Experiment 1: Fluid Properties

Key Concepts: Specific Weight, Dynamic Viscosity

Refer to: Roberson, Crowe & Elger, 7th ed., Chapter 2, pp. 13 -22

I. Introduction

The transportation and accumulation of sediment in waterways and reservoirs, the movement of dust and other pollutants in the atmosphere, and the flow of liquids through porous media are examples of phenomenon in which specific weight and viscosity play important roles.

Consider a sphere with diameter d and specific weight γ_s, falling at a constant velocity V through a liquid with viscosity μ, specific weight γ_l, and density ρ. The forces acting on the sphere are shown in Figure 1.

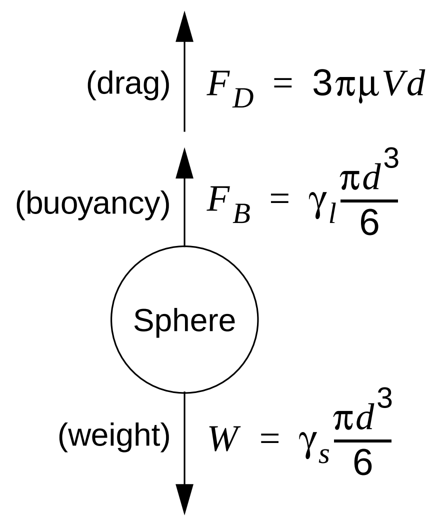

Figure 7. Free body diagram of falling sphere

Note that the expression given in Figure 1 for the drag force is derived from Stoke's Law and is valid only for small Reynolds number (see "Dimensionless Fluid Parameters" on page 8).

According to Newton's Second Law (since the sphere is not accelerating):

$$\sum F = 0 \tag{7}$$

$$F_D + F_B - W = 0 \tag{8}$$

$$3\pi\mu V d + \gamma_l \frac{\pi d^3}{6} - \gamma_s \frac{\pi d^3}{6} = 0 \qquad (9)$$

Algebraic manipulation yields an expression for μ in terms of γ_s, γ_l, d and V:

$$\mu = \frac{d^2(\gamma_s - \gamma_l)}{18V} \qquad (10)$$

Equation (4) is valid for a sphere falling far from a wall. The 'wall effect' occurs when the falling sphere is close to a wall. The 'wall effect' affects the sphere when:

$$\frac{\text{sphere diameter } (d)}{\text{tube diameter } (D)} > \frac{1}{3} \qquad (11)$$

The observed fall velocity, V_o, must then be corrected using:

$$\frac{V}{V_o} = 1 + \frac{9d}{4D} + \left(\frac{9d}{4D}\right)^2 \qquad (12)$$

The drag force on a sphere may also be calculated by:

$$F_D = C_D A_P \rho \frac{V^2}{2} \qquad (13)$$

where A_P is the projected area of the sphere and C_D is the coefficient of drag.

In this experiment: After measuring the terminal velocity of spheres falling through a fluid, the viscosity of a liquid will be determined according to (4). Equation (7) is then used to calculate the coefficient of drag.

II. Objective

Determine the specific weight and the viscosity of liquids at room temperature. Also determine a relationship between the coefficient of drag and the Reynolds number.

III. Anticipated Results

At a minimum, you should be able to anticipate:

1) What are the specific weight and viscosity of oil and glycerin?
2) What is the relationship between C_D and Reynolds number?

IV. Apparatus

1) Two liquids contained in three transparent vertical tubes: two large tubes and

one small tube. The small tube and one large tube should contain the first liquid (oil), while the second large tube should contain the second liquid (glycerin). Inside each tube is a bail bucket to catch the falling spheres. There is also a hooked rod to retrieve the bucket by the handle.

2) Calibrated volumetric containers of the above liquids.
3) Tweezers.
4) Thermometer, micrometer, meter stick, stopwatch.
5) At least five spheres of varying density and/or diameter (use marbles, shot-filled balls, etc.).

V. Procedure

1) Record the temperature of the liquids (use the ambient temperature if the liquids have been in the room for a long period of time).
2) Calculate the specific weight of each liquid by weighing a known volume. The tare weight of the calibrated containers (not including the stoppers) is scribed on the outside of each container.
3) Weigh each sphere and measure its diameter with a micrometer (to account for out-of-round conditions, take several measurements at various diameters and average the result). Calculate the specific weight of each sphere. NOTE: if the specific weight of the sphere is not greater than that of the fluid, it will float and not fall - choose another sphere.
4) Measure and record the inside diameter of the tubes.
5) Measure and record a vertical fall distance on each tube (the distance need not be the same for each tube). Use a scribed line or masking tape to locate the distance. There should be ample liquid above and below the lines so that the sphere will not be influenced by the bail bucket and to allow the person with the stopwatch an adequate distance to visually identify the sphere dropping. Check that the handle of the bucket will not interfere with the travel of the sphere.
6) Drop a sphere into the liquid using the tweezers and time the descent through the marked distance using the stopwatch. Record the travel time. The sphere should be dropped just at the fluid level so that the sphere will achieve terminal velocity prior to the marked distance.
7) Repeat item 6 for each sphere. When all spheres have been dropped, retrieve the bail bucket with the hooked rod. Remove the spheres from the bucket, cleaning them thoroughly with towels or rags. Push the bucket back down using the rod, then remove and clean the rod with towels or rags.
8) Repeat 6 and 7 for each tube.

VI. Data Control

Data control consists of calculating the viscosity, μ, for each drop. The consistency of the calculated data indicates the quality of the observed data.

VII. Results

1) Plot, at log-log scale, the coefficient of drag, C_D, of the spheres vs. the Reynolds number from the laboratory data. Since neither variable depends on properties of the fluid or the spheres, use all of the data points on the same plot.

2) Determine the equation of the plot for item 1 and compare it to the expected value. Hint: use equation (13) and Figure 7.
3) Compare your calculated values of viscosity and specific weight with an authoritative source.

VIII. Suggested Data Sheet Headings ([ ] indicates units of measurement)

	Liquid A	**Liquid B**
Volume [ ]		
Total mass [ ]		
Tare mass [ ]		
Mass of liquid [ ]		
Specific weight [ ]		
Temperature [ ]		

Sphere #	**Sphere Diameter [ ]**	**Mass [ ]**	**Volume [ ]**	γ_s **[ ]**

Liquid A/B	Tube Diameter [ ]	Sphere #	Sphere Diameter [ ]	Fall Distance [ ]	Time of Fall [ ]	Terminal Velocity [ ]	Corrected Velocity [ ]	Viscosity [ ]