EXPERIMENT 13

AIM

To determine the coefficient of viscosity of a given liquid by measuring the terminal velocity of a spherical body.

APPARATUS AND MATERIAL REQUIRED

A wide bore tube of transparent glass/acrylic (approximately 1.25 m long and 4 cm diameter), a short inlet tube of about 10 cm length and 1 cm diameter (or a funnel with an opening of 1 cm), steel balls of known diameters between 1.0 mm to 3 mm, transparent viscous liquid (castor oil/glycerine), laboratory stand, forceps, rubber bands, two rubber stoppers (one with a hole), a thermometer (0-50 °C), and metre scale.

PRINCIPLE

When a spherical body of radius r and density σ falls freely through a viscous liquid of density ρ and viscosity η, with terminal velocity v, then the sum of the upward buoyant force and viscous drag, force F, is balanced by the downward weight of the ball (Fig. E13.1).

= Buoyant force on the ball + viscous force

$$\frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g + 6\pi \eta r v \qquad \text{(E 13.1)}$$

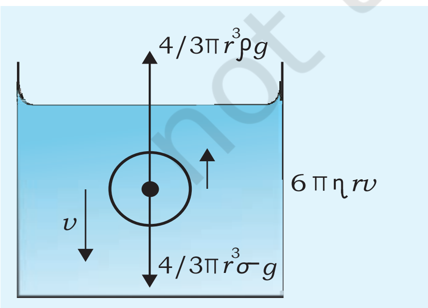

Fig.E 13.1: Forces acting on a spherical body falling through a viscous liquid with terminal velocity

or $$v = \frac{\frac{4}{3}\pi r^3 (\sigma - \rho) g}{6\pi \eta r} = \frac{2}{q}\frac{r^2 (\sigma - \rho) g}{\eta} \qquad \text{(E 13.2)}$$

where v is the terminal velocity, the constant velocity acquired by a body while moving through viscous fluid under application of constant force.

The terminal velocity depends directly on the square of the size (diameter) of the spherical ball. Therefore, if several spherical balls of different radii are made to fall freely through the viscous liquid then a plot of v vs r^2 would be a straight line as illustrated in Fig. E 13.2.

The shape of this line will give an average value of v/r^2 which may be used to find the coefficient of viscosity η of the given liquid. Thus

(E 13.3)

$$\eta = \frac{2}{9} g(\sigma - \rho).\frac{r^2}{v} = \frac{2}{9}\frac{(\sigma - \rho)g}{(\text{slope of line})}$$

$= \ldots\ \text{Nsm}^{-2}$ (poise)

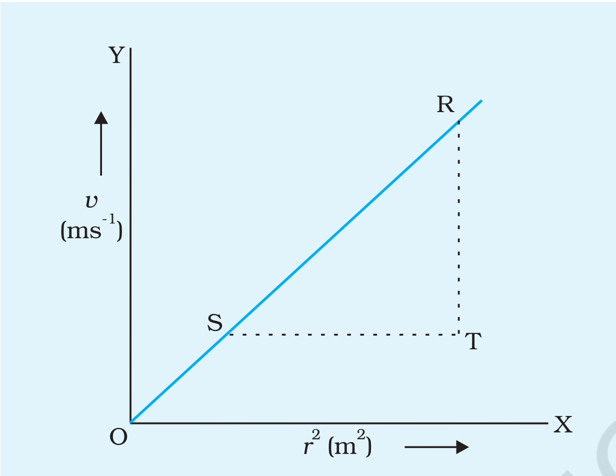

Fig.E 13.2: *Graph between terminal velocity v, and square of radius of ball, r^2*

The relation given by Eq. (E 13.3) holds good if the liquid through which the spherical body falls freely is in a cylindrical vessel of radius $R >> r$ and the height of the cylinder is sufficient enough to let the ball attain terminal velocity. At the same time the ball should not come in contact with the walls of the vessel.

PROCEDURE

1. Find the least count of the stop-watch.
2. Note the room temperature, using a thermometer.
3. Take a wide bore tube of transparent glass/acrylic (of diameter about 4 cm and of length approximately1.25 m). Fit a rubber stopper at one end of the wide tube and ensure that it is airtight. Fill it with the given transparent viscous liquid (say glycerine). Fix the tube vertically in the clamp stand as shown in Fig. E 13.3. Ensure that there is no air bubble inside the viscous liquid in the wide bore tube.
4. Put three rubber bands A, B, and C around the wide bore tube dividing it into four portions (Fig. E 13.3), such that AB = BC, each about 30 cm. The rubber band A should be around 40 cm below the mouth of the wide bore tube (length sufficient to allow the ball to attain terminal velocity).
5. Separate a set of clean and dry steel balls of different radii. The set should include four or five identical steel balls of same known radii (r_1). Rinse these balls thoroughly with the experimental viscous liquid (glycerine) in a petridish or a watch glass. Otherwise

these balls may develop air bubble(s) on their surfaces as they enter the liquid column.

6. Fix a short inlet tube vertically at the open end of the wide tube through a rubber stopper fixed to it. Alternately one can also use a glass funnel instead of an inlet tube as shown in Fig. E 13.3. With the help of forceps hold one of the balls of radius r_1 near the top of tube. Allow the ball to fall freely. The ball, after passing through the inlet tube, will fall along the axis of the liquid column.

7. Take two stop watches and start both of them simultaneously as the spherical ball passes through the rubber band A. Stop one the watches as the ball passes through the band B. Allow the second stop-watch to continue and stop it when the ball crosses the band C.

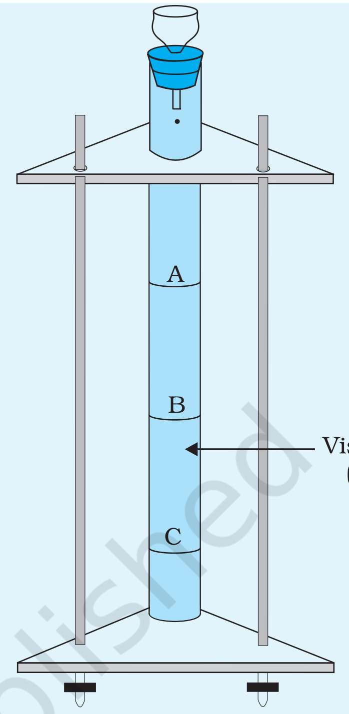

Fig.E 13.3: *Steel ball falling along the axis of the tube filled with a viscous liquid.*

8. Note the times t_1 and t_2 as indicated by the two stop watches, t_1 is then the time taken by the falling ball to travel from A to B and t_2 is the time taken by it in falling from A to C. If terminal velocity had been attained before the ball crosses A, then $t_2 = 2\ t_1$. If it is not so, repeat the experiment with steel ball of same radii after adjusting the positions of rubber bands.

9. Repeat the experiment for other balls of different diameters.

10. Obtain terminal velocity for each ball.

11. Plot a graph between terminal velocity, υ and square of the radius of spherical ball, r^2. It should be a straight line. Find the slope of the line and hence determine the coefficient of viscosity of the liquid using the relation given by Eq. (E 13.3).

OBSERVATIONS

1. Temperature of experimental liquid (glycerine) θ = ...°C.
2. Density of material of steel balls σ = ... kg m^{-3}
3. Density of the viscous liquid used in the tube = ... kgm^{-3}
4. Density of experimental viscous liquid ρ = ... kg m^{-3}

5. Internal diameter of the wide bore tube =... cm = ... m
6. Length of wide bore tube = ... cm = ... m
7. Distance between A and B = ... cm = ... m
8. Distance between B and C = ... cm = ... m

   Average distance h between two consecutive rubber bands = ... cm = ... m
9. Acceleration due to gravity at the place of experiment, = ... gms^{-2}
10. Least count of stop-watch = ... s

Table E 13.1: Measurement of time of fall of steel balls

S. No.	Diameter of spherical balls d (cm)	$r=d/2$ (m)	Square of the radius of the balls r^2 (m^2)	Time taken for covering distance h = ... cm between rubber bands: A and B t_1 (s)	A and C t_2 (s)	B and C $t_3=t_2-t_1$ (s)	Mean time $t=\frac{t_1+t_3}{2}$ (s)	Terminal Velocity $v=\frac{h}{t}$ (m^{-1})
1								
2								
3								

GRAPH

Plot a graph between r^2 and v taking r^2 along x-axis and v along y-axis. This graph will be similar to that shown in Fig. E 13.2.

Slope of line $\frac{v}{r^2}=\frac{\text{RT}}{\text{ST}}$

So $$\eta=\frac{2}{9}\frac{r^2(\sigma-\rho)g}{(\text{slope of line})}$$

Error $$\frac{\Delta\eta}{\eta}=\frac{2\Delta r}{r}+\frac{\Delta\text{slope}}{\text{slope}}$$

Standard value of η = ... Nsm^{-2}

% error in η = ... %

RESULT

The coefficient of viscosity of the given viscous liquid at temperature θ °C = ... ± ... Nsm^{-2}

PRECAUTIONS AND SOURCES OF ERROR

1. In order to minimise the effects, although small, on the value of terminal velocity (more precisely on the value of viscous drag, force F), the radius of the wide bore tube containing the experimental viscous liquid should be much larger than the radius of the falling spherical balls.
2. The steel balls should fall without touching the sides of the tube.
3. The ball should be dropped gently in the tube containing viscous/ liquid.

DISCUSSION

1. Ensure that the ball is spherical. Otherwise formula used for terminal velocity will not be valid.
2. Motion of falling ball must be translational.
3. Diameter of the wide bore tube should be much larger than that of the spherical ball.

SELF ASSESSMENT

1. Do all the raindrops strike the ground with the same velocity irrespective of their size?
2. Is Stokes' law applicable to body of shapes other than spherical?
3. What is the effect of temperature on coefficient of viscosity of a liquid?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Value of η can be calculated for steel balls of different radii and compared with that obtained from the experiment.
2. To find viscosity of mustard oil [**Hint:** Set up the apparatus and use mustard oil instead of glycerine in the wide bore tube].
3. To check purity of milk [**Hint:** Use mustard oil in the tall tube. Take an eye dropper, fill milk in it. Drop one drop of milk in the oil at the top of the wide bore tube and find its terminal velocity. Use the knowledge of coefficient of viscosity of mustard oil to calculate the density of milk].
4. Study the effect of viscosity of water on the time of rise of air bubble [**Hint:** Use the bubble maker used in an aquarium. Place it in the wide bore tube. Find the terminal velocity of rising air bubble].