drop for 1000 feet of duct in psi? **Answer: 0.04 psi**

9. Use a macroscopic momentum balance to relate pressure drop to vector fluid force on the walls in a straight pipe. **Answer: F=$\Delta p \pi R^2 e_z$, see lecture 8, page 15**

10. The terminal velocity of a sphere falling in a liquid is the velocity at steady state when the downward force due to gravity on the sphere is exactly balanced by the upward retarding force due to the fluid. What is the terminal velocity of a sphere of density rs falling in a fluid of density r in the Stokes-flow regime? **Answer: terminal velocity = $(\rho_s - \rho)(2/9)gR^2/\mu$**