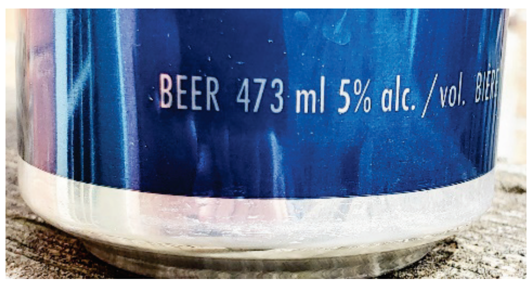
MEC516/BME516
Fluid Mechanics I

Chapter 1
Recommended Problem Set

I strongly recommended that you work through the details of these problems, with pen and paper. ***Be sure that you can solve these problems without looking at the solutions.***

1. SAE 10W oil has a specific gravity of SG=0.870 and a dynamic viscosity of μ=0.104 kg/(ms). What is the oil's kinematic viscosity, v?

2. In the alcohol industry, specific gravity is often measured to indirectly determine a beverage's alcohol content. Canadian beer is typically 5% alcohol *by volume*. The type of alcohol is ethanol. If the remaining 95% of the volume is assumed to be water (neglect dissolved sugar, etc.), estimate the specific gravity (SG) of beer at 20ºC.



3. Mixture concentrations are sometimes specified "by volume" or "by mass". What would be the specific gravity of beer (at 20ºC) if it was 5% alcohol ***by mass***?

4. The Stokes-Oseen formula for the drag force (F) on a sphere at low Reynolds number is:

$$F = 3\pi\mu DV + \frac{9\pi}{16}\rho V^2 D^2$$

where V is the fluid velocity, D is the sphere diameter, μ is the fluid dynamic viscosity, and ρ is the fluid density. Show that this equation is dimensionally homogeneous.

5. As we will show in Chapter 4, for laminar flow in a round pipe with diameter D, the exact solution for the volume flow rate is:

$$Q = \frac{CD^n \Delta p}{\mu L}$$

where C is a dimensionless constant, Q is the volume flow rate in cubic meters per second (m^3/s), Δp is the pressure difference, L is the length of the pipe, and μ is the fluid dynamic viscosity. What power of the exponent "n" is required to make this expression dimensionally homogeneous?

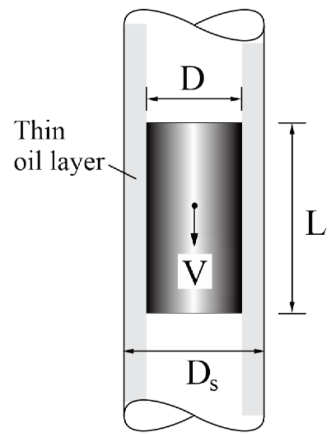
6. As will be discussed in Chapter 4, the following partial differential equation describes the conservation of x-momentum in an unsteady boundary layer flow:

$$\rho\frac{\partial u}{\partial t}+\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\mu\frac{\partial^2 u}{\partial y^2}+\rho g_x$$

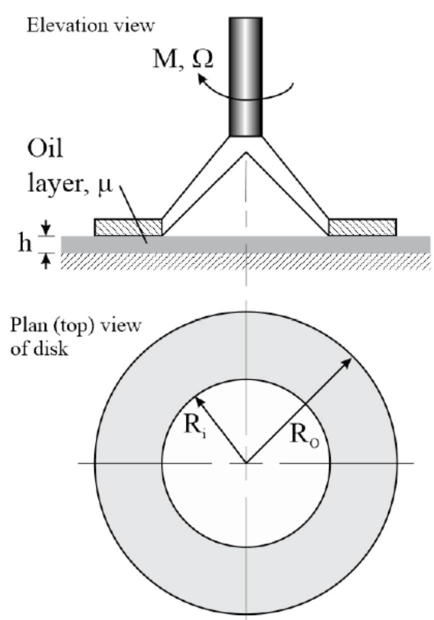
where u and v are the x- and y-components of velocity, p is pressure, μ is dynamic viscosity and g_x is the x-component of gravitational acceleration. Show that this equation is dimensionally homogeneous.

7. A tank contains 5.0 kg of carbon monoxide (CO) at 45ºC and an absolute pressure of 0.40 MPa. Use the idea gas equation of state to calculate the volume of the tank in litres.

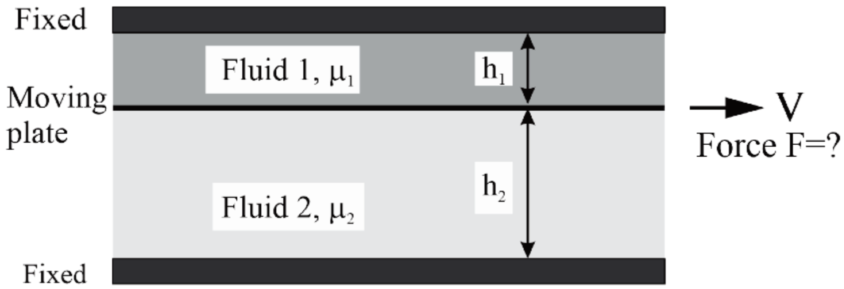
8. An aluminum cylinder weighing 30 N, D=6 cm in diameter and L=40 cm long, falls concentrically through a long vertical sleeve with an inside diameter of D_s=6.04 cm. The clearance is filled with a layer of SAE 50W oil at 20°C. Estimate the terminal velocity V of the cylinder. Neglect air resistance and assume a linear velocity distribution in the oil layer.



9. A thin layer of viscous oil lubricates the bottom surface of an annular round disk with inner radius R_i and outer radius R_o. The oil layer has thickness h and dynamic viscosity μ. Derive an expression of the torque M required to rotate the disk at a constant angular velocity Ω. Assume a linear velocity variation in the oil layer between the fixed surface and annular disk. Air resistance on the top surface can be neglected.



10. A thin moving plate is separated from two fixed plates by two fluids of unequal viscosity and unequal spacing, h_1 and h_2, as shown below. The contact area (one side) is A. Determine the force *F* required to move the central plate at constant velocity, *V*. Assume a linear velocity distribution between the plates. (We will prove that the velocity profile is linear in Chapter 4).

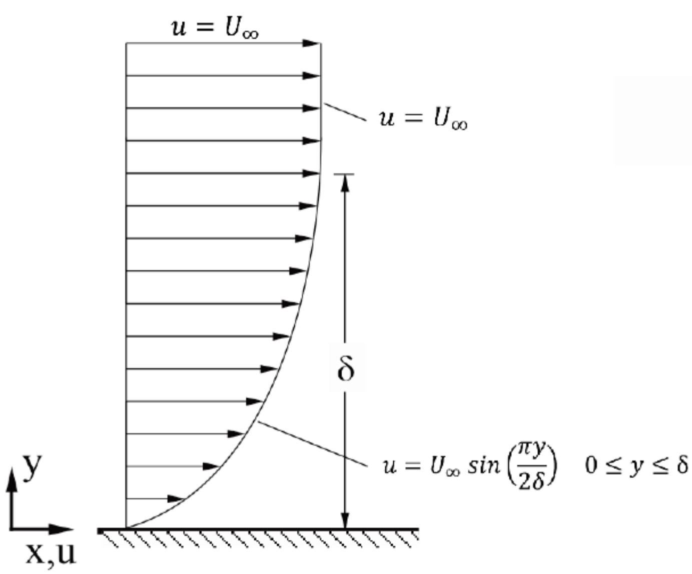


11. The internal diameter of a nominal ½ inch copper pipe is D_i=13 mm. When a hot water tap is opened, water at 50ºC flows with an average velocity of V=0.50 m/s. These are typical values for common house plumbing. Is the flow inside the pipe laminar or turbulent?

12. As shown below, assume that the velocity distribution in a boundary layer can be approximated as:

$$u = U_\infty \, sin\left(\frac{\pi y}{2\delta}\right) \qquad 0 \le y \le \delta$$

where U_∞ is the freestream velocity far from the plate surface, and δ is the boundary layer thickness. Consider air at 1atm and -40ºC flowing at a freestream velocity of $U_\infty = 5.2$ m/s. Calculate the shear stress on the surface for a boundary layer thickness of δ=4.5 mm. What is the direction of the force on the surface?



13. When water wets a surface, it is drawn up (against gravity) into narrow cracks by surface tension, i.e. by the capillary effect. See the diagram below. To what height h will water at 60ºC be drawn up between two long glass plates (d<<L) with a spacing of d=0.5 mm? Assume that water wets glass with a contact angle of θ=0º.