## Objective:

The meaning of viscosity is the measure of a fluid's resistance to flow. Therefore it is required for engineers to have the knowledge on viscosity and the value of it because it can have a huge effect on engineering projects and assignments or it can be used to assistance engineers with their projects or assignments. Viscosity changes with pressure and temperature, temperature having a large effect, which cannot be ignored, and the pressure having a small effect, which usually can be ignored. Oil is very viscous when it's cold, which leads to high fluid friction. When temperature is high the oil viscosity is reduced and the friction of the oil is decreased. The purpose of the experiment was to determine the dynamic viscosity of engine oil by measuring the velocity of different small spheres falling through oil. Students will obtain the necessary information in order to measure viscosity of the oil by using simple spherical ball with different masses and a graduated cylinder filled with oil. From the definition of viscosity the relation between the speed of the sphere in the oil and the density of the oil, the students will be able to measure viscosity.

## Theory:

The definition of viscosity of a liquid is its resistance to shear or angular deformation. Therefore in many engineering applications, the process of determining the value of the viscosity is very critical.

Equation used:

$$\tau = \mu \frac{\partial u}{\partial y} \tag{1}$$

In equation (1), $\mu$ is called *Dynamic viscosity*. Fluids that obey Eq. (1) are called *Newtonian fluids*.

To determine the viscosity of the fluid, is to measure the rate at which a sphere of known size and density falls through the liquid under the influence of gravity. When the sphere has reached a steady velocity the sun of forces on the sphere will be zero:

$$\Sigma F = ma = 0 F_D + F_B - W_s = 0 \quad (2)$$

In equation (2), terminal velocity, the weight of the sphere ( $W_s$ ) is balanced by the upward drag force ( $F_D$ ), and the upward buoyancy force ( $F_B$ ).

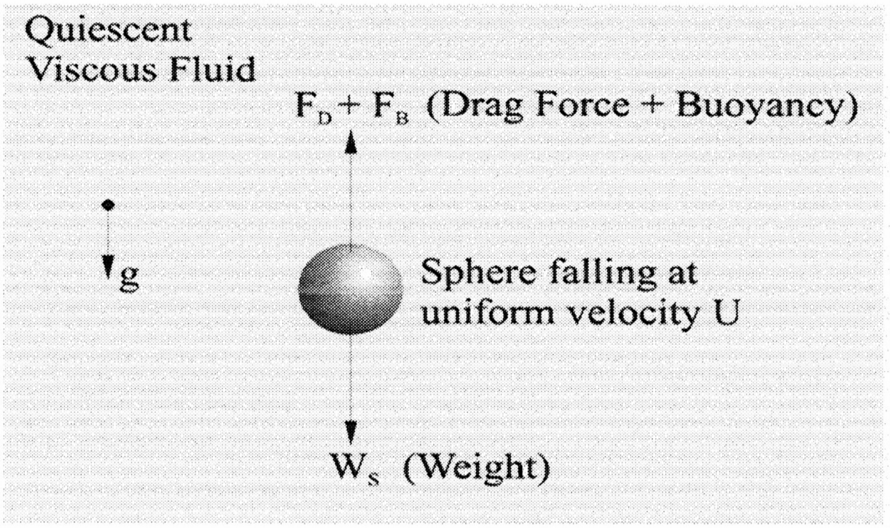


**Figure 1: Force balance on a sphere falling through a viscous fluid.**

## Procedure:

1. At the start of the experiment, the temperature of the oil was measured with a thermometer.
2. The specific gravity of the oil was determined by using the hydrometer.
3. For each size of the sphere, the steady velocity of the sphere in the oil was measured using a stopwatch.

4. Reproducibility of the result was checked by repeating the measurements for the largest sphere.

## Calculations:

$$Velocity=\frac{distance}{time}$$

$$Volume\,of\,sphere=\frac{4\pi r^3}{3}$$

$$F_{b=\gamma\pi\left(\frac{D^3}{6}\right)}$$

$$F_{d=3\pi\mu VD}$$

$$\frac{D}{6}$$

$$W=\gamma_s\pi(¿¿3)$$

¿

$$W-F_d-F_b=0$$

$$\mu=\frac{D^2g(\rho_s-\rho_f)}{18U}$$

(Derivation from the three Force analysis equations)

$$\frac{\rho_f UD}{\mu}<1$$

(Checking for validation)

## *Big Ball 1:*

Volume = $\frac{\pi \text{¿} 0.0125^3}{6}$ = $1.0226 \cdot 10^{-6} m^3$

Velocity= $\frac{20}{5.93} * 10^{-2}$ =0.0337 $m/s$

$(fluid) = \text{¿} \rho_{(water) \cdot s = 1000 \cdot 0.89 = 890}$

$\rho_{\text{¿}}$

Thus:

$$\mu = \frac{D^2 \times g \times (\rho_s - \rho_f)}{18 \times U}$$

For Ball 1: D=0.0125 m

$\rho_s = \text{¿}$ m/v= $\frac{1.22 \times 10^{-3}}{1.0226 \cdot 10^{-6}}$

U= 0.0337 m/s

$$\mu=\frac{0.0125^2\times 9.8\times(\rho_s-890)}{18\times 0.0337}=0.7649\,kg/m\cdot s$$

Checking for validation:

$$\frac{\rho_f UD}{\mu}<1 \quad , \quad \frac{890\times 0.0337\times 0.0125}{0.7685}=0.476<1$$

Meet the condition

*Big Ball 2:*

Volume = $\frac{\pi \text{¿} 0.0125^3}{6}$ = $1.0226\cdot 10^{-6}\,m^3$

Velocity= $\frac{20}{5.28}*10^{-2}$ =0.0378 $m/s$

$$(fluid)=\text{¿}\,\rho_{(water)\cdot s=1000\cdot 0.87=870}$$
$$\rho_{\text{¿}}$$

Thus:

$$\mu=\frac{D^2\times g\times(\rho_s-\rho_f)}{18\times U}$$

For Ball 1: D=0.0125 m

$\rho_s = ¿$ m/v= $\frac{1.22\times 10^{-3}}{1.0226\cdot 10^{-6}}$

U= 0.0378 m/s

$$\mu = \frac{0.0125^2 \times 9.8 \times (\rho_s - 890)}{18 \times 0.0378} = 0.6819\, kg/m\cdot s$$

Checking for validation:

$\frac{\rho_f U D}{\mu} < 1$ , $\frac{890 \times 0.0337 \times 0.0125}{0.6851} = 0.533 < 1$

Meet the condition

## *Medium Ball:*

Volume = $\frac{\pi ¿ 0.00946^3}{6}$ = $4.43\cdot 10^{-7}\, m^3$

Velocity= $\frac{20}{9.03} * 10^{-2}$ =0.0221 $m/s$

$(fluid) = ¿\, \rho_{(water)} \cdot s = 1000\cdot 0.87 = 870$

$\rho_{¿}$

Thus:

$$\mu = \frac{D^2 \times g \times (\rho_s - \rho_f)}{18 \times U}$$

For Ball 1: D=0.00946 m

$\rho_s = ¿$ m/v= $\frac{0.5 \times 10^{-3}}{4.43 \cdot 10^{-7}}$

U= 0.0221 m/s

$$\mu = \frac{0.00946^2 \times 9.8 \times (\rho_s - 890)}{18 \times 0.0221} = 0.5702\, kg/m \cdot s$$

Checking for validation:

$\frac{\rho_f U D}{\mu} < 1$ , $\frac{890 \times 0.0221 \times 0.00946}{0.5702} = 0.319 < 1$

Meet the condition

*Small Ball:*

Volume = $\frac{\pi ¿ 0.006175^3}{6}$ = $1.232 \cdot 10^{-7} m^3$

Velocity= $\frac{20}{19.4} * 10^{-2}$ =0.0103 $m/s$

$$(fluid) = ¿\, \rho_{(water)} \cdot s = 1000 \cdot 0.87 = 870$$

$$\rho_{¿}$$

Thus:

$$\mu = \frac{D^2 \times g \times (\rho_s - \rho_f)}{18 \times U}$$

For Ball 1: D=0.006175 m

$$\rho_s = ¿ \quad \text{m/v=} \quad \frac{0.16 \times 10^{-3}}{1.232 \cdot 10^{-7}}$$

U= 0.0103 m/s

$$\mu = \frac{0.006175^2 \times 9.8 \times (\rho_s - 890)}{18 \times 0.0103} = 0.8641\, kg/m \cdot s$$

Checking for validation:

$$\frac{\rho_f U D}{\mu} < 1 \quad , \quad \frac{890 \times 0.0103 \times 0.006175}{0.8641} = 0.064 < 1$$

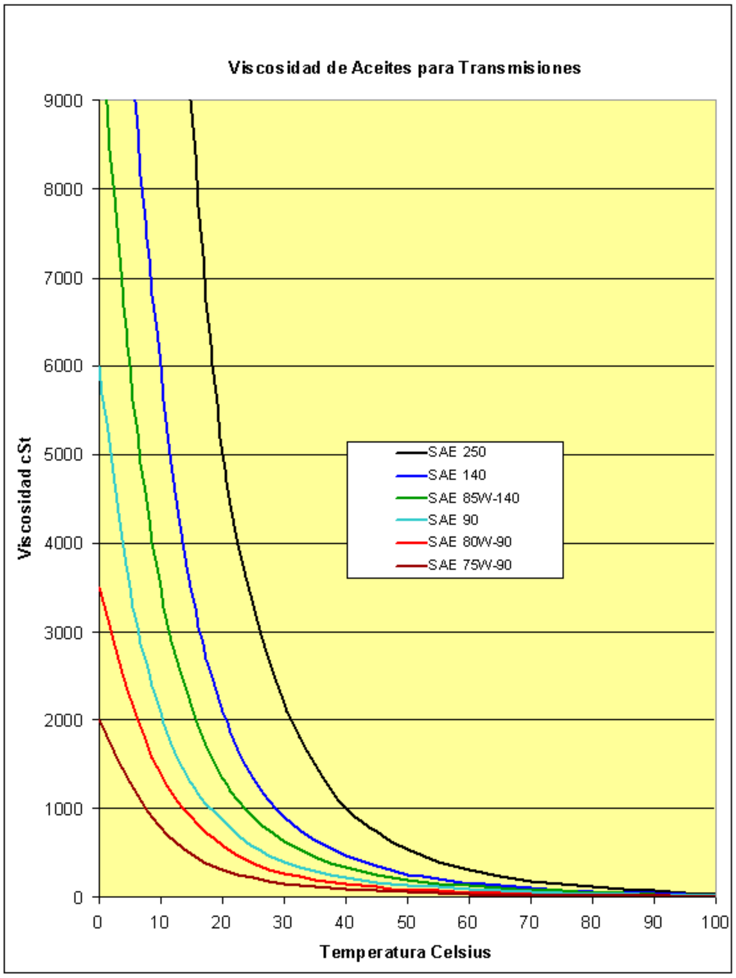
Meet the condition

|  | Diameter (mm) | Weight(g) | Time(s) | Distance (cm) | Velocity (cm/s) | Viscosity (kg/ m · s) |
|---|---|---|---|---|---|---|
| Big ball 1 | 12.500 | 1.22 | 5.93 | 20 | 0.042386 | 0.7649 |
| Big ball 2 | 12.500 | 1.2 | 5.28 | 20 | 0.042857 | 0.6819 |
| Medium | 9.460 | 0.5 | 9.03 | 20 | 0.026316 | 0.5702 |
| Small | 6.175 | 0.16 | 19.4 | 20 | 0.013629 | 0.8641 |

Table 1.2: data table with calculated $\mu$ and V

Therefore;

Average Viscosity = $\frac{\mu_1+\mu_2+\mu_3+\mu_4}{4}$ = 0.7291 $kg/m\cdot s$



Viscosity graph of different engine oil at certain temperature

Through the graph that we referenced, the assumption of the type of engine oil would be SAE 90, which is the light blue colour line. It is roughly matching the value of 729.1cSt.

## Discussion:

Errors are always there in the lab results and cannot be avoided. The minimum we can do is reducing the errors. In this specific lab, there are many reasons causing the errors that prompt to less accurate results. Wake effect is one of the principle reasons that caused such inaccurate results. The ball creates water flow in the tube and caused the water to have layers during the time it was travelling through the liquid. These layers are going to affect the final result. In addition, the ball caused the fluid level of the tube to increase when they are at the bottom of the tube. Thus it could possibly make the measurement of distance inaccurate. In order to minimize errors, one will have to inspect the instruments carefully and perform several runs for the experiment.

The viscosity values of the three balls are different from one another because of their surface area and the mass. When the ball travels through the oil, it creates different layers depending on the size of the ball. The viscosity values of the medium and the large balls are closer to the average. The small ball results are less accurate comparing to the values with the average viscosity. It is because the big ball has more surface area in contact with the fluid than the small sphere.

From the graph we assumed the type of engine oil would be SAE 90 (which is the light blue colure line). It is matching the value of 729.1cSt.The cylinder wall is providing resistance to the ball falling into the oil. It slows down the ball and stops it from free falling. In this particular lab the cylinder wall did not have much effect on the final results.

After the lab, we have a superior comprehension of the fluid viscosity. The viscosity of fluids can be controlled by numerous analyses, for example, the ball, the tube, doing basic measurements, utilizing suitable formulas and equations. However, it can be affected by some factors during the lab trials such as the mass of the spheres, temperature. For this experiment four small balls were dropped in an oil to test the viscosity. If the balls were dropped too early between drops the wake effect would return inaccurate results. The amount of time need to wait between drops would depend on the balls velocity, volume, and shape.  For our experiment, the balls had low velocities and a very small volume leading to the assumption that the wake effect would disappear quickly. Also due to the shape of a ball, it is able to pass more smoothly in a fluid, which also aids in the assumption. So 10 seconds between drops should be sufficient enough for the wake effect to fade in this experiment.