CE 3105 - Mechanics of Fluids Laboratory

Experiment 1: Fluid Properties

http://bit.ly/CE3105Fluids

1 Objectives

- Measure density, specific gravity of various fluids
- Measure the viscosity of a fluid

2 Theory

Density is a fundamental property of all materials including fluids. Density is typically defined using symbol ρ and is defined as the mass of the fluid to the volume occupied by it. Mathematically, density can be stated as:

$$\text{Density} = \frac{\text{Mass of the Fluid}}{\text{Volume occupied by the fluid}} \tag{1}$$

$$\rho = \frac{M}{V} \tag{2}$$

At a given temperature and pressure the density of a given fluid is constant. Let us say we keep pouring some fluid into a beaker, as the mass increases so does the volume and density which is the ratio of mass over volume stays constant. In SI system, the units of density is $\frac{kg}{m^3}$. In FPS system density is measured as $\frac{slugs}{ft^3}$ it is also expressed as $\frac{lb_m}{ft^3}$ where lb_m is pound mass.

Specific Weight is the weight per unit volume of the material. It is important to remember that weight is a **force** obtained by multiplying mass with acceleration due to gravity (g). Mathematically, specific weight can be expressed as:

$$\text{Specific Weight} = \frac{\text{weight}}{\text{volume}} \tag{3}$$

$$\gamma = \frac{W}{V} = \frac{m\dot{g}}{V} \tag{4}$$

At a given temperature, pressure and location, the specific weight of a fluid is constant. However, the acceleration due to gravity varies slightly with location. Therefore, the specific weight is not a universal constant. The specific weight of a fluid is slightly lower at the poles than at the equator even when the temperature and pressure of the fluid are the same at both locations.

Specific Gravity is another important fluid property which is defined as the ratio of the density of a fluid to the density of water at the same temperature. Clearly, the specific gravity is equal to 1.0 for water. Fluids denser than water have a specific gravity greater than 1 while those lighter than water have specific gravity less than 1.

$$\text{Specific Gravity} = \frac{\rho_s}{\rho_{H_2O}} \tag{5}$$

Being a ratio of two densities, specific gravity is a dimensionless quantity. Specific gravity can tell us whether a fluid will float or sink in water. Specific Gravity also provides consistency to compare fluids across different units.

Fluids are defined as substances that cannot completely resist shear stresses. A fluid starts to flow when shear stress is applied to them. However, different fluids flow at different rates when subjected to the same magnitude of shear stress. **Viscosity** measures the ability of the fluid to resist shear stress (i.e., internal resistance). One can also conceptualize viscosity as the frictional forces that exist between two layers of fluid that are in relative motion. **Dynamic Viscosity** measures the tangential force per unit area required

to move one horizonal plane relative to another at a unit velocity when maintaining unit distance apart.
The shear stress applied causes the fluid to flow and the according to Newton's law of viscosity, the shear stress τ is proportional to the velocity gradient $\frac{du}{dy}$ (see Figure 1). Dynamic viscosity μ is the constant of proportionality. Mathematically,

$$\tau = \mu \frac{du}{dy} \tag{6}$$

Using Equation 6 Dynamic Viscosity can be stated as the ratio of shear force to the velocity gradient. It has units of Pa.s or $\frac{kg}{(m\dot{s})}$. In cgs system the units of dynamic viscosity is Poise (or more commonly centipoise, cP). In US Customary units we express viscosity as $\frac{lb}{ft.s}$. In fluid mechanics, we often

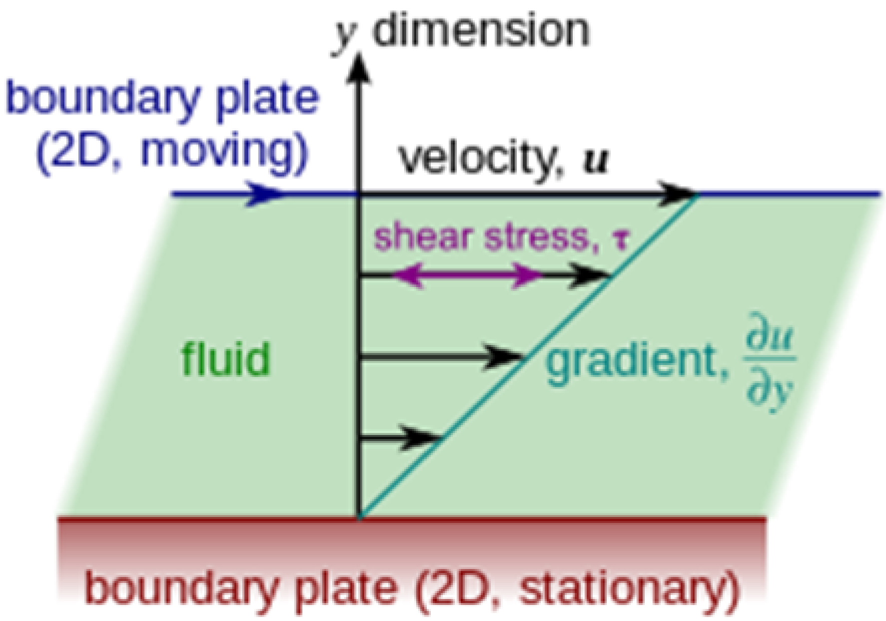

Figure 1: Shear Stress between two Parallel Planes

encounter the ratio of dynamic viscosity over density. This term is referred to as the **kinematic viscosity**. Mathematically,

$$\nu = \frac{\mu}{\rho} \tag{7}$$

Kinematic Viscosity has units of m^2/s and dimensions of length^2/s
One common method to calculate viscosity is to record the rate at which a sphere will fall through a fluid of interest. Under equilibrium conditions, the frictional forces experienced by the sphere will be equal to its weight. The sphere will fall at a constant velocity known as the terminal velocity. This phenomenon is referred to as **Stokes law**. Using Stokes law we can write:

$$u = \frac{g\dot{d}^2}{18\nu}\left(\frac{\sigma}{\rho} - 1\right) \tag{8}$$

Where, g is the acceleration due to gravity, d is the diameter of the sphere, ν is the kinematic viscosity, σ is the density of the sphere, ρ is the density of the fluid.

3 Procedure

PART I - Density Measurements

1. Measure the temperature of the fluid
2. Weigh the beaker provided
3. Fill the beaker with fluid, and measure its mass (beaker + fluid)
4. Carefully measure or estimate the volume of the fluid in the beaker
5. Repeat your measurements (duplicates for each fluid assigned to you)

PART II - Specific Gravity

1. Carefully place the calibrated hydrometer into the fluid and record the value corresponding to the lower meniscus,
2. Make duplicate measurement for each fluid assigned to you

PART III - Viscosity

1. Take a steel ball (sphere) assigned to your group and note its diameter
2. Carefully drop the ball into the ball guide
3. Note the volume readings corresponding to the upper and lower level markers (i.e., the two rubber bands)
4. Start the stopwatch when the ball reaches the first level marker (upper rubber band).
5. Stop the stopwatch when the ball reaches the second level marker (lower rubber band).
6. The density of the sphere is 7800 kg/m^3
7. Repeat the above steps for each sphere assigned to you

4 Calculations

PART I - Density

1. Calculate the density of the fluid by dividing the mass over volume for each fluid and sample
2. Calculate the mean and standard deviation for the estimated density of each fluid
3. Calculate the mass of salt present in the brackish water sample. Calculate mean and standard deviation over all samples.

PART II - Specific Gravity

1. Tabulate the specific gravity measurements for each fluid.
2. For each fluid calculate mean and standard deviations
3. Plot density (calculated from PART I) (on X-axis) and specific gravity (on Y-axis). Fit a straight line and record the slope, intercept and coefficient of determination R^2

PART III - Viscosity

1. Calculate kinematic viscosity for each sample using Equation 8.
2. Use the density calculated in PART I to calculate dynamic viscosity for each sample.
3. Tabulate the mean and standard deviation for both kinematic and dynamic viscosity measurements

5 Interpretation Questions (for Report)

1. Why is it important to measure temperature when measuring density and viscosity?
2. How do you think the density and viscosity of water would change with temperature.
3. How do salts alter the density of groundwater? Why is measurement of brackish water density important for civil and environmental engineers.
4. What is standard deviation? What does it tell us about the accuracy of the measurements?
5. What are some potential sources of errors in your lab experiments. Please discuss this with respect to measuring density, specific gravity and viscosity.

6 Data Sheet

Data sheet will be provided in class.